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Application and Perception of Potassium Iodide Following Silver Diamine Fluoride Treatment

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Abstract

Silver Diamine Fluoride (SDF) is colorless and alkaline with a pH of 10. It has been used in Japan and other international countries for decades. The Food and Drug Administration gave approval for it as a means of treating hypersensitivity for individuals with chronic teeth pain. SDF is also used as a method to treat and arrest dental caries. SDF application is limited due to its negative esthetic effects, which is a black stain where the cavity was present on the tooth. Topical application of potassium iodide applied immediately after SDF has been shown in studies to reduce the color change caused by SDF. This study used topical application of silver diamine fluoride (SDF) and potassium iodide (KI) treatments on bovine teeth to determine if SDF and KI were efficacious in the treatment for carious lesions. The color change was detected by use of spectrophotometric analysis to determine L, a and b readings that demarcate light and color values following staining. The conclusion was made that the application of SDF followed directly by KI treatment produced L, a and b spectrophotometric values that indicated a significant reduction in teeth staining than the application of SDF alone. Therefore, this study supports the idea that SDF and KI can be used to treat carious lesions on bovine teeth while retaining surface enamel coloration.

Keywords

Carious Lesion Treatment, Silver Diamine Fluoride, Potassium Iodide, Spectrophotometry, Teeth Staining

1. Specific Aims

The purpose of this research is to find a way to reduce the staining effect of Advantage Arrest SDF on teeth without restorations. It is colorless and alkaline with a pH of 10 [1]. The aim is to apply Advantage Arrest SDF immediately followed by potassium iodide to determine if any color change is perceptible in relation to the original color of the teeth. Potassium iodide applied immediately after SDF has been shown in studies to reduce the color change caused by SDF [2]. Measurements of optical characteristics were performed using a spectrophotometer.

Hypothesis: Application of SDF immediately followed by Potassium Iodide on carious lesions in extracted teeth will result in a color difference that is not significantly different from the original unmodified teeth.

2. Significance

Silver diamine fluoride (SDF) is used in dentistry as a way to treat hypersensitivity and arrest and prevent dental caries [1]. With this revolutionary method that is transforming the field of dentistry, there come groundbreaking benefits for dental professionals and patients [3]. Yet, as with most new advancements, there is continuing research on its use, effectiveness, and ways to improve it. This proposal provides a background into the product, its potential in the future, and the details for a new research study that aims to improve the use of SDF.

Each component of silver diamine fluoride contributes to its mechanism of action. Silver acts as an antimicrobial which reduces the number of oral bacteria such as *S. mutans* and kills other pathogenic bacteria. Fluoride promotes the remineralization of enamel tissue and hardens the tissue that has been softened by decay, which makes that enamel more resistant to acid and abrasion. The ammonia group in the silver diamine metal complex stabilizes high concentrations of silver and fluoride in the solution, and a silver-protein conjugate layer forms. This increases resistance to acid dissolution and enzyme degradation [4]. A single treatment of SDF can lose its effectiveness over time, so recommended application is twice each year [1].

SDF is beginning to be more widely used in the field of dentistry. While 78% of American Dental Association Clinical Evaluators reported they have never used silver diamine fluoride, 16% use it on a monthly basis [5]. The use of SDF is limited due to its negative esthetic effects, a black stain where the cavity is on the tooth. Application of silver diamine fluoride causes cavities to darken, leading to concerns with parents who may not want their children to have a treatment that causes their teeth to become visually unpleasant. Its current use is primarily in limited problematic cases, including young children who may be difficult to treat through conventional methods. Examples of the current use of SDF include in children who have disabilities that hinder them from staying still while a dentist works on their teeth or children in under-served communities who need temporary relief from cavities but have limited access to proper dental care. Its use is usually further limited to baby teeth rather than adult teeth so that the darkened cavity will not be on the permanent adult teeth. There have been instances of the use of SDF on the elderly who also face complications associated with regular dental care [6].

If the negative aesthetic effects of SDF could be minimized or reversed, its applications could be expanded. Potassium iodide applied immediately after SDF has been shown in studies to reduce the color change caused by SDF [2]. This research proposal is intended to study the effects of potassium iodide on SDF, including how concentration affects color difference and how it relates to the perceptibility of color change to the human eye. If the color change after adding potassium iodide in relation to the color of the original teeth can be minimized, the application of SDF can be further expanded to its use in more children and adults.

3. Innovation

Since international countries have been using SDF for years before its acceptance in the United States, most research studies conducted so far have used brands of SDF that are not available to the United States. Although previous studies have used other internationally available brands of silver diamine fluoride, such as Riva Star, this study will use Advantage Arrest, which is the only FDA-approved silver diamine fluoride commercially available in the United States manufactured by Elevate Oral Care [7]. In a previous study, the perceptibility of the color change to the human eye was measured using simple human observation [8]. In this study, a spectrophotometer will be used in order to minimize the risk of human error and bias in determining the color difference.

One aspect of this study is to find ways to treat patients who cannot be treated with regular dental care. Therefore, the focus will only be on the application of silver diamine fluoride, not on restoration. Underserved communities who may not have access to dental care could benefit from arresting cavities and reducing possible damages from further decay, as a temporary solution to the constraints that hinder them from proper dental care [9].

4. Method

22 Bovine teeth were acquired from a butchery in Gainesville Florida. All samples were extracted from a singular healthy cow that showed no signs of dental disease or abnormalities in eating [10]. The samples were cleaned using an orthodontic handpiece and commercial fluoride free toothpaste. After the samples were cleaned a sandpaper-saw was used to produce a smooth surface unto each of the teeth. This was done to provide a flat uniform area to facilitate spectrophotometric analysis, as well as the application of SDF and KI. The saw was spun at 150 rpm using a 600 and 300 grit sandpaper disc so as to ensure that the dentine was not damaged and that only surface enamel was removed. Higher grid paper was then used to polish the surface of the tooth to facilitate the spectrophotometry readings. In between each step, the samples were stored in a 0.05% thymol solution, except during spectrophotometric analysis, whereby the samples were transferred to demineralized water baths.

In order to acquire a baseline measure of tooth hardness, a microhardness test was conducted on the enamel surface layer of all the samples. After this, demineralization was conducted on all of the tooth surfaces. This was done to simulate the formation of carious lesions on all of the samples. The demineralization solution used was comprised of a 1000 mL solution. This was made using 2.2E−03 moles $CaCl_2$ (0.2442 g), 2.2E−03 moles KH_2PO_4 (0.2994 g), and 2.8736 mL of acetic acid.

Microhardness tests were conducted again in order to quantify the change in hardness. All microhardness testing was conducted using a diamond bit HV tester. Acrylic moulds were also used to hold the teeth into the microhardness testing machine. Three main moulds were used as they were sufficient to hold the teeth in place. A fixative wax was also used to adhere the tooth sample unto the mould. Spectrophotometric analysis was then conducted to obtain a baseline measure of the colour of each tooth. Specific attention was placed on the "l", "a" and "b" readings during this analysis. Once all teeth were measured, the samples were randomly divided into three test groups and numbered. Advantage arrest silver diamine fluoride (AA SDF) was applied to 1/3 of the samples, followed immediately by potassium iodide (KI). Another 1/3 was treated with AA SDF only. The rest of the samples remained untreated and acted as a control group. Specifically, samples 1, 4, 7, 10, 13, 16, 19 and 22 underwent SDF and KI treatment. Samples 2, 5, 8, 11, 14, 17 and 20 underwent SDF treatment only, and the remaining samples had no treatment and served as a control. Spectrophotometric analysis was then completed again for all the samples in order to observe the change in colour of each tooth after the application of different treatments. Statistical analysis was then conducted to see of AA SDF followed by KI treatment was a viable means to reduce the staining effect of AA SDF when treating carious lesions.

5. Calculations

In order to access the effect of demineralization, the percent change in hardness values was determined for each of the teeth samples. As can be observed in **Table 2** below.

Based on the data provided in **Table 2**, it can be determined than the average percent change in harness values for each of the teeth was 29.3867%. This meant that after demineralization was performed, each of the teeth samples had lost about 29.4% of its initial harness value. As outlined in **Table 1**, sample 8 was omitted as the tooth was an outlier, having an HV too small to quantify. Sample 13 was also the only tooth to have a net increase in hardness, however the tooth did not have significant discoloration and was left in the study.

After the demineralization was performed, SDF and KI treatment was then conducted along with spectrophotometric analysis, as observed in **Tables 3-5**. The important values from these tables are the "l, a, b" readings, whereby "l" represents the lightness value (teeth whiteness), "a" represents the red-green difference (teeth discoloration) and "b" represents the yellow-blue difference (teeth staining). The first comparison conducted was that of the pre-demineralization

Table 1. Hardness Value (HV) readings of teeth samples before and after demineralization.

Sample	Mold	Pre-Demineralization Hardness	Post-Demineralization Hardness
1	A	189.4	152.4
2	B	196.9	142.3
3	C	69.2	42.3
4	A	170.1	116.4
5	B	249.6	114.4
6	C	46.2	37.8
7	B	247.6	94.0
8	C	N/A	N/A
9	B	186.2	122.2
10	A	224.4	149.8
11	A	248.3	142.9
12	B	203.9	142.0
13	C	28.2	54.0
14	C	41.2	30.8
15	A	153.8	92.1
16	B	184.4	42.5
17	A	331.3	310.8
18	B	223.9	172.4
19	C	187.3	82.7
20	C	69.2	37.3
21	A	53.7	41.0
22	B	40.0	32.4

Table 2. Percent change in hardness values following demineralization treatment.

Sample	Mold	Pre-Demineralization Hardness	Post-Demineralization Hardness	Change in Hardness after Demineralization	Percent Change in Harness (%)
1	A	189.4	152.4	37	19.5354
2	B	196.9	142.3	54.6	27.7298
3	C	69.2	42.3	26.9	38.8728
4	A	170.1	116.4	53.7	31.5697
5	B	249.6	114.4	135.2	54.1667

Continued

6	C	46.2	37.8	8.4	18.1818
7	B	247.6	94	153.6	62.0355
8	C	N/A	N/A	N/A	N/A
9	B	186.2	122.2	64	34.3716
10	A	224.4	149.8	74.6	33.2442
11	A	248.3	142.9	105.4	42.4487
12	B	203.9	142	61.9	30.358
13	C	28.2	54	-25.8	−91.489
14	C	41.2	30.8	10.4	25.2427
15	A	153.8	92.1	61.7	40.117
16	B	184.4	42.5	141.9	76.9523
17	A	331.3	310.8	20.5	6.18775
18	B	223.9	172.4	51.5	23.0013
19	C	187.3	82.7	104.6	55.8462
20	C	69.2	37.3	31.9	46.0983
21	A	53.7	41	12.7	23.6499
22	B	40	32.4	7.6	19

Table 3. One sample statistic for the l spectrophotometry values.

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PreDemin_L	116.755	21	0.000	73.3680000	72.061189	74.674811
PostDemin_L	88.814	21	0.000	72.9229091	71.215392	74.630427

Table 4. One sample statistic for the a and b spectrophotometry values.

One-Sample Statistics				
	N	Mean	Std. Deviation	Std. Error Mean
PreDemin_a	22	−1.395273	0.3070128	0.0654554
PostDemin_a	22	−1.291000	0.3699020	0.0788634
PreDemin_b	22	6.225818	3.2789554	0.6990756
PostDemin_b	22	6.077318	3.6090088	0.7694433

Table 5. One Sample Statistic for the a and b spectrophotometry values with extrapolated data.

One-Sample Test						
	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
PreDemin_a	−21.316	21	0.000	−1.3952727	−1.531395	−1.259151
PostDemin_a	−16.370	21	0.000	−1.2910000	−1.455005	−1.126995
PreDemin_b	8.906	21	0.000	6.2258182	4.772011	7.679626
PostDemin_b	7.898	21	0.000	6.0773182	4.477173	7.677463

and the post-demineralization l, a and b results. This was done by comparing the results from Table 3 and Table 4. A standard t-Test was conducted to look for the significance between the l, a and b readings.

6. Discussion

Demineralization was done to cause a cavitated carious lesions-break in tooth surface to expose enamel or dentine. This therefore acted to simulate the formation of natural cavities that would occur from mastication. Bovine teeth samples were used as it is larger than human teeth and easier to procure. The added benefit was that bovine teeth share similar properties to human teeth. As such, bovine teeth allowed the results of the experiment to potentially provide efficacy and predictability in human applications. (Tanaka *et al.*, 2008). The samples were stored in thymol at 37˚C. This was done as thymol served to keep the teeth samples stable throughout the experiment. More importantly, thymol did not affect the mineralization of the teeth samples. As such, it served as a useful medium for storage. This is corroborated by the data in Table 2 where the L, a and b readings of the teeth after demineralization are nearly identical to that of the readings before demineralization. The changes are therefore insignificant, making thymol an effective solution for storage. Table 3 further corroborates this as it showed a significant correlation (p value < 0.05) between the L readings for pre and post demineralization results. Thymol therefore did not alter the demineralization properties of the solution, nor did it affect the coloration of the teeth. As such, the assumption can be made that all changes in teeth coloration are as a product of the intervention of SDF and KI treatments. Further evidence can be observed in Figure 1, as the tooth presented was visually as white in coloration to those samples in Figure 2. Figure 3 shows the application of SDF only, without KI, which resulted in a dark permanent stain in the tooth enamel.

The observations from the aforementioned figures are statistically represented in Tables 6-11. Table 6 shows the correlation of the L spectrophotometry values. From this data, the SDF and KI treatment showed an insignificant change

Figure 1. Teeth samples in acrylic molds after SDF and KI treatment.

Figure 2. Teeth samples in acrylic molds before SDF and KI treatment.

Figure 3. Tooth sample after the application of AA SDF without KI.

Table 6. Correlation of the L spectrophotometry values.

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	SDF_KI_L & P_Demin_SDF_KI_L	8	−0.388	0.342
Pair 2	SDF_L & P_Demin_SDF_L	7	0.627	0.132

Table 7. Correlation of the L spectrophotometry values with extrapolated values.

	Paired Samples Test							
	Mean	Std. Deviation	Std Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
SDF_KI_L-P_Demin_SDF_KI_L	−8.2500000	26.9307634	9.5214627	−30.7646816	14.2646816	−0.866	7	0.415
SDF_L-P_Demin_SDF_L	−34.2470000	5.2091560	1.9688759	−39.0646658	−29.4293342	−17.394	6	0.000

Table 8. t-Test: Paired two sample for means of a values.

	SDF and KI	*SDF and KI*
Mean	−5.55113	−1.22325
Variance	1.18105	0.070739
Observations	8	8
Pearson Correlation	0.739478	
Hypothesized Mean Difference	0	
df	7	
t Stat	−13.4827	
P (T ≤ t) one-tail	1.45E−06	
t Critical one-tail	1.894579	
P (T ≤ t) two-tail	2.9E−06	
t Critical two-tail	2.364624	

Table 9. t-Test: Two-sample assuming equal variances for a values.

	SDF Only	*SDF Only*
Mean	3.093	−1.33314
Variance	8.463677	0.049598
Observations	7	7
Pooled Variance	4.256638	
Hypothesized Mean Difference	0	
df	12	
t Stat	4.013526	
P (T ≤ t) one-tail	0.00086	
t Critical one-tail	1.782288	
P (T ≤ t) two-tail	0.001719	
t Critical two-tail	2.178813	

Table 10. t-Test: Two-sample assuming equal variances for b values obtained after SDF and KI Treatments.

	SDF and KI	*SDF and KI*
Mean	17.33938	6.47875
Variance	36.207	10.20424
Observations	8	8
Pooled Variance	23.20562	
Hypothesized Mean Difference	0	
df	14	
t Stat	4.509083	
P (T ≤ t) one-tail	0.000245	
t Critical one-tail	1.76131	
P (T ≤ t) two-tail	0.000491	
t Critical two-tail	2.144787	

Table 11. t-Test: Two-sample assuming equal variances for b values obtained after SDF Treatment.

	SDF Only	*SDF Only*
Mean	11.54671	6.812714
Variance	80.32538	8.498636
Observations	7	7
Pooled Variance	44.41201	
Hypothesized Mean Difference	0	
df	12	
t Stat	1.328961	
P (T ≤ t) one-tail	0.104288	
t Critical one-tail	1.782288	
P (T ≤ t) two-tail	0.208577	
t Critical two-tail	2.178813	

(p value of 0.442) in tooth lightness values compared to the same samples after demineralization treatment. When only SDF treatment was conducted, there was an insignificant change in L values (p value of 0.132), however there was a strong positive Pearson correlation of 0.627. This indicated a higher degree of change in L values when KI was not applied after SDF treatment. Table 7 also shows a far greater standard deviation in results (~26.9308) and a greater standard error mean (9.5215) for the SDF and KI treatment. This table also showed that the correlation of SDF treatment only, showed a significant change, whereas

SDF and KI treatments had an insignificant change with a p value of 0.415. As such, the change in L values of the tooth were negligible when KI was applied after SDF. The teeth therefore kept their white coloration better when KI was applied. This then adds validity to the use of SDF and KI to treat carious lesions while retaining white coloration.

Table 8 shows the t-test results for the a values of samples that underwent SDF and KI treatment. This is a measure of the red-green difference of the teeth. Because the Pearson correlation was strongly positive (0.7395), the results show a strong correlation. The dataset did not have strong variance or outliers and as such the red-green difference remained roughly the same after treatment, which further solidifies the treatment for carious lesions while maintaining tooth coloration. Table 9 shows the data for the SDF treatment only. The p value for this dataset was significant (0.0017). The significant change shows that there was a major difference in the red-green difference when no KI was applied after SDF. KI therefore serves a major role in retaining tooth coloration in the process of using SDF as a means of carious lesion treatment.

Table 10 shows the t-test results for the b values of samples that underwent SDF and KI treatment. This is a measure of the yellow-blue difference of the teeth. The dataset did not have strong variance or outliers and as such the yellow-blue difference remained roughly the same after treatment, which further solidifies the treatment for carious lesions while maintaining tooth coloration. Table 11 shows the data for the SDF treatment only. The pooled variance was 44.41 which indicated a large variance in the dataset when no KI was applied after SDF. KI therefore serves a major role in retaining tooth coloration in the process of using SDF as a means of carious lesion treatment. This then adds credibility to SDF and KI application as a treatment for carious lesions.

7. Limitations

The study did not have significant limitations, however there are a few noteworthy points. Firstly, the bovine teeth samples had to be transported from Gainesville FL to NSU's Fort Lauderdale campus in South FL. As such, irregularities could have occurred while in transport as their freshness could have been affected. Another limitation is that all samples were taken from the same cow. Due to time restrictions, and availability of samples, the researchers were unable to acquire more samples from varying sources. Also, some of the sample teeth had significant plaque build-up before the experiment even began, which may have affected spectrophotometric data. Another limitation was that minor deviations could have occurred during the HV test as the College of Dental Medicine was undergoing construction in different parts of the building. As such, vibrations caused by the work may have affected data collection. Sample 8 was also omitted from the study as the tooth was far too soft to quantify using the in-house microhardness tester.

8. Conclusion

Through the results obtained from spectrophotometric analysis, as well as statistical t-Test and correlation computation, it was determined that SDF and KI are a useful treatment for carious lesions. This was observed as SDF and KI treatment showed an insignificant change (p value of 0.442) in tooth lightness values, red-green values and yellow-blue values compared to the same samples after demineralization treatment. This was juxtaposed with the use of SDF only which showed significant variation from the tooth samples before treatment (post-demineralization samples). As such, the change in L, a and b values of the tooth was negligible when KI was applied after SDF. Therefore, this study supports the idea that SDF and KI can be used to treat carious lesions on bovine teeth while retaining surface enamel coloration.

9. Future Research

Based on the results of the study, it does provide evidence that SDF and KI interventions can be a viable means to treat the development of carious lesions in organisms that have a similar teeth profile to cows. As such, following research should focus on human trials. In order to mitigate risks, children who have not yet grown their adult teeth should be the demographic of the study as if staining becomes permanent, they will simply lose their deciduous teeth. Another following study can be done to perform SDF/KI treatment on extracted human teeth as this will more readily reflect the results of treatments on adults in a clinical setting. Lastly, a cross efficacy analysis can be done using different brands of SDF/KI, whether it is commercially available or made in-lab.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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