ORIGINAL RESEARCH

Evaluation of Fluoride and Silver Ion Concentrations in e-Silver Diamine Fluoride and Advantage Arrest: An Ion Chromatography and Atomic Absorption Spectrometer Study

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Abstract

Aims and background: Dentin hypersensitivity (DH) is characterized by sharp shooting pain due to exposed dentin, and the most common method for treating this pain is the occlusion of the dentinal tubules with the help of desensitizing agents. E-silver diamine fluoride (e-SDF) (Kids-e-Dental, Mumbai, India) is a commercially available 38% SDF solution in the Indian market. Despite the fact that its application for caries prevention has been proven, the fluoride (Fl) and silver (Ag) ion concentrations of e-SDF for use in treating DH have yet to be standardized. The aim of this study is to determine and compare the Fl and Ag ion concentrations released from two commercially available 38% silver diamine fluoride (SDF) solutions.

Materials and methods: The two most common commercially available 38% SDF solution brands, namely Advantage Arrest and e-SDF were used. Two drops of each of these solutions were taken in three beakers and diluted with distilled water. The Fl ion concentration was evaluated using a calibrated ion-specific electrode. The free Ag ion concentration was assessed using an atomic absorption spectrometry (AAS).

Results: Release of Ag ions shows that on days 1, 2, 5, 6, and 7, concentration (mg/L) was higher in the Advantage Arrest group but is statistically nonsignificant. On days 3 and 4, it is higher in an e-SDF group with a *t*-value of 1.085 and 0.243 and is statistically nonsignificant. Release of Fl ion showed that in comparison to the baseline, it was more with Advantage Arrest on days 2, 4, and 7 with a *t*-value of –3.766, –0.999, and 0.347 and on day 2 was statistically significant. On days 3, 5, and 6 Fl ion release from baseline was more with e-SDF in comparison with Advantage Arrest but statistically insignificant.

Conclusion: The AAS analysis as well as the ion chromatography showed that the Ag and Fl ion release respectively on days 1–7 from e-SDF was similar to the one seen in the case of Advantage Arrest.

Clinical significance: This helps dentists choose among different brands of the same commercially available 38% SDF solutions depending on the cost and availability of the product.

Keywords: Caries, Fluoride ion, Hypersensitivity, Silver diamine fluoride, Silver ion.

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Introduction

Dentin hypersensitivity (DH) is characterized by sharp shooting pain due to exposed dentin and cannot be diagnosed as any other pathology of the tooth.[1] The pain is said to be exaggerated due to chemical, thermal, tactile, or osmotic stimuli.[2] A few common causes leading to DH can include gingival recession, tooth wear, and faulty tooth brushing techniques.[3] To explain the mechanism of DH, several ideas have been proposed. The hydrodynamic theory, initially developed by Brännström in 1996, is the most widely recognized theory. This concept proceeds with the claim that the stimulus-induced fluid flow in the dentinal tubules and subsequent activation of the nociceptor in the dentin/pulp boundary are what cause the dentin to be sensitive.[4]

Over the years, various methods and treatment techniques have been devised to treat this hypersensitivity. However, DH remains one of the most difficult problems to address in clinical dentistry. One of the most common methods for treating DH is the occlusion of dentinal tubules with the help of desensitizing agents.[5]

Various agents are used to treat DH through this technique. Silver diamine fluoride (SDF) is a clear solution that has been used primarily as a caries preventive and arresting agent. It was introduced to dentistry in 1969. It is an inexpensive and colorless solution with pH values varying from 9 to 10.[6–8] It is available

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commercially at concentrations of 10, 12, 30, and 38%. There is sufficient evidence that supports the use of 38% SDF solutions as caries arrest and preventive agents because they are more effective than the SDF solutions used in other combinations. Moreover, 38% SDF is easy to use and is quite efficient and noninvasive.[7] It is a painless, safe replacement for conventional cavity drilling techniques.[9] Due to its remineralization and antimicrobial qualities, SDF is popular among dentists. Additionally, those who are medically compromised or in need of extra assistance, as well as those who cannot tolerate invasive procedures, may benefit from this therapy.[8] Silver (Ag), which has a potent antibacterial effect, is present in SDF, making it a preferable agent for use in therapeutic treatment. The free fluoride (Fl) ions function as a remineralizing agent.[7]

The Food and Drug Administration (FDA) in the United States approved the use of SDF as a desensitizing agent in 2014.[7] SDF has been primarily used to prevent caries even though it is approved for use to desensitize hypersensitive teeth.[10,11]

Advantage Arrest (Elevate Oral Care, United States) is the most commonly available commercially marketed 38% SDF solution.[12] Although this agent is the most popular desensitizing agent and is standardized by the FDA, it is quite expensive and not easily available for use in most dental offices in India.

e-Silver diamine fluoride (Kids-e-Dental, Mumbai, India) is a commercially available 38% SDF solution in the Indian market that is inexpensive.[12] Despite the fact that its application for caries prevention has been proven, the Fl and Ag ion concentrations of e-SDF for use in treating DH have yet to be standardized.

The key objective of this research is to compare the free Fl and Ag ion concentrations of SDF to those of the FDA-accepted standard Advantage Arrest SDF solutions.

Materials and Methods

This study investigated two commercially available 38% SDF solutions, namely, Advantage Arrest and e-SDF. In June 2023, one bottle each of SDF and Advantage Arrest was collected for measurement. In July 2023, solutions from bottles containing freshly opened solutions were evaluated. Before testing, two drops of each of these solutions (two drops of e-SDF and two drops of Advantage Arrest) were placed in three beakers and diluted with distilled water at a dilution factor of 1:10,000. All tests were carried out in an air-conditioned laboratory at 37°C.

The Fl ion concentration was determined using ion chromatography, while the Ag ion concentration was evaluated with atomic absorption spectroscopy (AAS). Both the free Fl and Ag ion concentrations of the distilled water were evaluated before adding two solutions, after which the Fl and Ag ion concentrations were evaluated from the 1st to 7th days.

Evaluation of the Free Fl Ion Concentration

The free Ag ion concentration was assessed using ion chromatography (ICS 6000, Thermo Fisher, United States). To increase the ionic strength of the diluted SDF solutions, 10 mL of a pH-adjusted (pH 6.0) buffer solution (total ionic strength adjustment buffer) was added.[12] The flow rate was approximately 1 mL/minute. Sodium carbonate (4.6 mM) and sodium bicarbonate (2.8 mM) were used as diluents. Ion chromatography was standardized prior to determining the free Fl ion concentration of the tested solution and calibrated using four standardized fluoride solutions with fluoride concentrations of 1, 2, 5, and 10 ppm. A typical, conventional curve was generated by plotting a line graph of fluoride concentration vs electric potential, which was measured through an electrode, and then solving a linear equation based on the logarithm of the fluoride concentration.

The fluoride concentration was calculated from the measured electric potential of the tested solution using the standard curve. The measurements were repeated to ensure reliability.[12]

Evaluation of Ag Ion Concentration

The Ag ion concentration was determined with an atomic absorption spectrometer (AAS) (model ICE 3000 series). First, the AAS was calibrated with only distilled water solution to determine the baseline absorption. Then, two drops of the test solutions were added to the three beakers. The absorption of solutions containing varying known quantities of the element was tested *via* AAS analysis. A calibration curve was generated using these data. The calibration curve established the link between light absorbance and element concentration in solution.

Statistical Analysis

The data were tabulated in Microsoft Excel, and the percentage of Ag ions was evaluated using the Shapiro–Wilk test. Comparisons between the two groups were performed using an independent *t*-test if the data were parametric, and if the data were skewed, then the Mann–Whitney *U* test was used for analysis.

Results

The concentration of Fl ions released was greater with e-SDF than with Advantage Arrest, with *t*-values of –1.311, –2.203, –1.2, –2.068, –1.377, –1.282, and –1.02 on days 1–7, respectively, but these differences were not significant.

A comparison of the Ag ion release between day 1 and day 7 Conc (mg/L) between the two groups revealed that on days 1, 2, 5, 6, and 7, Conc (mg/L) was significantly greater in the Advantage Arrest group, with *t*-values of –1.333, –0.417, –0.087, –0.1, and –0.128, respectively. On days 3 and 4, Conc (mg/L) Ag ion release was greater in the e-SDF group, with *t*-values of 1.085 and 0.243, respectively, which were not statistically significant (Table 1).

Table 1: Fl and Ag ion release for e-SDF and Advantage Arrest from day 1 to day 7

	Fl ion concentration				*Ag ion concentration*			
Conc (mg/L)	*e-SDF (n = 3)*	*Advantage Arrest (n = 3)*	*t-value*	*p-value*	*e-SDF (n = 3)*	*Advantage Arrest (n = 3)*	*t-value*	*p-value*
	Mean ± SD	*Mean ± SD*			*Mean ± SD*	*Mean ± SD*		
Day 1	0.88 ± 0.07	0.82 ± 0.03	–1.311	0.26	1.05 ± 0.08	1.15 ± 0.1	–1.333	0.254
Day 2	0.73 ± 0.07	0.63 ± 0.04	–2.203	0.092	1.34 ± 0.17	1.38 ± 0.07	–0.417	0.698
Day 3	0.91 ± 0.1	0.83 ± 0.04	–1.2	0.296	1.55 ± 0.41	1.29 ± 0.06	1.085	0.339
Day 4	0.78 ± 0.06	0.66 ± 0.07	–2.068	0.108	1.37 ± 0.2	1.35 ± 0.05	0.243	0.829
Day 5	0.9 ± 0.09	0.82 ± 0.02	–1.377	0.24	1.38 ± 0.2	1.39 ± 0.07	–0.087	0.935
Day 6	0.98 ± 0.09	0.91 ± 0.02	–1.282	0.269	1.36 ± 0.19	1.37 ± 0.06	–0.1	0.925
Day 7	0.97 ± 0.09	0.92 ± 0.01	–1.02	0.412	1.38 ± 0.21	1.39 ± 0.06	–0.128	0.908

The concentration of Fl ions released was greater with e-SDF than with Advantage Arrest, with *t*-values of –1.311, –2.203, –1.2, –2.068, –1.377, –1.282, and –1.02 on days 1–7, respectively, but these differences were not significant.

Compared with that at baseline, the release of Fl ions was greater on days 2, 4, and 7, with *t*-values of –3.766, –0.999, and 0.347, respectively, and on day 2, the difference was statistically significant. On days 3, 5, and 6, Fl ion release from baseline was greater in the presence of SDF than in the absence of SDF, with *p*-values of 0.428, 0.236, and 0.706, respectively, which were not statistically significant (Fig. 1).

On comparison of the mean values for e-SDF, among day 1 Conc (mg/L) and day 2 Conc (mg/L), the mean value of day 2 Conc (mg/L) was greater, with a difference of 0.2879667. A comparison of the mean values of day 1 Conc (mg/L) and day 3 Conc (mg/L) revealed that the mean value of day 3 Conc (mg/L) was greater, with a difference of 0.5039667. A comparison of the mean values of day 1 Conc (mg/L) and day 4 Conc (mg/L) revealed that the mean value of day 4 Conc (mg/L) was greater, with a difference of 0.3259. A comparison of the mean values of day 1 Conc (mg/L) and day 5 Conc (mg/L) revealed that the mean value of day 5 Conc (mg/L) was greater, with a difference of 0.3272. A comparison of the mean values of day 1 Conc (mg/L) and day 6 Conc (mg/L) revealed that the mean value of day 6 Conc (mg/L) was greater, with a difference of 0.3086333. A comparison of the mean values of day 1 Conc (mg/L) and day 7 Conc (mg/L) revealed that the mean value of day 7 Conc (mg/L) was greater, with a difference of 0.3276667.

Compared with those of day 1 Conc (mg/L) and day 2 Conc (mg/L), the mean values of day 2 Conc (mg/L) were significantly greater, with a difference of 0.2346 and a *p*-value of 0.018. A comparison of the mean values of day 1 Conc (mg/L) and day 3 Conc (mg/L) revealed that the mean value of day 3 Conc (mg/L) was greater, with a difference of 0.1451667. A comparison of the mean values of day 1 Conc (mg/L) and day 4 Conc (mg/L) revealed that the mean value of day 4 Conc (mg/L) was greater, with a difference of 0.199966. A comparison of the mean values of day 1 Conc (mg/L) and day 5 Conc (mg/L) revealed that the mean value of day 5 Conc (mg/L) was significantly greater, with a difference of 0.2403667 and a *p*-value of 0.04. A comparison of the mean values of day 1 Conc (mg/L) and day 6 Conc (mg/L) revealed that the mean value of day 6 Conc (mg/L) was greater, with a difference of 0.2228667. A comparison of the mean values of day 1 Conc (mg/L) and day 7 Conc (mg/L) revealed that the mean value of day 7 Conc (mg/L) was significantly greater, with a difference of 0.2466333 and a *p*-value of 0.043 (Fig. 2).

Discussion

The Fl and Ag ion concentrations of two commercially available 38% SDF solutions were determined in this analysis. The findings of this investigation support earlier studies that compared different brands of commercially available 38% SDF solutions. To date, four studies have investigated fluoride concentrations and Ag ion release.[12–15] Only one brand of SDF solution was utilized in two studies.[14,15] Another study examined four different brands of 38% SDF solutions.[12] For testing, three bottles of each brand of SDF solution were used. Another study investigated 5 brands of 38% SDF solutions; however, a single bottle of each brand was utilized, and only one measurement was taken.[13] We investigated two commercially available 38% SDF solutions in this study. We utilized a single bottle of each brand for testing, and two drops of solution from each brand were placed in three different beakers for testing. For reliability, the measurements were repeated. Due to cost and availability, we did not have access to all of the widely used SDF products in our investigation. The unblinded nature of the analysis is one of the limitations of this study. This study might contain observer bias and experimental bias due to the researcher's anticipation.

Ion chromatography was employed in this work to assess the concentration of free Fl. The inorganic ions in an aqueous solution can be measured using this widely used analytical technique by measuring the electric potential. Ion chromatography is a cost-effective, fast, and simple technique for measuring Fl ions. To ensure that the ion chromatography system functioned well, it was utilized in accordance with the recommendations provided by the manufacturer. However, this approach has the following limitations, it lacks universal detection. Ion chromatography cannot provide structural information on the separated ions.[16,17]

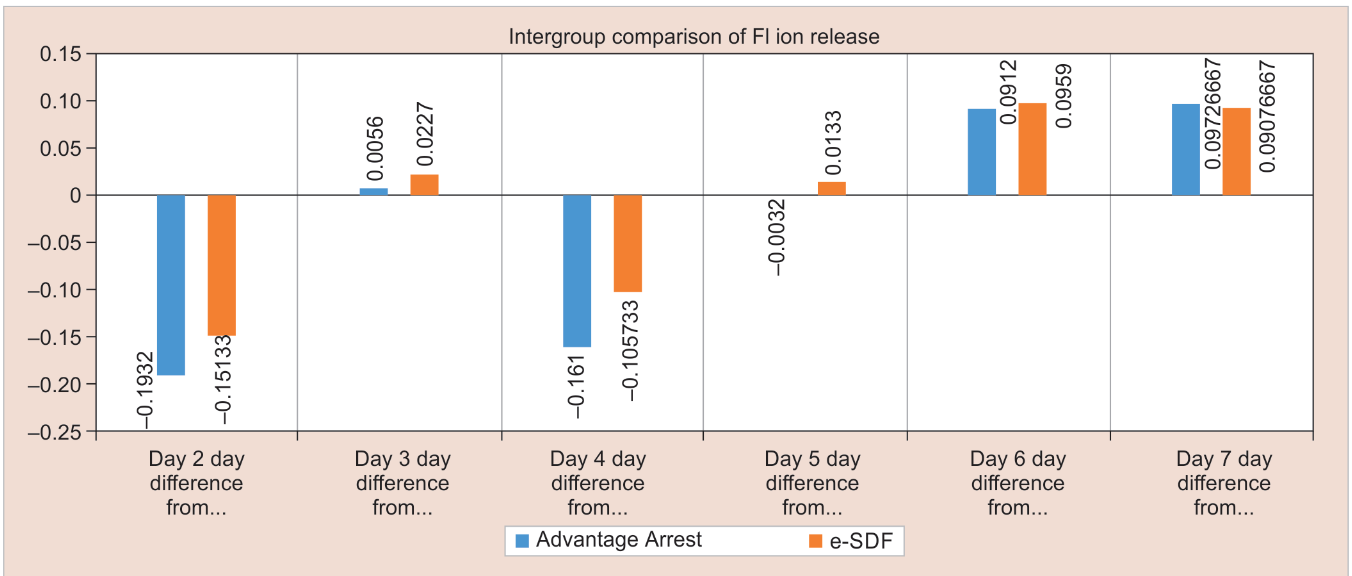

Fig. 1: The concentration of Fl ions released is greater with e-SDF than with Advantage Arrest

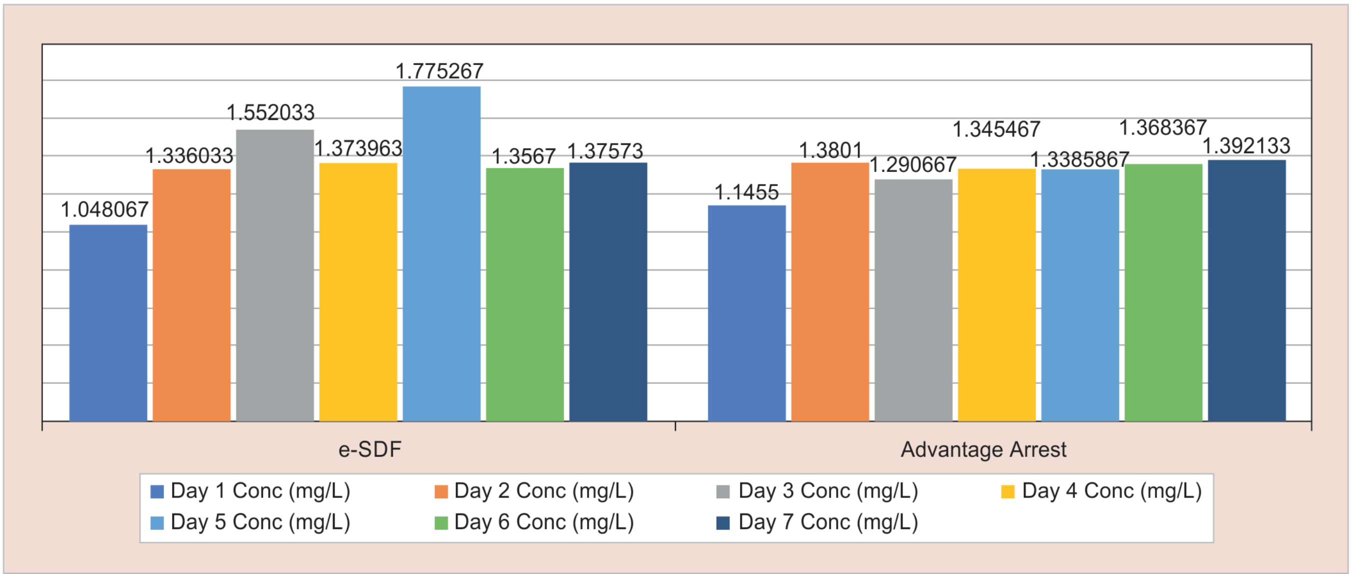

Fig. 2: Intergroup comparison of Ag ion release for e-SDF and Advantage Arrest

For Ag ion analysis, AAS was used. AAS is a highly accurate method for detecting metallic elements. It is a highly sensitive method of analysis. Another advantage of AAS is that it is a comparatively inexpensive means to accurately detect trace elements up to parts per billion of a gram.[18,19] Another alternative method for analyzing Ag ions is inductively coupled plasma optical emission spectroscopy (ICP-OES).[12,20] This method was not used due to the lack of availability of equipment inaccessible areas.

The analysis was performed in a clean laboratory, and the beakers and instruments used for analysis were washed thoroughly prior to analysis to reduce the influence of the environment. For the measurements, the laboratory temperature was controlled at 37°C.

Commercially available 38% SDF solutions from two different brands were purchased in June 2023. The shelf life of one brand (e-SDF) was 1 year, whereas the shelf life of the other brand (Advantage Arrest) was 2 years. This research was carried out in July 2023. Although the manufacturing dates for the two different brands of 38% SDF solutions were different, the dates should not have affected the results due to the long shelf lives of the two products. Although it was assumed that the SDF solutions were stable from their transportation, the researchers could not be sure of this. Although SDF is generally a safe product, a stable solution is produced by manufacturers to reduce any side effects for clinical use.

Since 2014, the use of SDF for the treatment of DH has increased. In general, 38% of SDF solutions are composed of 25% Ag ions, 5% Fl ions, and 8% ammonia solution.[12] However, several producers manufacture SDF according to their own formulations. A 38% SDF solution might be any mixture of silver, fluoride, and ammonia containing 38% of the total concentration. Because the quantities of silver, fluoride, and ammonia are all within an average range, the percentage of SDF cannot be exactly 38%.[12] Because the ion concentrations are not specified on the manufacturer's packaging or website, this study offered further information to medical practitioners and researchers concerning the two regularly used and commercially available 38% SDF solutions utilized in this investigation.

According to the findings of this investigation, Fl and Ag ion release was substantially equal in both brands of 38% SDF solutions (Advantage Arrest and e-SDF).

Conclusion

The quantities of Fl and Ag ions emitted in two commercially available 38% SDF solutions from two separate manufacturers were determined in this laboratory investigation. Atomic absorption spectroscopy revealed that Ag ion release from e-SDF on days 1–7 was identical to that found in the case of Advantage Arrest. Ion chromatography revealed that the Fl ion release from e-SDF from days 1–7 was identical to that found in the case of Advantage Arrest. Compared to other current fluoride agents, 38% of SDF solutions contain the most fluoride. This study helps dentists realize that the Fl and Ag ion concentrations in the two commercially available 38% SDF solutions are almost identical.

Clinical Significance

These findings are important for dentists for the following reasons:

- Dentists can infer that e-SDF is as efficient for arresting active dental caries and treating DH as is Advantage Arrest. e-SDF is easily available and cost-effective.
- This helps dentists choose among different brands of the same commercially available 38% SDF solutions depending on the cost and availability of the product.

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