Determination of Fluoride Concentration in Various Brands of Toothpaste Marketed in Nigeria Using Ion Selective Electrode Method

OE Adenumo, OM George-Taylor, AL Kolapo, AO Olubamiwa, R. Fayokun, OA Alawode

Department of Pharmaceutical and Medicinal Chemistry, Faculty of Pharmacy, Olabisi Onabanjo University, Sagamu Nigeria.

Biology Department, The Polytechnic, Ibadan, Nigeria

Medway School of Science, University of Greenwich, Chatham, Kent

GlaxoSmithKline Nig. Plc. Lagos, Nigeria

OE Adenumo, OM George-Taylor, AL Kolapo, AO Olubamiwa, R. Fayokun, OA Alawode;


ABSTRACT

The determination of the total fluoride concentration of 13 brands of fluoridated toothpastes marketed in Nigeria was performed using a fluoride ion-selective electrode (ISE). Eleven adult and 2 paediatric toothpastes of different brands were purchased from local markets/supermarkets in Lagos, Nigeria and their fluoride concentrations were determined using an Orion Bench top pH/ISE meter. The fluoride concentrations of the adult toothpastes were found to be between 348.79±1.0 and 925.78±1.0 ppm, whilst the paediatric toothpastes samples were found to be 349.1±0.495 and 726.19±0.5 ppm respectively. The comparison of these results with the permissible values given by the National Agency for Food and Drug Administration and Control (NAFDAC), Standard Organization of Nigeria (SON) and the World Health Organization (WHO), however revealed that none of the paediatric toothpastes fell within the approved range of 425-625ppm. On the other hand, three of the adult toothpastes samples conformed to the recommended fluoride concentration of between 825-1250ppm. Although fluoride is added to toothpastes and sometimes other products to promote dental health, the ingestion of excess fluoride increases the incidence of fluorosis, which may particularly affect paediatric users. This study has established that the fluoride content of only three out of thirteen toothpaste samples conformed to the SON and NAFDAC standards and therefore provided a rational basis for the quality assessment of various toothpastes. It also highlights the need for stringent regulatory control measures for the determination of fluoride content or concentration in dental products imported into developing countries like Nigeria.

Key words: Fluoride, toothpaste, fluoride ion-selective electrode.

Introduction

The primary purpose of brushing the teeth with dentifrice is to clean the accessible tooth surface of dental plaque, stains and food debris. Fluoride (F⁻) is an important anion present in various environments, clinical and food samples. In many countries, fluoride is purposely added to the water supply (water fluoridation) as sodium fluoride (NaF) and to toothpastes in 0.1% concentration as sodium monofluorophosphate, Tin difluoride or sodium fluoride [NaPO₃F, SnF₂, NaF] [6,3]. In Nigeria, topical fluoride agents are the main dental products used in caries prevention. Though a small amount of fluoride is beneficial, and has been used to treat osteoporosis [4], fluoride causes mottled teeth and...
bone damage at about 5mg L$^{-1}$ when it is present in water [11].

Studies have shown that bone cancer in male children and uterine cancer deaths are linked to water fluoridation due to fluoride’s gradual build up in the bones thereby causing adverse changes to the bone structure. Recent independent research has shown that fluoride build up in the brain of animals when exposed to moderate levels of fluoride. Two new epidemiological studies have also confirmed fluorides’ neurotoxic effects on the brain, as children exposed to higher levels of fluoride had lower IQs. Varner et al., [12], showed that rats drinking 1ppm fluoride (NaF) in water had histologic lesions in their brain similar to Alzheimer’s disease and dementia.

Fluoride has also been reported to cause birth defects and perinatal deaths, impaired immune system, acute adverse reactions, severe skeletal fluorosis at high levels, osteo-arthritis, acute poisoning and contributes to the development of repetitive stress injury. It is also known to inhibit the action of many key enzymes and increase lead and arsenic exposure, even though topical fluoride may help to remineralize cavities at the early stages. It is being proposed that the combination of a healthy diet, proper dental hygiene and saliva can have a similar effect as it is impossible to avoid swallowing some fluoride from fluoridated toothpastes [5].

The determination of fluoride concentration in the various samples requires very sensitive methods. Electro analysis, spectra analysis, chromatography and miscellaneous methods with various adaptations have been employed in the analysis of fluoride [14]. In many recent applications, ion-selective electrode (ISE) methods are replacing existing time consuming and expensive analytical methods with resulting increases in efficiency and simplicity of measurement. They are cost-effective, and sufficiently sensitive, selective, accurate and precise. [7,3]. The fluoride selective electrode is a solid-state type electrode consisting of a lanthanum fluoride crystal sealed over the end of an inert plastic tube which contains an internal electrode and filling solution usually, 0.1M NaCl and 0.1M NaF. A potential arises because of the difference in fluoride activity on either side of the crystal [8]. The ionic strength and the pH of sample and standard solutions should be matched when determining F$^-$ concentration using F-$\text{ISE}$ [10].

The fluoride ion levels in rain water, drinking water, bottled water, dust samples, plants [4,7] tea, dental care products, soil, fruit juices have been determined using the F-$\text{ISE}$ in previous studies [11]. In this study, the fluoride concentration of thirteen toothpaste samples (paediatric and adult) in Nigeria purchased from open markets and supermarkets were determined potentiometrically using a fluoride ion-selective electrode. Despite the claimed role of fluoride in preventing tooth decay, it can react with other ingredients in toothpaste to form insoluble components and therefore be unavailable to perform this role [13]. Monofluorophosphate (MFP) can equally hydrolyze to free fluoride and phosphate ions during storage [1]. It is therefore pertinent to determine the concentration of fluoride in toothpastes in order to evaluate the quality and stability of these samples. It is also very important to ascertain whether the fluoride concentration obtained from sample analysis conform to the permissible values given by the National Agency for Food and Drug Administration and Control (NAFDAC), Standard Organization of Nigeria (SON) and the World Health Organization [15].

**Materials and Methods**

**Instruments and Chemicals**

The fluoride analyses were performed using an Orion Bench top pH / ISE meter with a fluoride ion-selective electrode. Analytical-reagent grade chemicals (Merck, Darmstadt, Germany) were used without further purification. Distilled water was used throughout the experiments. Fluoride stock solution (1000 $\mu$g ml$^{-1}$) was prepared from sodium fluoride (NaF; USP reference standard which was dried for 4 hours at 150$^\circ$C and then cooled in a desiccator before use). This was stored in a plastic volumetric flask. A first stock standard solution of approximate F$^-$ concentration of 100 ppm was prepared from which 1, 5 and 50 ppm working standards were made for the standardization of the fluoride ISE.

A check standard of 5 ppm was then prepared from a second 100 ppm stock standard. For acceptance criteria, the scope of the standardization must fall between -56.2 and -60.4 mV/decade (95.0 and 102.0%) at room temperature. The measurement value for 5 ppm working standard must be between 4.85 and 5.15 ppm (i.e. +/-3% of its expected value) to evaluate the check standard. Ionic strength (IS) diluent was prepared from 100g of [Na$_2$EDTA.2H$_2$O] tetra sodium ethylene diamine tetra acetic acid, 15g of sodium hydroxide and 100g of sodium acetate trihydrate in a volume of 1000ml. The pH of the IS diluent was adjusted to pH 7.25 ± 0.03 using either concentrated HCl or 5NaOH. The IS solution regulates the ionic strength of all unknown samples and standard solutions, adjusts the pH, and prevents interferences with polyvalent cations such as Al (III), Fe(III) and Si (IV) which are able to complex or precipitate with fluoride and reduce the free fluoride concentration in the solution [8]. The sodium edetate preferentially forms more stable complexes with polyvalent cations (e.g. Al$^{3+}$, Fe$^{3+}$, Si$^{4+}$) present in water and / or aqueous solution than...
metal – fluoride complexes (AlF₆³⁻, FeF₆³⁻ etc.) thereby freeing the F⁻ from its complexes with the cations [Christian 1986; Skoog et al. 1991]. The electrode is selective for fluoride ion over other common anions by several orders of magnitude; only the hydroxide ion (OH⁻) appears to have serious interference. When the IS reagent is used, the concentration of fluoride rather than its activity is measured. [9].

Sampling

The toothpaste (adult and paediatric) samples of different brands were randomly sampled and purchased from open/local markets and supermarkets in Lagos, Nigeria.

Sample Preparation and Determination of Total Fluoride Concentration

For the determination of fluoride in the toothpaste samples, 5g of each toothpaste sample was accurately weighed into a 150ml plastic beaker. 39.0ml of water was added and the mixture was homogenized. 11.0ml of concentrated HCl was then added, the beaker covered and stirred for at least 1hour. The solution was allowed to cool to room temperature and the transferred to a 250ml plastic volumetric flask with a plastic funnel. It was then diluted to mark with the NAIS Diluent. The pH of the sample prepared should fall within 0.5units of that of the 5 ppm working standard solution. The sample must be re-prepared if its pH is not within the range of 6.5 to 8.0.

The reading (R) in ppm for each sample was determined in duplicate with the ion-meter and the total fluoride concentration in ppm was calculated using the following formula:

\[
(F') = \frac{R \times 250}{W}
\]

Where \((F')\) = total fluoride concentration (ppm)
\(R\) = reading for sample off the instrument (ppm)
\(W\) = weight of sample (g)

Results and Discussion

The claimed active fluoride ingredient and their fluoride content in percentages (%) as well as the claimed equivalent fluoride concentration in ppm F⁻, country of manufacture and the calculated total fluoride concentration for each of the 13 toothpastes sampled are given in Tables 1&2. According to the National Agency for Food and Drug Administration and Control (NAFDAC) and Standards Organisation of Nigeria (SON), the recommended permissible levels of fluoride for paediatric toothpastes is between 425-625ppm while the recommended permissible level of fluoride for adult toothpastes is between 825-1250 ppm, minimum to maximum range.

Concentrations of fluoride in paediatric toothpastes samples were 349.1±0.495 and 726.19±0.5 ppm respectively while those of the adult toothpastes were between 348.79±1.0 and 925.78±1.0ppm. As can be seen from Table 2, the highest fluoride concentration was observed in sample TP₄ (925.78±1.0ppm) followed by sample TP₉ (903.76 ppm) and then TP₆ (903.33±0.50 ppm).

Of all the samples of adult toothpaste investigated, only these three samples; TP₄, TP₉, and TP₆ had sufficient fluoride levels. The others had insufficient fluoride content. Their fluoride contents varied between 348.79±1.0ppm and 792.7ppm. Both samples of the paediatric toothpaste (TP₉₂, TP₉₃) did not conform to the approved standard, while sample TP₉₁ had fluoride content above the approved standard. It was also observed that none of the determined total fluoride concentrations conformed to the claimed fluoride concentrations stated on the labels of TP₉, TP₄, TP₉₆, TP₉₇, and TP₉₈. All of the derived were lower than the stated [Table 2]. It could be inferred that these six samples are substandard with reference to their country of manufacture and labelled fluoride concentration.

The concentration of fluoride in toothpastes depends on such factors as presence of ingredients which react with the fluoride to form insoluble compounds and therefore make fluoride unavailable to fulfill its therapeutic function; inappropriate storage could lead to hydrolysis of free fluorides especially for samples that contain Sodium monofluorophosphate which hydrolyzes to free fluoride and phosphate ions.

Samples TP₅, TP₇, TP₈ and TP₁₀ were purchased from a petty trader in an open market and these samples could have been exposed to temperatures as high as 32°C which could have led to the degradation of some of these samples. This may contribute to the non-conformance of samples TP₅, TP₇ and TP₁₀ to the accepted standard.

As a result of the practice of water fluoridation in some countries, the level of fluoride in dentificres in such countries may not be as high as the level approved in Nigeria and that is because water fluoridation already serves as a means of fluoride supply to individuals, thus fluoride levels in toothpastes are not expected to be as high in such countries since this can lead to fluorosis. This might account for the reason why samples TP₅, TP₇, TP₈, TP₉, TP₁₀, TP₁₁, TP₁₂ and TP₁₃ which are all imported from foreign countries did not conform to the approved NAFDAC and SON standard for Nigeria.
Table 1: Claimed fluoride concentrations of toothpaste samples and their country of manufacture.

<table>
<thead>
<tr>
<th>Toothpaste samples (TP)</th>
<th>Country of manufacture</th>
<th>Claimed active fluoride ingredient</th>
<th>Claimed active fluoride contents in %</th>
<th>Claimed Equivalent fluoride concentration (in ppm F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP_1</td>
<td>Senegal</td>
<td>NaPO₃; NaF</td>
<td>0.76; 0.10</td>
<td>1000 :450</td>
</tr>
<tr>
<td>TP_2</td>
<td>Korea</td>
<td>NaPO₃</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>TP_3</td>
<td>Korea</td>
<td>NaPO₃; NaF</td>
<td>0.1 */.</td>
<td>NS</td>
</tr>
<tr>
<td>TP_4</td>
<td>USA</td>
<td>NaPO₃; NaF</td>
<td>0.15 */.</td>
<td>NS</td>
</tr>
<tr>
<td>TP_5</td>
<td>Indonesia</td>
<td>NaPO₃; NaF</td>
<td>0.8</td>
<td>1000</td>
</tr>
<tr>
<td>TP_6</td>
<td>Korea</td>
<td>NaPO₃</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>TP_7</td>
<td>Korea</td>
<td>NaF</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>TP_8</td>
<td>Ireland</td>
<td>NaPO₃</td>
<td>0.8 */.</td>
<td>1000</td>
</tr>
<tr>
<td>TP_9</td>
<td>Nigeria</td>
<td>NaF</td>
<td>0.32</td>
<td>NS</td>
</tr>
<tr>
<td>TP_10</td>
<td>Nigeria</td>
<td>NaPO₃; NaF</td>
<td>0.85</td>
<td>NS</td>
</tr>
<tr>
<td>TP_11</td>
<td>Brazil</td>
<td>NaPO₃; NaF</td>
<td>1.14</td>
<td>1500</td>
</tr>
<tr>
<td>*TP_12</td>
<td>U.K</td>
<td>NaPO₃; NaF</td>
<td>NS</td>
<td>500</td>
</tr>
<tr>
<td>*TP_13</td>
<td>England</td>
<td>NaPO₃; NaF</td>
<td>0.8</td>
<td>1050</td>
</tr>
</tbody>
</table>

* - TP_1 and TP_2 are paediatric toothpastes
NS – not stated
NaPO₃ – sodium monofluorophosphate
NaF – sodium fluoride

Table 2: Fluoride concentrations determined for toothpaste samples marketed in Nigeria

<table>
<thead>
<tr>
<th>TPS</th>
<th>SW</th>
<th>1SR ppm</th>
<th>2SR ppm</th>
<th>MSR ppm</th>
<th>1TFC ppm</th>
<th>2TFC ppm</th>
<th>Mean TFC</th>
<th>SD</th>
<th>CFC ppm F-</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP_1</td>
<td>5.012</td>
<td>18.54</td>
<td>18.58</td>
<td>18.56</td>
<td>924.78</td>
<td>926.78</td>
<td>925.78</td>
<td>1</td>
<td>1450</td>
</tr>
<tr>
<td>TP_2</td>
<td>5.076</td>
<td>18.35</td>
<td>18.35</td>
<td>18.35</td>
<td>903.76</td>
<td>903.76</td>
<td>903.76</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>TP_3</td>
<td>5.007</td>
<td>11.02</td>
<td>11.06</td>
<td>11.04</td>
<td>550.23</td>
<td>552.23</td>
<td>551.23</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>TP_4</td>
<td>5.003</td>
<td>6.96</td>
<td>7.00</td>
<td>6.98</td>
<td>347.79</td>
<td>349.79</td>
<td>348.79</td>
<td>1</td>
<td>NS</td>
</tr>
<tr>
<td>TP_5</td>
<td>5.045</td>
<td>9.12</td>
<td>9.13</td>
<td>9.14</td>
<td>453.42</td>
<td>452.43</td>
<td>452.925</td>
<td>0.495</td>
<td>1000</td>
</tr>
<tr>
<td>TP_6</td>
<td>5.012</td>
<td>18.10</td>
<td>18.12</td>
<td>18.11</td>
<td>902.83</td>
<td>903.83</td>
<td>903.33</td>
<td>0.5</td>
<td>NS</td>
</tr>
<tr>
<td>TP_7</td>
<td>5.004</td>
<td>13.34</td>
<td>13.32</td>
<td>13.33</td>
<td>666.47</td>
<td>665.47</td>
<td>665.97</td>
<td>0.5</td>
<td>NS</td>
</tr>
<tr>
<td>TP_8</td>
<td>5.098</td>
<td>15.56</td>
<td>15.56</td>
<td>15.56</td>
<td>763.04</td>
<td>763.04</td>
<td>763.04</td>
<td>0</td>
<td>1000</td>
</tr>
<tr>
<td>TP_9</td>
<td>5.004</td>
<td>14.24</td>
<td>14.24</td>
<td>14.24</td>
<td>711.43</td>
<td>711.43</td>
<td>711.43</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>TP_10</td>
<td>5.065</td>
<td>16.06</td>
<td>16.06</td>
<td>16.06</td>
<td>792.70</td>
<td>792.70</td>
<td>792.70</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>TP_11</td>
<td>5.053</td>
<td>12.78</td>
<td>12.76</td>
<td>12.77</td>
<td>632.30</td>
<td>631.31</td>
<td>631.805</td>
<td>0.495</td>
<td>1500</td>
</tr>
<tr>
<td>*TP_12</td>
<td>5.063</td>
<td>7.06</td>
<td>7.08</td>
<td>7.07</td>
<td>348.61</td>
<td>349.60</td>
<td>349.105</td>
<td>0.495</td>
<td>500</td>
</tr>
<tr>
<td>*TP_13</td>
<td>5.009</td>
<td>14.56</td>
<td>14.54</td>
<td>14.55</td>
<td>726.69</td>
<td>725.69</td>
<td>726.19</td>
<td>0.5</td>
<td>1050</td>
</tr>
</tbody>
</table>

* TPS= Toothpaste Samples TFC= Total fluoride concentration
SW= Sample Weight SD= Standard Deviation
SR= Sample reading in ppm CFC= Claimed fluoride concentration
MSR= Mean Sample reading

Another factor that might affect the concentration of fluoride in some of these samples is if hydroxide ion was present in any of the reagents used in the analysis though this was taken care of with the use of TISAB solution.

In 1997, some Colgate fluoride toothpaste from Mexico and Canada were placed on detention without physical examination by the Food and Drug Administration (FDA) as a result of the product containing more that one fluoride ingredient. Such products were considered as new drugs without approved new drug applications. Although sample TP_1 fell within the approved NAFDAC and SON standard, it should not be allowed for sale because it contains more that one fluoride ingredient (Sodium monofluorophosphate and Sodium fluoride) and the Final Monograph on Fluoride Dentifrices (21CFR355) does not permit the combination of two fluoride ingredients. Imported toothpaste products like TP_1 with more than one fluoride ingredient or those containing fluoride at a level higher than that allowed in OTC anticaries toothpastes or containing other non-permitted ingredients should have their importation into developing countries banned.

Fluoride was major public health success when it was found to be important in dentistry, because of its ability to inhibit dental caries. This led to the incorporation of fluoride into various substances for human use, for example, as additive in toothpastes and some mouthwashes as a tooth decay preventative ingredient and into water. Thus the determination of fluorides which are everywhere throughout the environment is very crucial to public health. Small amounts sodium fluoride help prevent tooth decay and very low levels of fluorides are not believed to be harmful but high levels may harm human health. In light of the foregoing, the determination of fluoride concentration in consumer products particularly toothpaste cannot be overemphasized consequent of its public health implications.

**Conclusion**

The potentiometric determination of fluoride using ion-selective electrode is simple and inexpensive but not readily available in developing countries like Nigeria. This non-availability may contribute to the problem of no analysis or inaccurate results from determinations using less sensitive instruments than the fluoride ion selective electrode.
The WHO specifies 2-4 mg/day optimum fluoride intake for humans while the Australian National Occupational Health and Safety Commission (NOHSC) gives 2.5mg/m³, occupational exposure limit for 8-hour time weighted average fluoride. The short time exposure limit of 15 minutes is given as 2ppm (3.1mg/m³). This study has shown that most of the toothpaste samples have substandard levels of fluoride concentrations and this may have implication in their effectiveness at combating dental caries thus predisposing the population to a public health burden particularly in regions where their fluoride intake is not balanced through levels in drinking water. This places a major task on regulatory bodies to ascertain by analysis that the fluoride concentrations of local and imported fluoridated products are within permissible levels.

References