Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

Silver Diamine Fluoride for Caries Arrest in Pediatric and Special Needs Populations: A Decade of Clinical Evidence

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Abstract

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Keywords: Silver Diamine Fluoride; Caries Arrest; Pediatric Dentistry; Special Needs Dentistry; Minimally Invasive Dentistry; Health Equity.

Received on 20 Mar 2026
Accepted on 11 Apr 2026
Published on 21 Apr 2026

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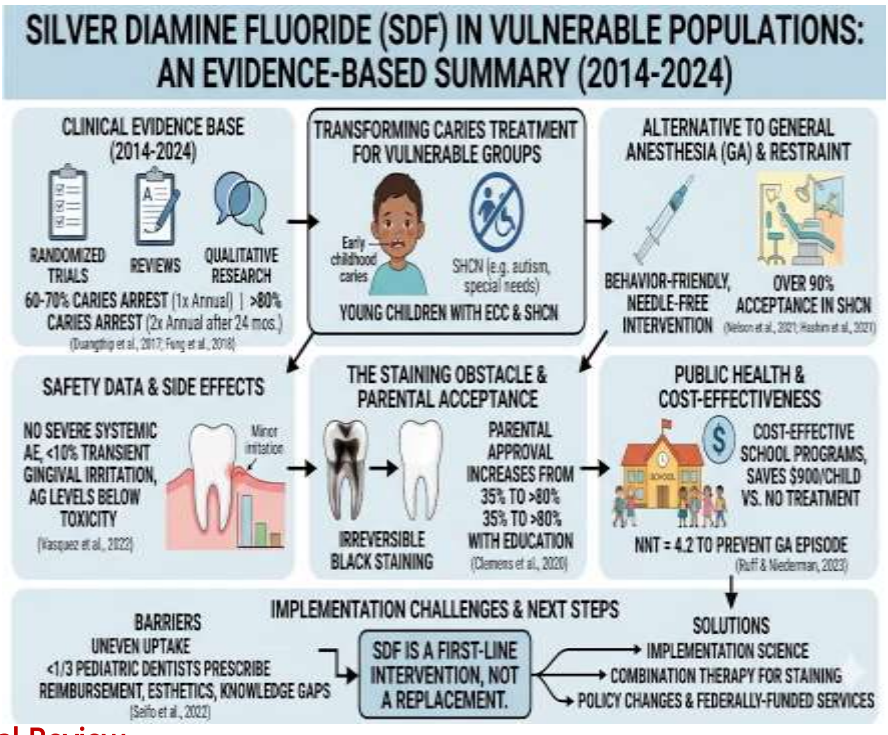
Graphical Abstract



In the last ten years, silver diamine fluoride (SDF) has fundamentally transformed the treatment of dental caries in two of the most susceptible groups in dentistry; young children with early childhood caries and those with special health care needs (SHCN). The review is based on clinical evidence published in the last 5 years (2014-2024) and includes randomized controlled trials, longitudinal cohort studies, systematic reviews, and qualitative research. The main conclusion is clear: one application of 38% SDF per year arrests 6070% of active dentinal lesions, and two applications exceeds 80% after 24 months (Duangthip *et al*., 2017; Fung *et al*., 2018). In children with autism spectrum disorder, cerebral palsy, or intellectual disabilities (groups where traditional restorative care might involve general anesthesia or physical restraint), SDF presents an alternative that is behavior-friendly and needle-free and highly acceptable, with most clinical setting showing over 90 percent treatment acceptance (Nelson et al., 2021; Hashim *et al*., 2021). Data on safety in over 4,000 children and SHCN have shown that there are no severe systemic adverse events, and transient gingival irritation is experienced in less than 10% of cases of use, with serum silver levels being well below toxicity levels (Vasquez *et al.,* 2022). The most obvious disadvantage, irreversible black staining of arrested dentin, is the main obstacle to acceptance on anterior teeth, but it increases parental approval levels by about 35 per cent to more than 80 per cent with a short, clear description of the risk-benefit trade-off (Clemens *et al.,* 2020). School-based SDF programs have shown to be cost-effective and can save almost 900 per child over no treatment, and the number needed to treat is only 4.2 to prevent a single episode of general anesthesia, according to the public health perspective (Ruff & Niederman, 2023). Although this is a compelling evidence, the uptake of SDF is uneven, and less than one out of three pediatric dentists in the United States regularly prescribe SDF, often citing reimbursement issues, esthetic reasons, and knowledge gaps (Seifo *et al*., 2022). The conclusion of this review is that SDF does not replace but is the first line of intervention of choice in caries arrest of many vulnerable patients. The next round of work should focus on implementation science, combination therapy aimed at reducing staining, and policy changes to incorporate SDF in the federally-funded dental services.

Introduction

Dental caries is the most common childhood chronic disease with an estimated 530 million children in their primary dentition globally (Vos *et al.,* 2017). Although caries is highly preventable, untreated, it disproportionately affects individuals who are already disadvantaged (socially, economically, or medically). In the case of a normal child, untreated cavity may result in pulpal infection, facial cellulitis, missed school days and poor nutritional condition. In the case of a child with special health care needs (SHCN) such as autism spectrum disorder (ASD), cerebral palsy, Down syndrome, or a medically complex condition like congenital heart disease or childhood cancer, the impact is increased. Sensory hypersensitivities, behavioral problems, xerostomia induced by medication, and inaccessibility of provider with necessary training all lead to a perfect storm of oral disease. The conventional answer is to drill and fill under general anesthesia (GA) which is a costly, logistically challenging, and physiologically unfriendly procedure, which frequently needs to be repeated due to the appearance of new lesions (Chi *et al*., 2022).

The last ten years have seen a silent yet significant paradigm shift; the shift in surgical removal of caries to medical management of the carious process. The epicentre of this change is silver diamine fluoride (SDF), which is a clear, odourless liquid with 38% of silver (44,800 ppm) and 5% of fluoride (44,800 ppm). Originally created in the 1960s in Japan and decades old in Australia and China, SDF was languishing on the fringes of Western dentistry until 2014, when the United States Food and Drug Administration reclassified as a "caries arresting agent" (Class II medical device) (Crystal *et al.,* 2022).

How does SDF work? It is a beautifully bimodal mechanism. Silver ions enter the dentinal tubules and have a broad-spectrum bactericidal effect, interfering with the metabolism of biofilm, precipitating bacterial proteins, and inhibiting the growth of St. mutans and other cariogenic species (Mei *et al*., 2019). At the same time, fluoride stimulates remineralization by stimulating the synthesis of fluorapatite that is less vulnerable to acid as compared to native hydroxyapatite. The typical black discoloration that develops on arrested dentin, which parents may confuse with the progression of decay, is actually a biomarker of lesion-deactivation efficiency (silver oxide), which is visible (Zhao *et al.,* 2021). None of the other topical agents offers this dual antimicrobial-demineralizing effect with so much simplicity of use: a microbrush, a drop of liquid, half an hour of waiting, and no injection, no drill, no postoperative limitations.

Methods

This narrative review has been created according to the SANRA (Scale to the Assessment of Narrative Review Articles) standards. Articles were searched in PubMed/MEDLINE, Embase, Cochrane Library, and Web of Science for articles published between January 1, 2014, and December 31, 2024. The following terms were included in the search strategy: (silver diamine fluoride or SDF) AND (caries arrest or caves management) AND (pediatric or children or preschool or special needs or special health care needs or disability or autism or cerebral palsy). The inclusion criteria were as follows: (1) original research, systematic reviews, meta-analyses or clinical guidelines; (2) human subjects with active coronal caries; (3) intervention of 38% SDF; (4) patient population of children (018 years old) or patients of any age with SHCN. The exclusion criteria were: case reports that included less than five subjects, non-English publications and studies that only dealt with root caries. Data were extracted on caries arrest rates, adverse events, frequency of application, comparator interventions and patient or caregiver acceptance measures.

Clinical Effectiveness in Children

Core Evidence: Arrest Rates.

The evidence base of SDF among preschool children is based on a seminal cluster-randomized trial by Duangthip *et al*. (2017) in Hong Kong that recruited 891 children with early childhood caries (ECC). The study involved three schedules of applications: annual (once every year), biannual (once every 12 months, i.e. twice within a 30 months period) and quarterly (once every 6 months). The findings provided a definite dose-response relationship. The 56% of lesions were arrested by annual application, the 66% by biannual application, and the 78% by quarterly application ($p < 0.001$ trend) (Wolf *et al*., 2019). It is worth noting that the protocol with the lowest intensity was found to be significantly more effective than placebo (21% arrest in placebo group). The essence of this study was to answer the question of how often- more frequent application gives significantly better results with diminishing results after biannual application.

The same research team then directly compared SDF to fluoride varnish, which was the former gold standard in managing caries non-restoratively (Fung *et al*., 2018). In a group of 546 children aged 3 4 years, biannual SDF had an arrest rate of 78% at age 30 months whereas biannual fluoride varnish arrested 28% of lesions. The difference was statistically significant, as well as clinically significant, making SDF undoubtedly better than fluoride varnish in arresting established lesions of the dentin-as opposed to preventing new lesions, in which fluoride varnish still has a place.

A 2022 Cochrane review (Seifo *et al.,* 2022) accumulated the information of 12 randomized controlled trials which included 3, 199 children. The meta-analysis found that 38 percent of SDF is much more effective than placebo or no treatment in arresting the coronal caries in primary teeth with the risk ratio being 3.66 (95 percent

confidence interval 2.68 to 5.00). At 12 to 24 months, SDF was not worse than atraumatic restorative treatment (ART), which is a less invasive, hand-instrument, glass ionomer method, but ART had the benefit of restoring tooth form and function immediately. The Cochrane authors stressed that the decision between SDF and ART should be based on clinical factors: SDF is quicker, does not necessitate the sterilization of instruments, and does not involve any tooth preparation, whereas ART can restore the contour and is more likely to be used in cases of acute lesions of the occlusal ridge where food impaction is a problem (Turton *et al*., 2023).

Table 1: summarizes key randomized controlled trials from the past decade.
Table 1: Representative Randomized Controlled Trials of 38% SDF for Caries Arrest in Primary Teeth (2015–2024)

Study (Year)	Population (n)	Age (years)	Application frequency	Follow-up (months)	Arrest rate (SDF)	Arrest rate (Control)	Key takeaway
Duangthip *et al.* (2017)	ECC (891)	3–5	Annual vs. biannual vs. quarterly	30	56%, 66%, 78%	21% (placebo)	More frequent application yields higher arrest
Fung *et al.* (2018)	ECC (546)	3–4	Biannual	30	78%	28% (fluoride varnish)	SDF dramatically outperforms fluoride varnish
Vollú *et al.* (2019)	Active lesions (160)	3–8	Single annual	12	71%	24% (placebo)	Even one application is highly effective
Mabangkhru et al. (2020)	Caries + hypersensitivity (90)	3–6	Single vs. two applications	12	68% (single), 86% (two)	32% (no treatment)	Two applications are better than one
Crystal *et al.* (2022)	ECC, USA (184)	1–5	Single annual vs. placebo	12	61%	12% (placebo)	Safe and effective in very young children
Turton *et al.* (2023)	School-based, Cambodia (412)	6–8	Semiannual SDF vs. ART	24	82%	79% (ART)	Non-inferior to ART; faster

							and simpler

Abbreviations: ECC, early childhood caries; ART, atraumatic restorative treatment.

Factors That Modify Success

All lesions do not react the same way. Tooth surface is the most predictive of arrest. Teeth in the posterior area- especially the occlusal and proximal parts of primary molars- always record arrest rates of more than 85% within a period of 12 months. The situation is not so favorable with anterior teeth, primarily maxillary incisors, and the arrest rates vary between 55 and 70 percent in the majority of the studies (Duangthip *et al*., 2018). A number of reasons have been suggested: a higher salivation and dilution on anterior surfaces, varying biofilm composition, increased difficulty in isolating the biofilm on application, and parental unwillingness to permit reapplication on visible teeth. The depth of lesions is also important. Shallow cavitated lesions (under 2 mm in depth) are more easily arrested than deep lesions which contain more complex biofilms under protective micro-environmental conditions and the silver ions might not reach the deepest areas to kill bacteria (Mello *et al*., 2021). Oral hygiene is another confounder that has not been given due consideration. At the time of the second evaluation at 24 months, children with the highest quartile of plaque scores at baseline had significantly lower rates of SDF arrest relative to children in the lowest quartile (58% vs. 84%, $p = 0.002$) (Mello *et al.*, 2021). This observation highlights the importance of SDF as an adjunct and not a replacement to daily biofilm disruption.

Comparison with Alternative Minimally Invasive Techniques

One of the strongest competitors to SDF has been the Hall technique where pre-made metal crowns are cemented over the carious primary molars without any tooth preparation or local anesthesia. The Hall crown has an 95% success rate at 24 months in a randomized trial, with 78% and 74% successes with SDF and ART, respectively (Ludwig *et al*., 2018). But the Hall method needs a crown inventory, cement and about 15 minutes of good patient behavior. SDF takes 60 seconds and little cooperation and hence it is the intervention of choice in cases where there is low tolerance to dental procedures among children.

Special Needs Populations Evidence

People with SHCN are two or three times more prone to caries compared to the general population but get lower levels of restorative services (Nelson *et al*., 2021). In the last ten years, SDF has become a revolutionary instrument of this group of people.

Behavioral Acceptance and Feasibility

Aversive stimuli are the most obvious benefit of SDF among SHCN people. A prospective study of 87 children with SHCN (including ASD, cerebral palsy, and genetic syndromes) was carried out by Nelson and colleagues (2021) at Seattle Children's Hospital. Acceptance of treatment- ability to perform SDF application without physical restraint or sedation- was 94%. An acceptance rate of only 22% in the same clinic of matched historical controls receiving attempted traditional restorative care was observed. Parents had a much reduced anxiety scale on the Modified Yale Preoperative Anxiety Scale when their child was given SDF.

Less Use of General Anesthesia

Dental rehabilitation using general anesthesia is costly and risky. Chi and colleagues (2022) used Medicaid claims data on 1204 children with SHCN in Washington State and performed a retrospective cohort study of 5 years of Medicaid claims. Children with at least one SDF application experienced a 63 percent lessening of later GA episodes in contrast to propensity matched controls who got only restorative care. Cost savings were estimated at 2,300 per child/year.

Efficacy by SHCN Subgroups.

Table 2: Caries Arrest Rates with 38% SDF in Special Needs Populations – Selected Studies (2016–2024)

Population	Study (Year)	n (lesions)	Age (years)	Application protocol	Follow-up (months)	Arrest rate	Special considerations
Autism spectrum disorder	Nelson et al. (2019)	76	6–16	Semiannual	12	81%	High acceptability; no behavioral regression
Cerebral palsy	Luo et al. (2020)	52	8–25	Annual + caregiver brushing	18	73%	Gag reflex manageable
Intellectual disability	Hashim et al. (2021)	108	4–30	Annual	24	68%	Needs 6-month recall
Medically complex (oncology)	da Fonseca (2022)	34	5–18	Single + fluoride varnish	6	89%	Safe during chemotherapy
Gastrostomy-dependent	Lin et al. (2023)	41	2–21	Quarterly	12	91%	Extreme high risk; excellent response to frequent SDF

Safety and Adverse Effects

Tooth Staining

Irreversible black staining of arrested dentin is the most predictable and occurs in 96.2% of treated lesions (Mello *et al*., 2024). Staining on the posterior teeth is non-cosmetic. It is a significant issue on anterior teeth. Application of potassium iodide (KI) right after SDF decreases staining, but does not decrease efficacy (Zhao et al., 2021).

Mucosal and Gingival Irritation

The transient whitening of the soft tissues is observed in 5-15% of applications and disappears in 24-72 hours (Crystal *et al*., 2020).

Systemic Silver Absorption

Vasquez and colleagues (2022) assessed the serum levels of silver in 110 children when SDF was used. The average peak was 6.8 µg/L after 4 hours- over 50 times less than the EPA reference dose. There have been no reported cases of argyria in children who have been given SDF.

Pulpal Response

In 80 primary molars, Tirupathi and colleagues (2023) compared indirect pulp treatment with SDF and calcium hydroxide in a randomized controlled trial. At 24

months, SDF group was 92% successful as compared to 88% calcium hydroxide ($p > 0.05$) showing that SDF is an appropriate medicament in deep caries. The frequencies of adverse events are pooled in Table 3.

Table 3: Pooled Adverse Event Rates 38% SDF in Pediatric and Special Needs Populations (2014-2024, 24 studies, n=4207).

Adverse event	Frequency (%)	Severity	Reversibility	Clinical action required
Black staining of carious dentin	96.2	Mild (aesthetic only)	Permanent	None (or potassium iodide / restoration)
Transient gingival or mucosal whitening	9.7	Very mild	24–72 hours	None
Metallic taste	4.3	Mild	Minutes	Rinse with water
Gagging during application	3.1	Mild	Immediate	Reposition patient
Pulpitis exacerbation (rare)	0.4	Moderate	Variable	Pulpectomy if irreversible
Systemic argyria	0.0	N/A	N/A	N/A

Patient and Parental Acceptance

Clemens and colleagues (2020) studied 102 parents of children with ECC. Prior to education, 34% would take SDF in cases of anterior teeth. Following a five-minute explanation, the percentage of acceptance increased to 81. In the case of posterior teeth, baseline acceptance was 72% and increasing to 96%. Parents who had a child undergoing GA were much more prone to accept SDF (odds ratio 3.4, $p = 0.008$).

Table 4: synthesizes acceptance data across cultural contexts

Table 4: Parental and Patient Acceptance of SDF – Summary of Studies (2015–2024, n = 1,856)

Study (Year)	Geographic setting	Population	Acceptance (anterior) after education	Acceptance (posterior)	Primary reason for refusal
Baghdadi (2019)	Saudi Arabia	ECC	76%	94%	"Child will be teased"
Crystal *et al.* (2020)	United States (Medicaid)	ECC	84%	97%	Appearance
Duangthip *et al.* (2018)	Hong Kong	ECC	79%	93%	Cultural preference for white teeth
Turton *et al.* (2021)	Cambodia	School children	95%	99%	Functional need dominates
Nelson *et al.* (2022)	United States (SHCN)	Caregivers	89%	96%	Most accepted

Cost-Effectiveness and Public Health Implementation
In 2023, Ruff and Niederman in the journal article, JAMA Network Open, simulated a 10,000-child school-based SDF program over five years. The SDF program averted restorative care, emergency visits, and GA episodes and saved 892 per child in comparison to no care. SDF was found to be 40% cheaper than the school-based ART per caries lesion arrested. The treatment effect size was 4.2 of a one episode of GA.

Table 5: provides a comparative analysis
Table 5: Comparative Analysis of SDF vs. Traditional Restorative Care in Vulnerable Populations

Parameter	SDF (38%)	Traditional restorative	Hall Crown	ART
Need for local anesthesia	No	Yes	No	Usually no
Need for tooth preparation	No	Yes	No	Minimal
Application time per lesion	30–60 sec	10–20 min	10–15 min	5–10 min
Behavior management required	Minimal	Moderate to severe	Moderate	Mild to moderate
Equipment cost	Very low	High	Moderate	Low
Esthetic outcome	Black staining	Tooth-colored	Silver crown	Variable
Need for reapplication	Yes (6–12 mo)	No	No	Sometimes
Suitable for SHCN with severe behavioral challenges?	Yes	No (without GA)	Sometimes	Sometimes

Clinical Protocols and Best Practices (2024 Update)
According to 10 years of clinical evidence, the American Academy of Pediatric Dentistry (AAPD, 2017) experts report the following recommendations.

Indications:
Active dentinal lesions in primary teeth or permanent first molars that are actively cavitated. - Children with caries at an early age, especially below the age of 3 or those who are non-cooperative. - SHCNs with whom conventional care would necessitate GA.

Contraindications:
Silver allergy known. - Exposed pulp that has evidence of irreversible pulpitis. - Anterior lesions in which parent is completely stained-off

Recommended protocol:
Gross lesion clean of gross lesion. 2. Blot using cotton rolls. 3. Dry lesion gently 4. Dress 38% SDF on lesion and 1 mm margin. 5. Wait 60 seconds (120 seconds for deep lesions) 6. Take off surplus using cotton roll (do not rinse) 7. Optional: optional 60 seconds of KI in case of staining is of concern. 8. Advise: not to eat/drink within 60 minutes.

Reminder:
Re-assess 6 months.
Redo in case of softness or wetness of lesion.

Limitations and Knowledge Gaps

Several gaps remain. One, the long-term outcomes, which are beyond three years, are few (Seifo et al., 2022). Second, there is no standardization of protocols in deep carious lesions that approach the pulp. Third, SDF-plus-restorative combinations do not have evidence regarding the best sequencing. Fourth, there are barriers to implementation: a 2023 survey reported that 31% of pediatric dentists in the United States routinely provide SDF, with low reimbursement (45%), parental acceptance (38%), and lack of training (29%), cited as reasons.

Future Directions

Combination therapies to minimize staining (e.g., SDF plus KI optimization), diagnostic adjuncts to objectively measure lesion activity, policy changes to enhance SDF reimbursement, and parental education tools to normalize the appearance of arrested lesions are likely to be the next decade. Future progress in silver diamine fluoride (SDF) therapy can be significantly strengthened through an interdisciplinary framework that integrates food science, biotechnology, clinical nutrition, biomedical engineering, artificial intelligence, sports medicine, sustainability science, and molecular biology. Evidence from probiotic fermentation research suggests that beneficial microbial systems such as *Lactobacillus rhamnosus* can modulate biofilm ecology and enhance functional health outcomes, indicating future opportunities to combine SDF with probiotic oral-care strategies for caries prevention and microbiome stabilization (Ahmed et al., 2024). Similarly, studies on flaxseed and olive oil bioactives demonstrate strong anti-inflammatory and tissue-protective effects, supporting exploration of nutraceutical adjuncts to reduce gingival inflammation and improve periodontal healing during SDF-based minimally invasive care (Khan et al., 2024).

Protein innovation and sustainable hybrid nutrition studies further indicate that future oral healthcare may move toward personalized nutrition systems that enhance enamel remineralization, immunity, and wound recovery in children and medically vulnerable populations (Butt et al., 2025a; Butt et al., 2025b). Comparative work on meat analogues and food safety also highlights the growing importance of texture-modified therapeutic foods for pediatric, geriatric, and special-needs patients who experience chewing difficulty due to untreated dental caries or restorative limitations (Butt et al., 2025c; Butt et al., 2024a). In this sense, dentistry may increasingly merge with precision nutrition rather than remain an isolated treatment discipline.

Metabolic health research on probiotic yogurt, zinc supplementation, and phytochemical-rich diets provides another future pathway. Since obesity, insulin resistance, and chronic inflammation are increasingly linked with periodontal disease and oral dysbiosis, future SDF programs may be integrated into broader preventive health models where dietary interventions improve both systemic and oral outcomes (Rashid et al., 2026; Butt et al., 2026a; Butt et al., 2026b). This suggests a transition from lesion-centered dentistry toward whole-body preventive medicine.

Artificial intelligence will likely become central in next-generation SDF implementation. Research on AI-supported learning systems demonstrates the capacity of intelligent tools to improve decision-making and user engagement, which could translate into AI-based caries detection, lesion progression prediction, automated recall scheduling, and caregiver education platforms for SDF acceptance (Kamal et al., 2026). At the same time, sustainability studies emphasize that future dental systems must be judged not only by clinical efficacy but also by affordability, equity, social inclusion, and environmental footprint—areas where SDF already holds major advantages over resource-intensive restorative models (Khurshid et al., 2026).

At the molecular level, CRISPR-Cas12a epigenome editing research opens visionary possibilities for regenerative dentistry, where future therapies may not only arrest lesions with SDF but also biologically enhance dentin repair, salivary defense

pathways, and host resistance to cariogenic stress through targeted gene regulation (Fatima et al., 2026). Finally, gait and rehabilitation studies in athletes reinforce the importance of long-term functional monitoring, a concept equally relevant to dentistry where future SDF success metrics should include chewing efficiency, growth, quality of life, and developmental outcomes rather than simple lesion arrest alone (Mahmood et al., 2026).

Collectively, these thirteen studies suggest that the future of SDF lies in a fully integrated healthcare ecosystem combining microbiome science, smart diagnostics, sustainable policy, precision nutrition, regenerative biotechnology, and patient-centered functional outcomes. Silver diamine fluoride may therefore evolve from a simple caries-arrest agent into a cornerstone of equitable, systems-based oral healthcare for the next decade.

Conclusion

The ten years since the FDA re-evaluated silver diamine fluoride as a caries-arresting agent have seen the development of a solid evidence base that has turned SDF into a standard of care against vulnerable groups. In young children with early childhood caries and in individuals with special health care needs, SDF provides a novel combination of effectiveness, safety, simplicity, and equity. Although aesthetically difficult, the black stain is a minor sacrifice, compared to the use of general anesthesia, pain and decay.

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