

# Survival of Silver Diamine Fluoride Among Patients Treated in Community Dental Clinics: A Naturalistic Study

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## Research article

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## Abstract

**Objectives:** To describe survival outcomes of silver diamine fluoride (SDF) among a population-based sample receiving care in community settings.

**Methods:** We analyzed data on SDF applications from de-identified dental claims on Oregon Health Plan patients served by Advantage Dental in 2016, who had been seen in 2015. Survival rates of SDF alone, SDF applied with a sedative filling, and SDF with a same-day restoration were compared. Failure was defined as a restoration or extraction of the tooth 7 to 365 days after initial application, while survival was defined a patient that returned 180 or more days after application and the tooth did not have restoration or extraction. Differences were assessed through Wilcoxon equality of survivor function tests and log-rank equality of survivor tests to compare failure rates, Cox Proportional Hazards models to assess factors associated with survival of SDF, and Kaplan-Meier survival estimate to calculate the probability of survival over time.

**Results:** SDF alone had an overall survival rate of 76%. SDF placed with sedative filling and with a same-day restoration had survival rates of 50% and 84% respectively, likely reflecting the intent of treatment. SDF alone survived exceptionally well on primary cuspids, permanent molars, and permanent bicuspid and among patients aged 10 to 20 years, with modest variation across caries risk assessment categories. A single annual application of SDF was successful in 68% of cases. Among SDF failures on permanent dentition, more than two-thirds of teeth received a minor restoration.

**Conclusions:** SDF is a minimally invasive non-aerosolizing option that demonstrably prevented and arrested early stage dental caries among patients in one “real world” community dentistry setting. Professional organizations, policy makers, providers, and payors should consider broadening the option to use SDF by informing clinical guidelines, reimbursement policies, and treatment decisions, especially amidst COVID-19 pandemic driven guidelines to minimize risk of exposure to airborne pathogens. Future research should address clinical, social, health service delivery, workforce, and economic outcomes including costs and invasive procedures deferred, using diverse population-based samples, and the mechanisms underlying the success of a single application and the potential for SDF to prevent caries found in this study.

**Trial registration:** N/A

## Background

Dental caries, the most common disease of childhood and most prevalent health condition worldwide, persists despite concerted clinical and public health efforts to eliminate it over the last half-century [1,2]. Untreated caries contributes to health problems including pain, poor quality of life, and psychosocial suffering, as well as societal burdens that include reduced productivity at work and school [1,3,4]. Preventing dental caries through oral health education, home hygiene, the avoidance of fermentable carbohydrates, consumption of fluoridated water, and access to and utilization of routine dental screenings, examinations, and care is essential in reducing disease incidence and burden, meeting population-level oral health goals, and addressing patient concerns [1,4]. Because dental caries is a progressive disease, treating it as early as possible can halt extant disease, prevent or forestall subsequent cases, improve the longevity of teeth and their supporting structures, and, when possible, help patients avoid more invasive procedures and associated risks [4,5]. As in primary prevention, secondary approaches that leverage treatment-as-prevention are particularly valuable when implemented at the population level [1,5,6]. Dental public health and oral health stakeholders seek to maximize caries prevention and treatment approaches that are safe, simple, effective, low-cost, minimally invasive, and amenable to delivery in a variety of community settings and by multiple members of dental treatment teams.

Silver diamine fluoride (SDF) has been approved for dental use in numerous countries including, since 2014, the United States, where its off-label use for the secondary prevention of caries beginning in 2016 has been subsequently formalized through clinical guidelines released in 2018 [7-9]. SDF has gained prominence among other non-invasive treatments in arresting established caries, though effectiveness varies by frequency of application (e.g., annually vs. biannually), preparation of concentrations, tooth type (e.g. permanent versus primary), and tooth surface (e.g., coronal vs. root surfaces) [6,10-17]. SDF has also been demonstrated to prevent new carious lesions on root surfaces among older adults, while limited evidence indicates its potential to prevent caries in primary teeth for at least 24 months following initial application [15,18,19]. Numerous

characteristics of SDF reflect those valued in dental public health interventions, including being minimally invasive, affordable, portable, and appropriate for use at scale in community settings by various multiple dental and medical team members, outside of clinical applications. In addition, amidst the proliferation of the SARS-CoV-2 virus (COVID19), SDF has been recommended as an appropriate, non-surgical, non-aerosolizing caries management procedure that complies with guidance from public health officials, regulatory bodies, and professional associations to limit the risk of exposure to airborne pathogens [18-21]. Concerns regarding the staining effects of SDF potentially limit its desirability for use on anterior dentition [22,23]. However, recent evidence also documents its acceptability among dentally underserved patient groups for use on posterior dentition, and when posited to parents as a safe, minimally invasive, and effective alternative to procedures that could be painful or for which their children might otherwise be sedated, with particular suitability for children with behavioral challenges, often surpassing provider preference for using SDF [24-29].

The existing literature on SDF focuses primarily on young children who still have primary dentition [10,13,15, 22-28] and older adults [16,30], often omitting older children, adolescents, and working-age adults. The strongest evidence on SDF derives from randomized controlled trials (RCTs) whether individual or aggregated into evidence reviews, which compare SDF with placebo or other treatments, limit the intervention to SDF alone versus when used in combination with restorative procedures, and generate findings from samples treated under ideal clinical conditions and from analyses that control for covariates [6,10-17]. While this evidence supports SDF effectiveness in arresting caries lesion development and progression, accounts or analyses of “real world” concerns such as the settings in which treatments are delivered, patient volume at scale, and clinical decision-making when multiple treatment options are available, are limited in literature, as is evidence of the potential for SDF to prevent caries

This study aims to address some of these limitations, with particular concern for dentally underserved patients who obtain care in community settings, who are also historically excluded from clinical trials due to geographic and other barriers. It describes the survival rates of SDF among patients in one large-scale real-world multi-practice setting. Advantage Dental is the largest dental accountable care organization in the state of Oregon. Advantage Dental is responsible for delivering services to approximately 284,000 members of the Oregon Health Plan, the state’s Medicaid program, and contracts with 14 of the 16 of the state’s coordinated care organizations. Operating in a value-based care design, it prioritizes community care delivered by remote supervision dental hygienists, many working in rural and other outreach-focused settings, with an emphasis on disease prevention and management vis a vis assessment, preventive services, and referral to interprofessional oral healthcare. In 2016, Advantage incorporated twice-annual 38% Silver Diamine Fluoride into the clinical guidelines as a treatment option as determined by risk assessment, following an established protocol [7,31,32]. SDF was made available for caries prevention and arrest in addition to placement of temporary restoration without excavation where appropriate, as well as for hypersensitivity. The goal of increased adoption and utilization of SDF was to bolster efforts to reduce oral health disparities by optimizing community-based approaches with multi-disciplinary teams to arrest or prevent early stage caries disease [32]. Utilizing a retrospective claims analysis, this study examines the survival of SDF as applied in practice settings, over the course of one year. To our knowledge, it is the first study to assess SDF survival among a population sample treated in a real-world practice setting, both when used alone and in combination with a sedative filling or restoration.

## Methods

We analyzed data on SDF applications from de-identified dental claims on Oregon Health Plan patients served by Advantage Dental in 2016, among patients who had been seen in 2015. The study population included all Advantage Dental patients age 0 to 64 who had at least one SDF application, defined as the presence of CDT code D1354 on a patient claim. We analyzed teeth that were treated with an SDF application and sedative filling (D2940/D2941) on the same day or SDF application and restoration on the same day separately from teeth that received only an SDF application (Appendix 1).

We assessed survival of SDF among teeth that had been tracked for at least 365 days. As a result, the survival analysis only included patients with teeth that had an initial application of SDF treatment in 2016 and for which the tooth number was identified. To reduce the potential for survival to be associated due to right-censoring, patients were only included in the cohort if they had been a patient in 2015. SDF treatments were considered to have survived if the patient was seen by Advantage Dental 180 days or later after the initial application (and the treated tooth did not have a failure). Failures were defined as the treated

tooth receiving a restoration, endodontic treatment, or extraction seven or more days after initial application, except for sedative filling/protective restorations (D2940/D2941) if they occurred within 10 weeks of the initial application. Third molars were excluded from the analysis, as were teeth in which both SDF and a sealant were placed on the same day and teeth for which a remnant was removed. We limited the sample age range to 64 years old in order to limit the potential for our analysis to conflate use of SDF for caries prevention and arrest versus for hypersensitivity, which can become more common as patients age [33].

We assessed variations in application and survival by demographics, in particular, age group. We examined survival by primary vs. permanent teeth and location in the mouth (lower and upper incisors, cuspids, bicuspid, and molars). Clinical guidelines indicate SDF use for patients at high risk for caries. Therefore, we also compared variation by caries risk. Caries risk was assessed chairside using visual techniques guided by three clinical screening questions and one patient history question, and recorded within claims records as D0601 (low caries risk), D0602 (moderate caries risk), and D0603 (high caries risk). If multiple assessment scores were reported, we used the first reported risk assessment in the period of the study.

We used various statistical methods in the analysis. We used Wilcoxon equality of survivor function tests and log-rank equality of survivor tests to determine differences in overall survival rates between types of SDF applications. We used Cox Proportional Hazards models to assess the factors associated with survival of SDF. These models use robust clustered standard error to correct for the non-independence of standard errors to account for the multilevel design of the data, in which teeth are nested in patients. Finally, we used Kaplan-Meier methods to calculate the probability of survival over time.

## Results

### *Description of Study Participants*

Overall, 7,787 teeth from 2,269 patients were included in the study. The majority of patients (91%) received only SDF, with 7,475 teeth receiving SDF alone (2,063 patients), 220 receiving both an SDF application and a sedative filling (185 patients), and 92 receiving SDF with a same-day restoration (76 patient, Table 1). Study participants were well-distributed by age, ranging from 1 to 64 years. The study sample disproportionately included the youngest beneficiaries relative to the overall age distribution, likely due to the high prevalence of delivery of these treatments to children (Appendix B).

Participants aged 1 to 20 accounted for the majority of all SDF delivered (75%, Table 1). The provision of SDF generally tapered as adults progressed through working age. Half of SDF with a same-day restoration were among adults 21 and older. As expected, SDF was commonly applied to those at increased caries risk, with 45–58% of applications delivered to patients assessed to be at high caries risk and 23–34% delivered to patients who did not have a caries risk assessment within the claims record. By contrast, only 4–5% of SDF was delivered to low-risk patients.

SDF alone and SDF with a sedative filling were more often placed on primary teeth than on permanent teeth, primarily on molars (43% and 55% on lower molars, respectively, and 42% and 44% on upper, Table 1). The remaining SDF-alone placements on primary teeth were applied primarily to upper incisors and upper cuspids (8% and 4%, respectively). SDF with a same-day restoration was more often placed on permanent teeth than on primary teeth and, in particular, permanent molars (32%-38%) and upper bicuspid (18%). When SDF was applied alone at the index visit, just over a third of teeth received one or more additional SDF applications within one year (38%).

Table 1  
Descriptive Statistics of Teeth Treated with Silver Diamine Fluoride Only or Combined with Sedative Filling or Restoration

	SDF		SDF + Sedative Filling		SDF + Restoration	
	Count	%	Count	%	Count	%
Total	7,475		220		92	
<b>Age</b>						
1-5	1,696	23%	45	20%	5	5%
6-9	2,374	32%	81	37%	23	25%
10-14	923	12%	43	20%	12	13%
15-20	641	9%	7	3%	6	7%
21-30	578	8%	13	6%	13	14%
31-40	427	6%	13	6%	17	18%
41-50	303	4%	9	4%	4	4%
51-64	533	7%	9	4%	12	13%
<b>Caries Risk</b>						
No Assessment	1,723	23%	75	34%	18	20%
Low	401	5%	12	5%	4	4%
Moderate	1,331	18%	35	16%	17	18%
High	4,020	54%	98	45%	53	58%
<b># of Applications within 1 Year</b>						
1	4,567	61%	186	85%	82	89%
2	1,827	24%	25	11%	8	9%
3+	1,081	14%	9	4%	2	2%
<b>Primary vs. Permanent</b>						
Primary	4,152	56%	131	60%	27	29%
Permanent	3,323	44%	89	40%	65	71%
<b>Tooth Type - Primary Teeth</b>						
Lower Incisor	35	1%	0	0%	0	0%
Lower Cuspid	59	1%	0	0%	0	0%
Lower Molar	1,801	43%	72	55%	15	56%
Upper Incisor	350	8%	1	1%	2	7%
Upper Cuspid	161	4%	1	1%	1	4%
Upper Molar	1,746	42%	57	44%	9	33%
<b>Tooth Type - Permanent Teeth</b>						
Lower Incisor	84	3%	0	0%	0	0%

	<b>SDF</b>		<b>SDF + Sedative Filling</b>		<b>SDF + Restoration</b>	
Lower Cuspid	86	3%	1	1%	1	2%
Lower Bicuspid	490	15%	7	8%	4	6%
Lower Molar	1,001	30%	31	35%	21	32%
Upper Incisor	160	5%	1	1%	1	2%
Upper Cuspid	85	3%	3	3%	1	2%
Upper Bicuspid	514	15%	8	9%	12	18%
Upper Molar	903	27%	38	43%	25	38%

Table 2

Comparisons of Survival Rates of Teeth treated with SDF Applications Alone vs. SDF Application with Same Day Restoration among Advantage Dental Patients 64 and Under

	<b>SDF Survival %</b>	<b>SDF + Sedative Filling Survival %</b>	<b>SDF + Restoration Survival %</b>
Overall	<b>76%</b>	<b>50%</b>	<b>84%</b>
<b># of SDF Applications within One Year</b>			
1	75%	49%	84%
2	77%	56%	--
3+	75%	33%	--
<b>Caries Risk</b>			
Low	81%	50%	--
Moderate	76%	51%	82%
High	75%	42%	79%
No Assessment	75%	59%	94%
<b>Age</b>			
1-5	69%	53%	--
6-9	77%	57%	61%
10-14	84%	53%	83%
15-20	82%	29%	100%
21-30	76%	23%	92%
31-40	77%	31%	100%
41-50	72%	33%	50%
51-64	68%	44%	92%
<b>Primary vs. Permanent</b>			
Primary Tooth	74%	56%	74%
Permanent Tooth	78%	40%	88%
<b>Tooth Type - Primary Teeth</b>			
Lower Incisor	74%	--	--
Lower Cuspid	86%	--	--
Lower Molar	71%	51%	73%
Upper Incisor	77%	--	--
Upper Cuspid	83%	--	--
Upper Molar	75%	60%	67%
<b>Tooth Type - Permanent Teeth</b>			
Lower Incisor	70%	--	--
Lower Cuspid	69%	--	--
Lower Bicuspid	82%	29%	100%

	SDF Survival %	SDF + Sedative Filling Survival %	SDF + Restoration Survival %
Lower Molar	80%	39%	81%
Upper Incisor	50%	--	--
Upper Cuspid	69%	--	--
Upper Bicuspid	75%	--	100%
Upper Molar	82%	47%	88%
Note: Cells are empty if sample size is less than 10. Failure is defined as a restoration or extraction after application. Sedative fillings are not considered to be failures if they occur within 70 days of initial application. Survival is defined as a patient that returned 180 or more days after application and had no restoration or extraction. Equality of Survivor Tests for Overall Rate Between SDF Applications: Wilcoxon Test, 79 (2 df), p < 0.000; Log-Rank Test, 91.5 (2 df), p < 0.000			

An analysis of the relationship between caries risk and number of SDF applications not included in this paper shows that single applications of SDF were more common among patients whose claims record did not contain a risk assessment than among patients whose claims record contained a risk assessment (64% versus 58%, respectively). Multiple applications of SDF during the study period (three or more) were marginally more common among patients assessed to be at high risk of caries than among patients assessed to be at low or moderate risk (17% versus 13%, respectively). While the following analyses present results by tooth, outcomes by patient produced by analyses not presented in this paper are consistent with findings by tooth.

### Survival Analyses

SDF alone had an overall survival rate of 76%, while SDF with a sedative filling had a survival rate of 50% and SDF with a same-day restoration has a survival rate of 84%. These survival rates are significantly different with both the Wilcoxon and Log-Rank tests (Table 2). Kaplan-Meier estimates of SDF survival alone and with a restoration remained above 90% survival to 162 days and 215 days, respectively, with SDF alone holding its overall survival rate of 76% well beyond a year, to day 446 (Fig. 1). SDF applied with a sedative filling fell below 90% at day 80 and remained at 58% at one year after application.

SDF survival varied little based on the number of applications. However, there is substantial variation across other categories (Table 2). SDF alone survived well on all primary teeth with lower molars (71%) having the lowest survival rate and lower and upper primary cuspids (86% and 83%, respectively) performing well. SDF alone performed well on permanent molars (80–82%) and bicuspid (82 – 75%), with lower survival rates on incisors and cuspids. SDF survival rates also varied across age categories. It performed well among those aged 10 to 20 years (83%). Survival rates were substantially lower among young children and adults age 41 and older. With regard to risk assessment, SDF survival was highest among patients with a low risk assessment (81%), while patients with a moderate risk assessment met the overall survival rate (76%). SDF survival among patients aged 6 to 40 years old and among patients with a high-risk assessment or lacking a risk assessment in their record fell short of the overall survival rate by one percentage point (75%).

Table 3  
Cox Proportional Hazards Regressions Estimating Silver Diamine Fluoride Failure among Advantage Dental Patients 64 and Under

	Haz. Ratio		95% C.I.	Robust Clustered S.E.
Type of Application (Reference: SDF Alone):				
SDF + Sedative Filling Survival %	2.48	***	2-3.06	0.27
SDF + Restoration Survival %	0.60		0.33-1.08	0.18
# of SDF Applications (Reference: One):				
2	0.93		0.78-1.11	0.08
3	0.98		0.77-1.24	0.12
Caries Risk (Reference: Low)				
No Assessment	1.36		0.95-1.93	0.24
Moderate	1.34		0.92-1.94	0.25
High	1.42	***	1.03-1.97	0.24
Age (Reference: 6-9)				
1-5	1.33	**	1.07-1.65	0.15
10-14	0.77		0.57-1.02	0.11
15-20	0.94		0.62-1.43	0.20
21-30	1.37		0.93-2.03	0.27
31-40	1.29		0.82-2.05	0.30
41-50	1.66	*	1.09-2.55	0.36
51-64	1.79	***	1.23-2.62	0.35
Tooth Type - Primary Teeth (Reference: Lower Molar)				
Lower Incisor	0.66		0.23-1.91	0.36
Lower Cuspid	0.40	*	0.18-0.89	0.16
Upper Incisor	0.61	**	0.43-0.87	0.11
Upper Cuspid	0.51	**	0.33-0.78	0.11
Upper Molar	0.86	*	0.75-0.98	0.06
Tooth Type - Permanent Teeth (Reference: Lower Molar)				
Lower Incisor	1.22		0.8-1.86	0.26
Lower Cuspid	1.17		0.72-1.88	0.28
Lower Bicuspid	0.77	*	0.6-0.98	0.10
Upper Incisor	2.65	***	1.89-3.72	0.46
Upper Cuspid	1.35		0.89-2.04	0.28
Upper Bicuspid	1.17		0.9-1.52	0.16
Upper Molar	0.86		0.7-1.06	0.09
Number of Teeth	7,787			

	Haz. Ratio	95% C.I.	Robust Clustered S.E.
Number of Patients	1,957		
Likelihood Ratio Chi-Square	154.48 ***	22 df	
Note: * p < .05; **p < .01; ***p < .001.			

Among those with SDF applied with a sedative filling, survival rates by category never exceeded 60%. Moreover, SDF with a sedative filling failed at 2.5 times the rate of SDF alone, even after controlling for number of applications, caries risk, age, and tooth type and location (OR 2.49, p < .001, Table 3). This finding most likely reflective of the interim nature of sedative fillings in current dental practice. Survival rates were highest among those under age 14 and lowest among patients between 15 and 50 years of age. SDF applied with a same-day restoration had the overall highest survival rates, with some categories reaching 100%, although the small sample size (n = 92) is important to keep in mind as is the intended longevity of the procedure and the potential selection bias of application only to teeth likely to succeed with this treatment.

Table 4  
Procedures Performed on Teeth that Fail after SDF Application among Advantage Dental Patients 64 and Under

Panel A: SDF Alone											
	Overall	Permanent vs. Primary		Tooth Type - Permanent Teeth							
		Prim.	Perm.	L. Incisor	L. Cuspid	L. Bicuspid	L. Molar	U. Incisor	U. Cuspid	U. Bicuspid	U. Molar
Minor Restoration	39%	36%	68%	64%	74%	68%	65%	68%	69%	70%	69%
Major Restoration	29%	43%	8%	8%	0%	10%	12%	6%	4%	4%	6%
Endodontics	1%	0%	2%	4%	7%	1%	1%	1%	0%	3%	1%
Extraction	21%	20%	22%	16%	19%	20%	21%	25%	27%	21%	23%
Other	0%	0%	1%	8%	0%	1%	0%	0%	0%	2%	0%
Total	1,831	1,094	737	25	27	87	204	80	26	128	160
Panel B: SDF + Sedative Filling						Panel C: SDF + Restoration					
	Overall	Permanent vs. Primary		Tooth Type - Permanent Teeth		Overall	Permanent vs. Primary				
		Prim.	Perm.	L. Molar	U. Molar		Prim.	Perm.			
Minor Restoration	39%	10%	70%	53%	80%	60%	71%	50%			
Major Restoration	41%	66%	15%	21%	10%	13%	29%	0%			
Endodontics	3%	0%	6%	5%	5%	13%	0%	25%			
Extraction	17%	24%	9%	21%	5%	13%	0%	25%			
Other	0%	0%	0%	0%	0%	0%	0%	0%			
Total	111	58	53	19	20	15	7	8			

SDF applied to patients who had a high caries risk was likely to fail at approximately one-and-a-half times the rate of SDF applied to low-risk patients (OR 1.42, p < 0.001). SDF was significantly more likely to fail among patients aged 1–5 years and older than

41 years of age, when compared with those aged 6–9. On primary teeth, lower molars had significant higher rates of failure than other teeth, but no statistically significant difference from lower incisors. On permanent teeth, lower bicuspid were about 25% less likely to fail than lower molars, while upper incisors were about 2.7 times more likely to fail (OR .77,  $p < .05$  and OR 2.65,  $p < .001$ ). There were no significant differences in failure rates by number of applications.

This study also assessed procedures performed on teeth on which SDF failed (Table 4). When SDF was applied alone, minor restorations were the most common procedures overall, performed on 39% of all failed applications, followed by major restorations (29%) and extractions (21%). Among primary teeth, the most common procedure following an SDF failure among teeth treated with SDF alone and in combination with a same-day sedative filling was a major restoration (43% and 66% respectively), while among permanent teeth it was a minor restoration (68% and 70%). When combined with a same-day restoration, the most common procedure associated with a failure was a minor restoration. The permanent teeth most commonly extracted following SDF alone were upper bicuspid (27%), although this accounts for a fairly small number of cases ( $n = 26$ ). Among the permanent tooth type with the most instances of SDF failure alone (lower molars,  $n = 204$ ), minor restorations remained the most common subsequent procedure (65%), followed by extractions (21%), and major restorations (12%). Endodontic procedures were relatively uncommon across the entire sample.

## Discussion

This study assessed the survival of SDF delivered to community dental clinic patients served by a large dental accountable care organization in Oregon. To our knowledge, it is the first study to examine population-level SDF survival in a real-world context characterized by *in situ* treatment decision-making, the first study to examine SDF outcomes using dental claims data, and one of the few studies to examine SDF survival among older children, adolescents, working-age adults, and patients prioritized in community dental outreach other than school-based settings. Overall, our findings support previous conclusions that SDF is an effective treatment that arrests caries [6, 10–17]. Importantly, our study finds also merit in using SDF to prevent early carious lesions, thus contributing meaningful evidence to the knowledge gap that underlies national guidelines in which SDF is only recommended for treating extant disease [8, 9]. We also found, consistent with other studies [e.g. 11,16], that meaningful limitations emerged when SDF survival was analyzed by patient age, tooth type, patient risk assessment profile, and other characteristics, including whether SDF was applied alone or used together with a sedative filling or restoration. Findings also indicate the importance of conducting future studies to examine SDF application cycles and risk-stratified care delivery, as well as targeted clinical studies addressing the use of SDF to prevent early carious lesions, among other topics.

SDF placed in combination with a restoration had the best overall survival. This finding likely reflects the intended longevity of the restoration and the health of the tooth that was eligible to receive it, as well as the small sample size ( $n = 92$ ). By contrast, the modest survival of SDF placed with a sedative filling on primary upper molars (60%) suggests interim utilization to bolster the technique of “calming” a tooth with more evident decay and managing it through behavioral modification in order to forestall or avoid a subsequent invasive procedure, which impedes its likelihood of long-term success.

SDF applied alone survived well on primary teeth overall and on upper primary incisors and upper and lower primary cuspids in particular. It yielded lower results on molars, findings consistent with other studies [11, 13, 16]. Our analysis also indicated the propensity of SDF to support the arrest of decay and precarious lesions on permanent dentition, including children’s permanent teeth, in contrast to one recent study [16]. This finding is particularly evident in lower permanent bicuspid, which not only exceeded the overall survival rate by six percentage points but also whose SDF applications were the least likely to fail among all permanent teeth. The exceptional survival rate of SDF on upper primary incisors, upper and lower primary cuspids, permanent teeth overall, and working age adults indicates the merit of this treatment for teeth types and patients for whom dental sealants, another low-cost, minimally-invasive, community-delivered preventive service, is not indicated in clinical guidelines [34, 35]. The higher success rate of SDF in posterior dentition, as compared with anterior dentition, may reflect patients’ desire for a more esthetic restoration in the latter and a tolerance for the dark staining that occurs after SDF placement in the former. Taken together, our findings indicate the merits of considering SDF among the numerous complementary services available to optimize the primary and secondary prevention of caries and precarious lesions in primary and permanent dentition.

Importantly, we find that a sole application of SDF in a year can successfully arrest caries or precarious lesions, a conclusion produced by the “natural experiment” of SDF delivery via a single application in a year for reasons indeterminable by using claims

data despite clinical guidelines indicating twice-annual delivery. This finding, which usefully exploits service delivery variations found in real world contexts, is consistent with one recent study [6], addresses evidence limitations identified in other studies [11, 15], and contrasts other literature and practice guidelines [8, 9, 12], including the practice guidelines for the project from which this study's data were extracted [33]. We interpret this finding to indicate the importance of providing clinicians with the option to use SDF in unideal oral health service delivery circumstances, for example as others have noted rural community clinics [10, 11] where patients may not be able to return for a second application within the recommended time frame. This finding also highlights the importance of future studies to understand the mechanisms underlying the success of the single application, with particular emphasis on treating non-cavitated lesions with SDF.

As expected, SDF had the highest survival rate among patients assessed to be at low risk (81%), with patients in all other risk categories either meeting the overall survival rate (patients at moderate risk) or falling just below it (patients at high risk or lacking a risk assessment in their record). We interpret this modest difference of five-to-six percentage points to support the clinical merit of SDF across all risk categories, in particular as contrasted with other oral health treatments whose survival is more dramatically differentiated by risk assessment categories [38,39]. Nonetheless, the finding that SDF applications to high risk patients were likely to fail at approximately one-and-a-half times that of SDF applied to low-risk patients warrants further investigation, in particular when considering the potential for SDF to be used in community and safety net settings and among patients likelier to present with more unmet dental needs. Survival rates by risk stratification, in particular among patients assessed to be at low or moderate risk as determined by the absence of early stage disease and, in the case of low risk patients, history of disease, suggests the capability of SDF to prevent caries. This finding indicates the importance of conducting targeted clinical studies on using SDF to prevent caries in order to address the evidence gap that limits national SDF guidelines to treatment of nascent decay rather than the full spectrum of prevention [8–10]. The finding that when SDF applied alone failed, minor restorations were the most common procedures overall (39%) and in particular among permanent teeth (68%) also evinces the potential of SDF to contribute to overall oral health by helping patients avoid or delay more invasive procedures and support the longevity of existing teeth and their supporting structures.

This study gains broader importance toward the realization of population health goals when considered within the contexts of its use, including evidence on the acceptability of SDF among diverse patient groups [23–29]. Findings indicate how this non-invasive, cost-effective, setting-flexible treatment may be understood as a meaningful option that providers can confidently consider based on patient characteristics, treatment goals, and other factors. Our findings also indicate the importance of considering how SDF may expand opportunities for preventive care toward oral health equity, given its appropriateness for delivery by multiple medical and dental providers working in diverse community settings. SDF may also meaningfully remediate the limitations of practice guidelines and payor norms, for example the application of sealants only to pristine permanent molars, commonly among school-aged children [34–35]. Our findings take on additional importance in light of the COVID19 pandemic and the immediate- and longer-term transformations in dental service delivery changes necessitated to minimize risk for transmission of airborne pathogens [18–21] with which SDF, a non-aerosolizing treatment, complies.

Future research directions should include studies to assess SDF longevity beyond one year among community-based population samples; comparative effectiveness using both clinical and patient-centered measures; survival rates when SDF is used in combination with other treatments not documented in this study such as dental sealants [36, 37], clinical applications of SDF to prevent carious lesions, and survival rates and post-failure procedures with respect to individualized patient diagnostic data, particularly among high-risk patients and with more diverse patient samples, provider type and costs of treatment, as well as societal outcomes including costs deferred. We also encourage more implementation research to understand factors associated with the implementation of SDF in diverse community settings [38].

## Limitations

This study has several limitations. The sample excluded patients from the overall beneficiary group (Appendix A) with missing data. Outcomes were only assessed among patients with a follow-up visit at a minimum of 180 days after initial treatment to ensure that teeth did not appear to survive due to the patient failing to return to the dentist. Analyzing data by individual diagnosis (e.g., non-cavitated carious lesions vs. cavitated lesions, hypersensitivity versus nascent decay), proximity of the

treated tooth to other teeth, rationale for providing only one SDF application in a year, or other important information from the dental record was prohibitive due to dentistry's convention of not including diagnostic codes in claims data. In particular, this limitation prohibited us from making causal claims regarding the use of SDF to prevent caries in primary dentition versus to arrest disease despite our results indicating this outcome[16] and from assessing the impact of on patient preference on SDF use on anterior dentition versus posterior dentition, another gap in the literature [22–28]. Because our interest is in a treatments suitable for primary prevention or the secondary prevention-oriented treatment of dental lesions and extremely early stage caries, our study likely sampled a healthier population, and should not be considered generalizable to a population with more advanced dental caries. It should also be noted that the utilization of SDF and its coding for benefit practices were new to most of the provider group represented in this analysis. Most SDF applications in this study were applied to the occlusal surface of teeth, as is expected, but thereby indicating that more work may be necessary to ascertain its effectiveness on the other non-occlusal surfaces of teeth. This study also did not follow teeth for longer than two years, so additional research may be needed to address the long-term efficacy of SDF.

## Conclusion

Silver diamine fluoride is a valuable option for preventing or arresting early stage dental caries that can improve patient and population-level oral health. Professional organizations, policy makers, dental and medical providers, dental payors, and patients themselves should consider the relative success and limitations of this treatment in informing clinical practice guidelines, reimbursement policies, and treatment decisions. Importantly, SDF is a key preventive and therapeutic caries management technique in our armamentarium to minimize aerosols in the dental setting while providing urgent dental care during the COVID-19 mitigation period, and as mitigation tactics are gradually lifted once an effective vaccine is not only developed, but also administered broadly among US residents and the world more broadly. However, this pandemic has illuminated a critical gap in the dental infection control standards that are not adequately poised to implement transmission-based precautions to address threat of air-borne pathogens. Thus, there is an immediate—and likely long-standing—need to reduce aerosol-generating procedures in the management of oral disease., to minimize patient-to-patient transmission of SARS-CoV-2, to protect dental health care workers from harm, and to address in the long term a movement toward minimizing aerosol-generating procedures in dentistry. Future research should address clinical, social, health service delivery, workforce, and economic outcomes including costs and invasive procedures deferred, using diverse population-based samples.

## List Of Abbreviations

ADA  
American Dental Association  
SDF  
Silver Diamine Fluoride

## Declarations

This study received exemption from review by the Western Institutional Review Board.

### Consent for publication

Not applicable

### Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request and subject to compliance with patient privacy regulations.

### Competing interests

Sarah Raskin was a paid consultant on this paper.

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Not applicable

## Authors' contributions

All authors contributed equally to study design, the interpretation of results, and the editing of this manuscript. EPT and IO co-led data analysis and SER led manuscript writing.

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## Figures

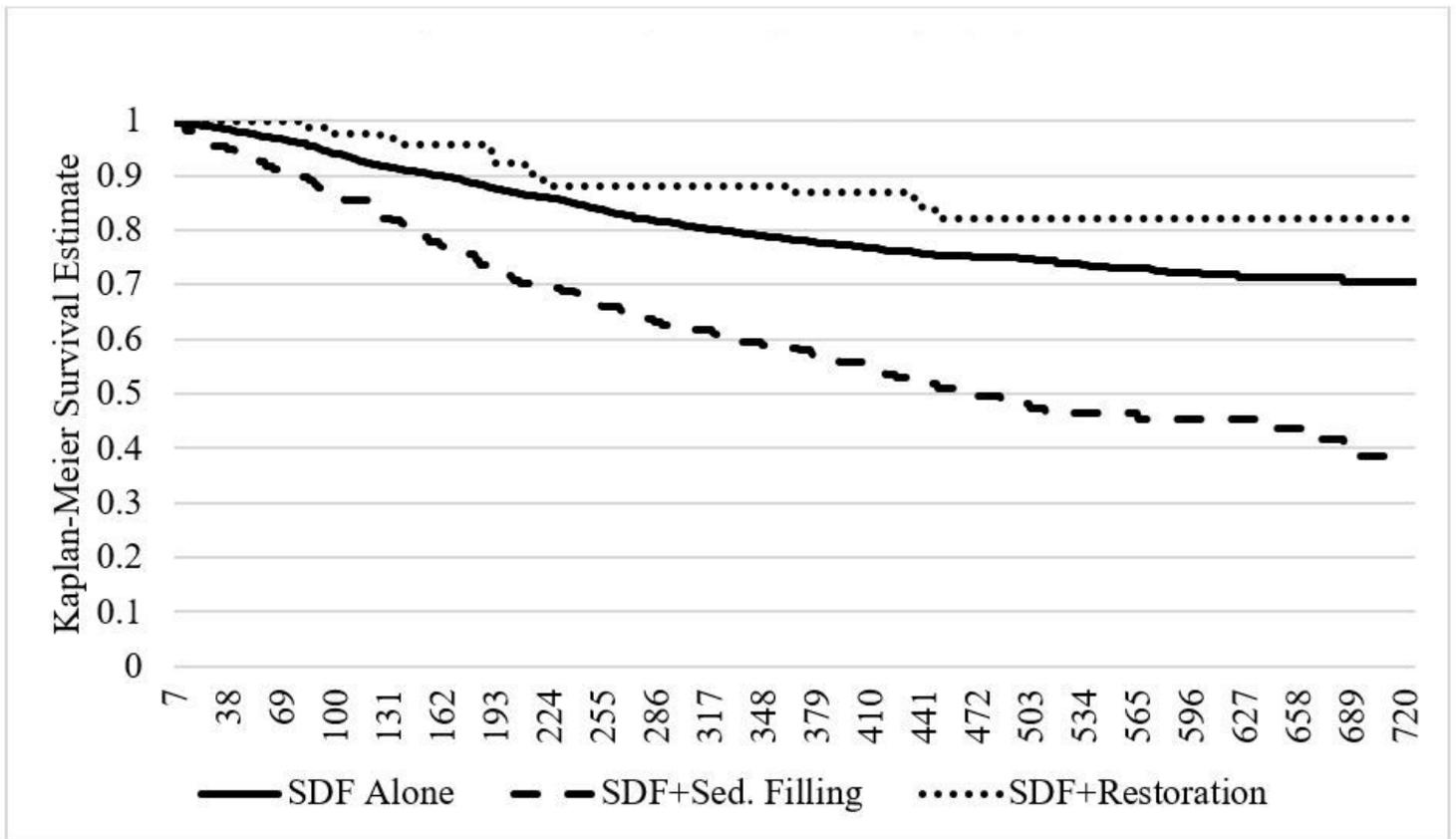


Figure 1

Kaplan-Meier Survival Plot

## Supplementary Files

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