Odontol. Sanmarquina 2023; 26(3): e24828
https://doi.org/10.15381/os.v26i3.24828

ODONTOLOGÍA SANMARQUINA
ISSN-L 1560-9111; eISSN: 1609-8617
Artículo Original

Determination of bioavailable fluoride in toothpastes marketed in Medellín, Colombia, through capillary electrophoresis

Fluoruro biodisponible en cremas dentales comercializadas en Medellín – Colombia mediante electroforesis capilar

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Conflict of interest: None exists.

Funding source: No sources to report.

Received: 27/02/23
Accepted: 30/06/23
Published: 29/09/23

Abstract

Currently, the FDI recommendation (World Dental Federation) for fluoride concentration in toothpastes is that the total fluoride content declared by manufacturers be between 1,000 and 1,500 ppm, and of this amount, at least 800 ppm should be bioavailable fluoride. The aim of this study was to describe the market of toothpastes marketed in Medellín and to measure the concentration of bioavailable fluoride by capillary electrophoresis to verify their compliance with the FDI recommendation for the prevention of dental caries. After sampling the toothpastes available for sale in the 16 communes of the city of Medellin, a single operator measured in triplicate the concentration of bioavailable fluoride in 36 samples of previously blinded toothpastes using the capillary electrophoresis (EC) technique. Most of the evaluated toothpastes that declared a content of 1,000–1,500 ppm fluoride met the recommendation of presenting at least 800 ppm bioavailable fluoride. Measurement of bioavailable fluoride in toothpastes with MFP (sodium monofluorophosphate) is recommended, as it is known that binding to the abrasive can decrease its concentration over time.

Keywords: fluoride, fluoride analysis, toothpastes, available fluoride, capillary electrophoresis (source: MeSH NLM).

Resumen

Actualmente la recomendación de la FDI (Federación Dental Internacional) sobre la concentración de fluoruro en cremas dentales es que el contenido de fluoruro total declarado por los fabricantes sea entre 1.000 y 1.500 ppm, y que de esta cantidad al menos 800 ppm sea fluoruro biodisponible. El objetivo de este estudio fue describir el mercado de las cremas dentales comercializadas en Medellín y medir en estas la concentración de fluoruro biodisponible por electroforesis capilar para verificar su cumplimiento de la recomendación de la FDI para la prevención de la caries dental. Luego de realizar un muestreo en las 16 comunas de la ciudad de Medellín sobre las cremas dentales disponibles a la venta, un solo operador midió por triplicado la concentración de fluoruro biodisponible en 36 muestras de cremas dentales previamente cegadas, mediante la técnica de electroforesis capilar (EC). La mayoría de las cremas dentales evaluadas que declaraban contenido de 1.000 a 1.500 ppm de fluoruro, cumplieron la recomendación de presentar al menos 800 ppm de fluoruro biodisponible. Se recomienda realizar la medición del fluoruro biodisponible en las cremas con MFP, ya que se conoce que la unión al abrasivo puede disminuir su concentración en el tiempo.

Palabras clave: Fluoruro, análisis de fluoruro, cremas dentales, fluoruro disponible, electroforesis capilar (fuente: DeCS BIREME).

Introduction

Dental caries is a dynamic disease in which the balance between mineralization and demineralization is lost, leading to a net loss of calcium and phosphate from the tooth surface and the eventual formation of carious lesions [1]. In this process, metabolic events occur at the enamel–biofilm interface through the interaction of multiple factors, including the consumption of fermentable carbohydrates, the characteristics of dental tissue and the biofilm, which has cariogenic potential by the metabolism of sugars and producing a pH drop, thus favouring mineral loss [2-4].

Based on current evidence, strategies for the preventive management of dental carious lesions are selected according to the individual risk of the patient. Less invasive approaches focused on overall health are used to consider oral health from a global perspective, achieve the long-term preservation of dental structure, and increase patient satisfaction and engagement. Individual patient analysis allows for the establishment of protective factors, such as daily use of fluoridated toothpastes (1,000 ppm or more) and regular access to oral health services that include the application of topical fluoride [5].

In caries control, fluoride has an effect by increasing remineralization and decreasing demineralization [6]. Fluoride favours remineralization because calcium and phosphate can be recovered more efficiently when fluoride is present in the biofilm. Fluoride decreases demineralization because it allows minerals lost in the form of hydroxyapatite to be recovered as fluorapatite, which is more resistant to reduced pH[3].

Toothpaste is the most widely used vehicle for the incorporation of fluoride into the intraoral environment through daily brushing [7]. Regular use of fluoridated toothpaste is associated with a 24% reduction in caries formation in permanent teeth [8]. Low-fluoridated toothpastes (250–550 ppm) have been found to have no positive effects on caries control compared to high-fluoridated toothpastes (1,055–1,450 ppm) [9]. Currently, the FDI (World Dental Federation) recommends toothpastes with 1000–1500 ppm fluoride and at least 800 ppm available ionic fluoride [10].

Sodium fluoride (NaF), sodium monofluorophosphate (MFP), stannous fluoride (SnF), and combinations of these ingredients are commonly used in toothpaste formulations [11]. The fluoride contained in dentifrices can be classified as total soluble (bioavailable) fluoride, insoluble fluoride, or total fluoride. Total soluble fluoride (TSF) refers to the active compound in the reduction of demineralization and the promotion of remineralization, which can be present as free ionic or ionizable fluoride. Insoluble fluoride is the compound that is generated when fluoride binds with elements such as calcium, forming insoluble compounds such as calcium fluoride (CaF_2) and decreasing the concentration of TSF. Finally, total fluoride is the sum of TSF and insoluble fluoride [12]. The concentration of fluoride in toothpastes can vary depending on the formulation. In its ionic state (F-), fluoride can interact with divalent cations, which are chemical elements that have lost their two valence shell electrons [13]. This interaction forms poorly soluble salts that decrease the concentration of bioavailable fluoride, thereby reducing the effect on caries control [8-14].

Studies carried out in various countries have indicated that the concentrations of total and bioavailable fluoride contained in toothpastes do not always coincide with those declared by the manufacturers on the labels of these products [15-20]. In Bogotá, Colombia, it was found that the concentrations of fluoride in some toothpastes and mouthwashes for children were lower than those recommended to have an adequate effect on caries control [21].

Various methods of measuring fluoride concentrations in toothpastes were discussed in a consensus published in 2018 by the European Organization for Caries Research. This consensus highlighted two main techniques: fluoride-specific electrode measurement and gas chromatography. This consensus also discussed the advantages, disadvantages, and limitations of these methods, aiming to standardize a technique for fluoride measurement. In addition to these techniques, the consensus mentioned capillary electrophoresis as a new method of fluoride measurement [14]. This method allows for the separation and quantification of charged species contained in a sample solution to be carried out in a quick, sensitive, and simple manner [22]. Through comparison with gas chromatography and fluoride-specific electrode methodologies, capillary electrophoresis has been validated for the measurement of MFP and free fluoride in toothpastes. Compared to fluoride-specific electrode measurement, capillary electrophoresis was also found to require less time for measurement because it does not require hydrolysis of the MFP [23,24].

The objective of this study was to describe the market of toothpastes marketed in Medellín and measure the concentrations of bioavailable fluoride using the capillary electrophoresis technique to verify whether these toothpastes comply with the FDI recommendation (minimum 800 ppm bioavailable fluoride for toothpastes with 1,000 to 1,500 ppm total fluoride) for the prevention of dental caries.

Materials and methods

A market research study was carried out; information on toothpastes available in the selected markets of each commune of Medellín was collected, and a descriptive analysis approach was used. In addition to the variety of brands, references and ingredients, measurements of bioavailable fluoride contained in these toothpastes were included, which gives a quantitative and analytical character to this study.

This study was endorsed by the bioethics committee of the Faculty of Dentistry of the University of Antioquia in Concept No. 37-2019 of Act No. 14 of 2019.

Toothpaste selection

Medellín is a Colombian district, capital of the department of Antioquia. It is the most populous city in the department and the second most populous in the country after Bogotá, with a population of 2,533,424 inhabitants (2020). It is located in the central mountain range of the Andes. The latitude and altitude of the city result in an equatorial climate, since every month there are above 18 °C and 60 mm of rain, although due to the height the temperatures are not very high, the climate is temperate and humid, with an average temperature of 21.6 °C, with a fairly uniform climate throughout the year, but with many differences in terms of the climate of the different neighbourhoods of the city, the hottest neighbourhoods are located in the centre of the city and in the northern part of the banks of the Medellín river, while the coldest neighbourhoods are located in the parts surrounding mountains.

To identify the toothpastes available in Medellín, two supermarkets or stores were chosen for convenience and were visited in each of the 16 communes into which the city is divided, in addition to three popular stores located in various parts of the city. A record of the dentifrices offered by these stores was made with photos of their list of ingredients, lot numbers, and expiration dates. The ingredients of these toothpastes were recorded in a Microsoft Excel® version 16.52 spreadsheet, and the toothpastes were then grouped according to their concentrations, types of fluoride, and abrasive agents. From each resul ting group, the toothpastes that were found most frequently were selected for the study sample. After the selection process described, thirty-six different toothpastes were purchased from five chain stores to control for storage and transportation variables (Figure 1).

Sample blinding

A third party was in charge of assigning a random numerical code to each tube of toothpaste, which was previously wrapped with black adhesive paper by another individual to obscure the brand and fluoride concentration information. A record of this coding system was kept in a sealed envelope until analysis.

Fluoride quantification

The measurement of bioavailable fluoride was carried out in the laboratory of the interdisciplinary group of molecular studies of the Faculty of Exact and Natural Sciences of the University of Antioquia using the EC technique, which comprised measuring in triplicate and repeating the procedure three times for each of the toothpaste references using fluoride standards (Sigma–Aldrich, St. Louis, MO, USA) to quantify bioavailable fluoride. The analysis protocol was adapted by a group of laboratory personnel, and the measurements were

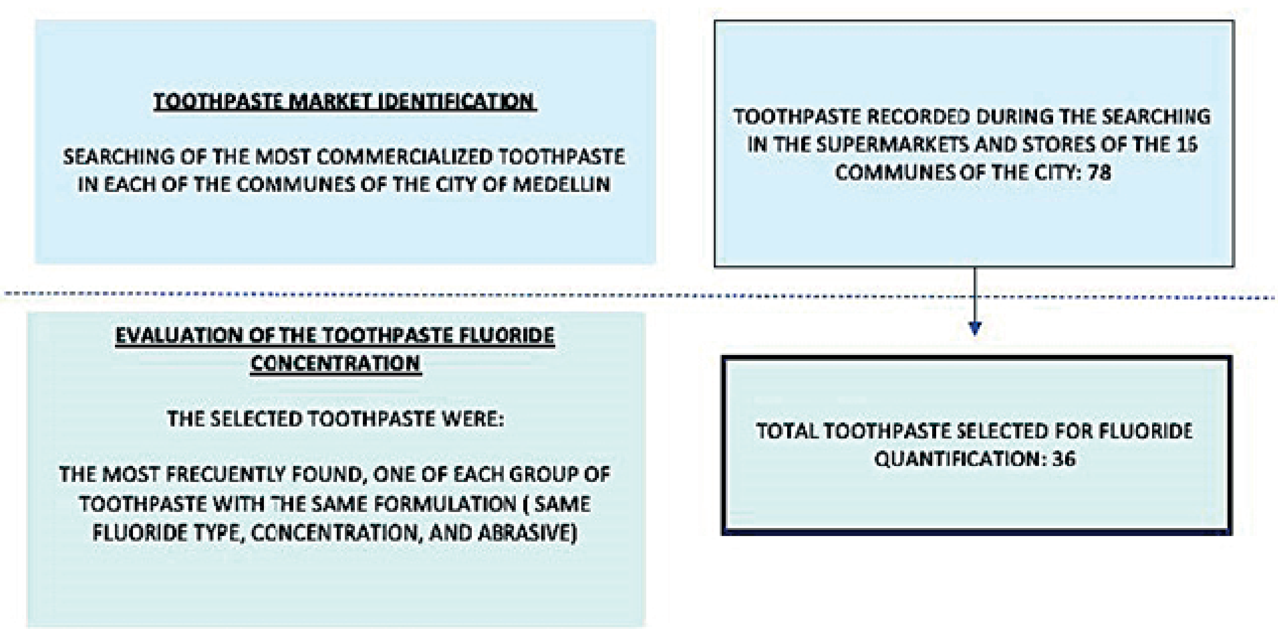

Figure 1. Identification of toothpastes available in Medellin and selection of toothpastes for the measurement of bioavailable fluoride

performed by a single person with experience measuring other elements using the EC technique. The measurements obtained were analysed as a group.

Several techniques have been used to measure diffe rent types of fluoride in toothpaste: electroanalysis with ion-selective electrodes, gas chromatography (GC), isotachophoresis, ion chromatography (IC) and capillary electrophoresis (CE). Each of these techniques has specific analytical situations, such as in the case of GC, for which an MFP hydrolysis step is needed before the measurement of total fluoride or the weak binding affinity of fluorides to common ion exchangers used in IC, which is why fluoride generally elutes rapidly from the column and is located very close to the injection peak containing the solvent and other components not retained by the column. On the other hand, CE is excellent for anion analysis and identification, especially when used with appropriate internal standards. Wang et al. (1997) compared IC and CE in fluoride measurement, finding that CE has an obvious advantage over traditional methods in that it can separate many anions in a very short time. They found CE to be very useful, especially when the analysis of large numbers of samples is required and applicable as a technique for quality control in toothpaste formulation and manufacturing[22].

o Reagents and solutions

All reagents were of analytical grade. Acetic acid, sodium acetate, sodium citrate, lactic acid (Lac), l-histidine (His) (Labsynth. Diadema, SP, Brazil), tetradecyltrimethylammonium bromide (TTAB), tartaric acid, and NaF (Aldrich. Milwaukee, WI, USA) were used. Deionized water was obtained from a Milli-Q water purification system (Millipore, Bedford, MA). A buffer solution (pH 4.0) containing 15 mmol L – 1 His, 25 mmol L – 1 Lac, and 2.5 mmol L – 1 TTAB (electroosmotic flux modifier) was used as a background electrolyte (BGE). The solutions were prepared and stored in polypropylene matrices. Individual stock solutions of tartaric acid (1,500 mL-1) and NaF (420 mL-1) were prepared by dissolving the corresponding solid reagents in deionized water.

o Preparation of the sample

First, 0.1 g of toothpaste was suspended in 10 mL of deionized water, vortexed for 2 min, and sonicated by ultrasound for 5 min. The suspension was placed in 1.5 mL microtubes and centrifuged at 13,000 rpm for 7 min. Subsequently, 200 µL of the supernatant was collected in glass screw cap vials (Agilent, Santa Clara, CA, USA) and submitted to EC.

o Instrumentation and procedure

To perform the CE, an Agilent 7100 model (Agilent Technologies, Santa Clara, CA, USA) equipped with a diode array UV−Vis detector (RFID tags of long-life deuterium lamps [8 pins], Santa Clara, CA, USA) was used. OpenLab with ChemStation software was used on a computer connected to the equipment for the control and collection of information. Fused silica capillaries with a 75-µm inner diameter and 365-µm outer diameter that were 80.5 cm in length (Polymicro Technologies. Phoenix, AZ, USA) were used. The effective capillary length was 72 cm. The capillaries were preconditioned by rinsing for 500 sec with a 0.1 mol/L NaOH solution, then with deionized water for 5 min, and finally with BGE for 10 min. Subsequently, the capillaries were washed for 33 min with a running buffer to equilibrate them. Between analyses, the capillaries were reconditioned for 3 min with 0.1 N NaOH solution and 5 min with a moving buffer. The separation conditions were a constant temperature of 20 °C with a voltage ramp of 30 kV for 0.3 min. The samples were hydrodynamically injected with a pressure of 50 mbar for 4 seconds, followed by the injection of a running buffer under the same conditions.

Statistical analysis

The information on the study variables was recorded in Microsoft Excel® version 16.52. From this record, frequency lists, tables, and graphs were generated for analysis. To describe the general characteristics of the samples, the distribution of the absolute and relative frequencies of each of the qualitative and quantitative variables was used.

Results

During the visits to the supermarkets and stores of the communes of the city of Medellín, 78 references of toothpastes available for sale were identified.

In total, dentifrices of 17 different brands were found, which are listed in Table 1. The 10 dentifrices most frequently found were from Colgate (seven), Fortident (two), and Fluocardent (one), and the most widely available reference was Colgate Triple Action, which was found in 89% of the places visited. Dentifrices for sensitivity were less common, with the most commonly available being Colgate Sensitive Whitening, which was found in 20% of the places visited (Figure 2). The most frequently found children's toothpaste was Fluocardent Kids, which was present at 34% of the sites visited.

Of the dentifrices identified, four stated that they did not contain fluoride, and of the remaining 74 that were fluoridated, six reported a content of less than 1,000 ppm fluoride. Of these, 74% contained exclusively NaF, 13% MFP, and 1% SnF. Combinations of NaF with MFP and NaF with SnF were also found (Table 2).

NaF-containing toothpastes were accompanied by the following abrasives: calcium carbonate, silica, hydrated silica, sodium calcium phosphosilicate, and dicalcium phosphate dihydrate. The abrasives present in MFP toothpastes were calcium carbonate, calcium sodium phosphosilicate, dihydrate dicalcium phosphate, silica, and calcium pyrophosphate.

All the ingredients declared on the packaging, including the abrasives, were reviewed, and those with divalent cations were identified; these were the pH regulator and abrasive calcium carbonate (contained in six references);

Table 1. Commercial brands of toothpastes found and quantity according to the brand.

BRAND NAME	Number of toothpastes found by brand
ampm®	1
Bucarine®	4
Colgate®	25
CREST®	1
Dentiblank®	1
Fitokids®	1
Fluocardent®	8
Fortident®	3
Gum®	1
JamesFreshhh®	1
OralB®	13
Oralplus®	6
Parodontax®	1
Pro®	1
Proquident®	3
Sensodyne®	6
Vitis®	2
Total de cremas	78

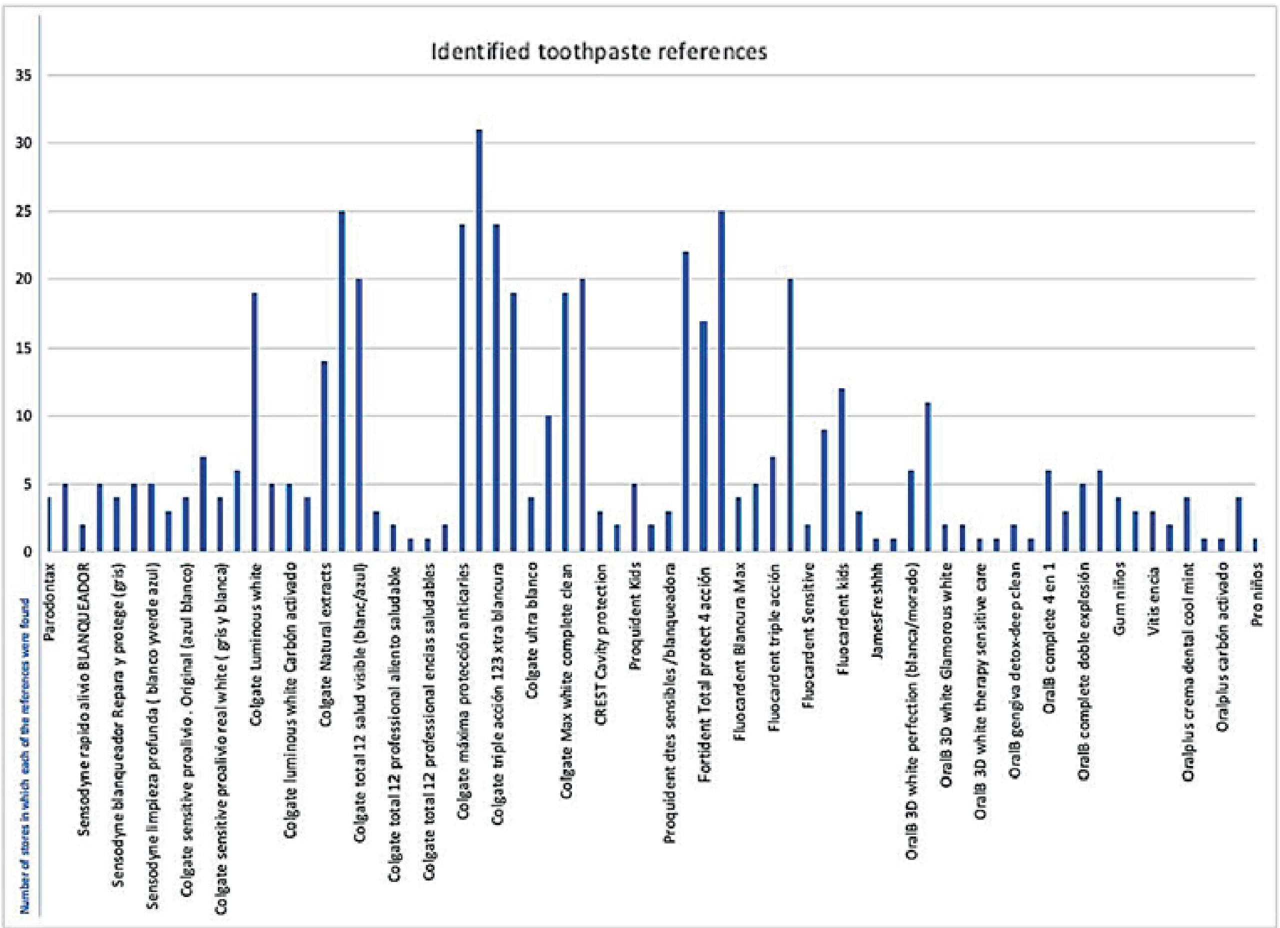

Figure 2. Number of stores in which each of the references were found

the abrasives dicalcium phosphate dihydrate (two references), calcium pyrophosphate (one reference), and sodium calcium phosphosilicate (two references); and the bleaching, abrasive, and stabilizing agents zinc oxide (two references) and zinc citrate (three references) (Table 3).

In this work, the bioavailable fluoride of 36 dentifrices, which were selected according to their formulations and greater commercial availability, was measured using the capillary electrophoresis technique. Of the analysed samples, 30 contained NaF, two a combination of NaF with SnF, one MFP with NaF, and one SnF alone, while two claimed that they did not contain fluoride at all.

Of the 30 dentifrices with NaF, 28 reported total fluoride concentrations between 1,000 and 1,500 ppm on the label, one reported 500 ppm, and another did not report the amount of fluoride. The measurements of bioavailable fluoride indicated that one did not comply with the FDI recommendation regarding the concentration of bioavailable fluoride (minimum 800 ppm)—the label had reported a total fluoride concentration of 1,450 ppm, but it was found to contain 319 ppm bioavailable fluoride. In the toothpaste that reported 500 ppm, 573 ppm was measured. The toothpaste that did not report the amount of fluoride was found to contain 1334 ppm fluoride (Table 4).

The three kinds of toothpaste that presented a combination of fluorides reported concentrations between 1,000 and 1,500 ppm on their labels. Their measurements showed that all three met the FDI recommendation for at least 800 ppm bioavailable fluoride. The sample containing SnF reported a content of 1,000 ppm and was measured as containing 1,078 ppm bioavailable fluoride. In the two that reported that they did not contain fluoride, none was detected (Table 4).

Discussion

In this work, a complete sampling of the 16 communes of the city of Medellín was undertaken to obtain comprehensive information on the toothpaste market, without excluding brands or references according to their sales, because this information was unavailable for the city, which has a diverse market. A search was carried out in two supermarkets or stores in each of the 16 communes of the city, and the toothpastes found were subsequently classified into groups by the frequency of their appearance in the supermarkets and stores visited and their fluoride and abrasive formulations. We thus aimed to cover the largest number of toothpastes available in the city without limiting ourselves to an area, supermarket, or store.

Table 2. Type of fluoride reported on the labels of toothpastes in Medellín, frequency and percentage.

Fluoride	n	%
NaF	58	74,36%
MFP	10	12,82%
NaF + MFP	2	2,56%
NaF + SnF	3	3,85%
SnF	1	1,28%
Fluoride free	4	5,13%

Table 3. Commercial references of dentifrices containing ingredients with divalent cations.

Toothpaste	Fluoride	Ingredients with divalent cations
Sensodyne® Blanqueador Repara y Protege	NaF + MFP	Sodium calcium phosphosilicate
Sensodyne® Blanqueador Extrafresh	NaF	Sodium calcium phosphosilicate
Colgate® Sensitive Pro Alivio Reparación completa	MFP	Zinc citrate and zinc oxide
Colgate® Sensitive Pro Alivio Inmediato	MFP	Calcium carbonate
Colgate® sensitive Pro Alivio original	MFP	Calcium carbonate
Colgate® Luminous White Carbón Activado	MFP	Calcium pyrophosphate
Colgate® Total 12 Antisarro	NaF	Zinc citrate and zinc oxide
Colgate® Máxima Protección Anticaries	NaF + MFP	Dicalcium phosphate dihydrate
Fluocardent® Niños	MFP	Dicalcium phosphate dihydrate
James® Freshhh	MFP	Calcium carbonate
Oral B® 100%	NaF	Zinc citrate
Bucarine® protección blanqueadora	NaF	Calcium carbonate - Sílica
Bucarine® Triple Acción	NaF	Calcium carbonate - Hydrated silica
am/pm® plus crema dental triple acción	NaF	Calcium carbonate - Hydrated silica

Table 4. Characteristics declared on the labels of the most commercialized toothpastes in Medellin and concentration of bioavailable fluoride. ppm: parts per million.

Toothpaste	Fluoride	Bioavailable fluoride (ppm)	Fluoride reporte don the label (ppm)	Abrasive	Expiring date	Manufacture date
Parodontax®	NaF	319.4	1400	Sodium bicarbonate	sept-22	oct-20
Vitis® Encías	NaF	1 421.1	1 450	Sílica	mar-22	Not reported
Colgate® Triple Acción 123	NaF	1 446.3	1 450	Hydrated silica	jan-23	Not reported
Colgate® Natural Extracts	NaF	1 037.2	1 000	Hydrated silica	sept-22	Not reported
Colgate® Total 12 Clean Mint	NaF	1 484.1	1 450	Hydrated silica	may-22	Not reported
Sensodyne® repara y protege	NaF	1 276.8	1 426	Hydrated silica	sept-22	Not reported
Crest® Cavity Protection	NaF	1 044.1	0.24%	Hydrated silica	dec-21	Not reported
Sensodyne® Blanqueador Extrafresh	NaF	1 034.9	1 426	Hydrated silica	may-22	jun-20
Fluocardent® Kids	NaF	965.2	1 100	Hydrated silica	jan-24	Not reported
Oral B® 3D White Perfection	NaF	1 120	1 450	Hydrated silica	dec-22	Not reported
Sensodyne® Limpieza profunda	NaF	1 067.0	1 426	Hydrated silica	oct-23	nov-20
Fluocardent® Frescura max	NaF	1 697.6	1 500	Hydrated silica	feb-24	Not reported
Oral B® Complete 4 en 1	NaF	1 502.1	1 450	Sílica	ago-23	Not reported
Oral B® 100%	NaF	1 574.9	1 450	Sílica	sept-23	Not reported
am/pm® plus crema dental triple acción	NaF	1 469.0	1 452	Calcium carbonate - Hydrated silica	jul-23	Not reported
Proquident® Dientes Sensibles / Blanqueadora	NaF	1 299.4	1 357	Sílica	mar-22	Not reported
Colgate® Luminous White Instant	NaF	1 057.3	1 100	Hydrated silica	dec-22	Not reported
Fortident® Cuatriacción Limpieza Profunda	NaF	1 344.9	1 450	Sílica - Sílica Hidratada	jul-23	Not reported
GUM® gel dental (para niños)	NaF	964.7	1 000	Hydrated silica	apr-23	Not reported
Colgate® Total 12 Antisarro	NaF	1 392.0	1 450	Hydrated silica	nov-22	Not reported
Oral Plus® Crema Dental Cool Mint	NaF	1 002.9	1 350	Hydrated silica	Not reported	Not reported
Bucarine® Triple Acción	NaF	1 274.7	1 452	Calcium carbonate - Hydrated silica	dec-23	Not reported
Colgate® Kids	NaF	1 103.3	1 100	Hydrated silica	dec-23	Not reported
Bucarine® Junior con flúor	NaF	1 161.3	1 100	Hydrated silica	nov-23	Not reported
Bucarine® protección blanquea-dora	NaF	1 648.0	1 452	Calcium carbonate - Hydrated silica	feb-24	Not reported
Oral Plus® White Purificante	NaF	1 207.2	1 450	Hydrated silica	Not reported	Not reported
Oral B® Kids	NaF	1 093.1	1 100	Hydrated silica	ago-22	Not reported
Proquident®Junior	NaF	971.9	1 100	Hydrated silica	jan-23	Not reported
Colgate® Smile niños	NaF	573.4	500	Hydrated silica	jan-22	Not reported
Dentiblank®	NaF	1 334.5	Not reported	Hydrated silica	mar-20	Not reported
Sensodyne® Blanqueador Repara y Protege	NaF - MFP	1 240.9	NaF 1 426 – MFP not reported	Sílica	sept-22	Not reported
Sensodyne® Rápido Alivio	NaF - SnF	968.9	1 426 - (0.454%)	Hydrated silica	Jul-22	Not reported
Oral B® Pro Gengiva Original	NaF- SnF	990.7	350 -1 100	Sílica	jan-22	Not reported
Oral B® Gengiva Detox - Deep Clean	SnF	1 078.5	1 100	Sílica	jun-21	Not reported
Oral Plus® Sin flúor para niñas / niños	-	Less than 1.0	Fluoride free	Hydrated silica	Not reported	Not reported
Fito Kids®	-	0	Fluoride free	Hydrated silica	sept-23	Not reported

The availability in the intraoral environment of fluoride from a toothpaste depends on the abrasive used. For dentifrices with NaF, the most commonly used is silica, while MFP is usually accompanied by calcium carbonate because it contributes to its stability. In this case, calcium can interact with the fluoride product of the hydrolysis of MFP, forming insoluble complexes. The hydrolysis undergone by the MFP is due to phosphatases present in saliva [25] and is a reaction that occurs over time, decreasing the total soluble and bioavailable fluoride contained in the toothpaste [19,20]. In the case of toothpastes containing silica and NaF, the fluoride concentration remains stable, regardless of whether the fluoride is ionic or ionizable, because silica does not inactivate it [19].

In this work, it was found that although most toothpastes with NaF are accompanied by silica, others contain abrasives with calcium, such as calcium carbonate, sodium calcium phosphosilicate, and dicalcium phosphate dihydrate. Dentifrices with MFP were also found in combination with abrasives containing calcium—including calcium carbonate, sodium calcium phosphosilicate, dicalcium phosphate dihydrate, and calcium pyrophosphate—and silica, which in the case of the hydrolysis of MFP, would not form insoluble fluoride compounds. An in vitro study [26] on the stability of fluoride in the forms of NaF, MFP, and SnF validated the recommendation to combine MFP with calcium carbonate abrasives by concluding that there is a high affinity between them because the MFP behaves in a nonreactive way when accompanied by calcium carbonate. However, in the same study, it was found that bioavailable fluoride is lost from both MFP and NaF when accompanied by abrasives such as tricalcium phosphate and calcium pyrophosphate—the latter of which was found in formulations sold in the city of Medellín that contain MFP. NaF dentifrices lose available fluoride in the presence of calcium carbonate and calcium orthophosphate, while MFP remains stable with these abrasives [26].

Divalent cations are chemical elements that have lost their two valence shell electrons [13]. In the presence of ionic fluoride, they can react by forming compounds with very low solubilities. In addition to finding calcium in some of the toothpaste formulations, another divalent cation, zinc, was found in three toothpastes as zinc oxide or zinc citrate, both of which are whitening agents, abrasives, and stabilizers. Calcium and zinc can form calcium fluoride and zinc fluoride, respectively, lowering the concentration of bioavailable fluoride in toothpaste, but in two of the toothpastes in which zinc was found and which had NaF in their formulations, no decrease in bioavailable fluoride below the recommended level was observed.

Two key variables have been identified in the stability of toothpastes; the first is time because, for example, the hydrolysis undergone by MFP and the subsequent decrease in bioavailable fluoride is evident after several months of storage at room temperature. The second is heat, which, as has been shown in ageing studies, accelerates the hydrolysis of the MFP [14-20]. It can thus be said that the stability of a dentifrice depends on time, storage temperature, and ingredients. Due to the decreased bioavailability of fluoride, the current recommendations have been expanded to include not only the total amount of fluoride that a toothpaste must contain but also the minimum concentration of bioavailable fluoride to achieve a therapeutic effect in the control of caries. The FDI recommends that of the 1,000 to 1,500 ppm fluoride that toothpastes should contain, at least 800 ppm should be in the form of bioavailable fluoride [10]. In Colombia, health legislation adheres to what is established by the European Union, which imposes a fluoride limit of 1,500 ppm [27]. In this study, it was found that of 32 dentifrices with NaF, 31 met the recommendation of containing between 1,000 and 1,500 ppm, and only one reported concentrations on the label lower than recommended (500 ppm). Of the toothpastes that reported having more than 1,000 ppm, only one did not meet the recommendation of 800 ppm bioavailable fluoride, offering only 319 ppm. This is notable because, being a toothpaste with NaF and with silica as an abrasive, the concentration of bioavailable fluoride should remain stable [19-25] as with the others. Two additional toothpastes with the same label from two different batches were therefore purchased, and the measurements were repeated, but both gave similar results to the first evaluation: 283 ppm and 267 ppm. This was similar to the findings of the study carried out in Bogotá, in which it was found that most of the toothpastes had fluoride concentrations consistent with those reported by the manufacturers, with the exceptions of two with NaF and silica and one with MFP and calcium carbonate content below what was declared, which was associated with the fact that, in both studies, the majority of the measured dentifrices contained NaF with silica abrasives, which have been reported to be stable. Unlike the Bogotá study, which measured toothpastes for children without reporting the commercial reference, most of which had concentrations lower than those recommended by the FDI [10], the present study covered a wider range of toothpastes marketed in Medellín, including references with different fluoride concentrations, but mostly within the values recommended for having a positive effect in caries control [21].

As the concentration of bioavailable fluoride in toothpastes can be altered, directly influencing the potential therapeutic effect, measuring bioavailable fluoride is important to verify that it meets the requirements. Among the analysis methods for measuring fluoride in toothpaste, fluoride-specific electrodes have commonly been used in studies of this type [15-20]. However, capillary electrophoresis is a method [14] that allows for rapid and simultaneous determination of free fluoride and MFP. Among the advantages are high efficiency, detection limits down to the ppm level, minimal preparation of samples, minimal consumption of samples and reagents, fast analysis time, and allowing several anions to be separated in a short time, which is useful for analysing a large number of samples [22,23]. This technique has been shown to be effective in measuring free fluoride and MFP in toothpastes and in achieving a high level of measurement agreement compared to the fluoride-specific electrode technique, with the additional advantage of not needing to hydrolyse the MFP during sample preparation, which saves processing time and costs. Additionally, the hydrolysis of the samples with MFP can decrease the precision of the analysis since incomplete hydrolysis would lead to lower total fluoride measurements and the formation of insoluble CaF2 complexes [24].

Future work could measure bioavailable fluoride of the toothpastes with MFP using the capillary electrophoresis technique, which was shown to be fast and accurate in simultaneously measuring MFP and free fluoride [23,24], and to evaluate the stability of the bioavailable fluoride when samples are subjected to ageing, taking into account that temperature and time can affect stability [14-20].

In Colombia, the national study of oral health IV (ENSAB IV) reported that 75.7% of caregivers had not received information on the type of toothpaste they should use for minors [28]. In this work, through an examination of toothpastes available for sale in the city of Medellín, four dentifrices without fluoride and six with less than 1,000 ppm fluoride were found. Although most caregivers did not have information on the type of toothpaste they should use, 98.5% still reported using toothpaste for oral hygiene. However, there are toothpastes in Colombia that contain less fluoride than recommended, so the protective effect of using fluoride toothpaste during brushing could be limited [28].

It is therefore important to analyse toothpastes to verify that the products used by the population comply with the recommendations. It is also important to offer good education on the topic to ensure the benefits of incorporating fluoride into the oral environment, using vehicles such as toothpastes, for the prevention of caries.

Within the limitations of this work, it was found that most of the toothpastes did not have a manufacturing date, which would have been considered as an inclusion criterion, so selection was based on the furthest expiration date at the time of purchase. In Colombia, according to the Food and Drug Surveillance Institute (INVIMA), toothpastes with up to 1,500 ppm fluoride are considered cosmetic, for which it is not mandatory to indicate the shelf life or expiration date [29]. However, according to laws of Mercosur and the European Union, whether fluoridated or not, toothpastes must have an expiration date three years after manufacture [30,31].

We consider that models are needed to estimate the bioavailable fluoride contained in toothpastes, based on manufacturing date and formulation, to develop more precise estimates of the periods during which each product complies with the relevant norms and is therefore useful for dental caries prevention.

Conclusion

Most of the toothpastes in Medellín that declared a content of 1,000 to 1,500 ppm fluoride met the recommendation of providing at least 800 ppm bioavailable fluoride.

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