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Ingredients in Children's Fluoridated Toothpaste: A Literature Review

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Abstract

Children's fluoridated toothpastes are supplemented with ingredients intended to increase appeal. A comprehensive list of children's toothpastes and their ingredients was compiled from nine pharmacies in New York City. A broad literature review was then conducted to describe the purpose of the ingredient and the known contamination risks associated with chronic consumption of each ingredient. The final sample size comprised 26 children's toothpastes and 45 unique ingredients. The purpose and known contamination risks of the 45 identified ingredients were documented. A proportion of ingredients (28.9% [n = 13]) were found to be both unnecessary to improving the oral health of children and solely used to increase their appeal. Of this list of unnecessary ingredients, 69.2% (n = 9) were shown to have contamination risks associated with chronic consumption, including enamel demineralization. The authors recommend that toothpaste manufacturing practices be limited to include only ingredients that are necessary for improved oral health and care and only using natural flavorings when needed.

Keywords: toothpaste, toxicology, oral health, children

1. Introduction

Toothpaste has been used for hundreds of years. It first appeared in a tube in the 1800's and its ability to curb dental disease was lacking (Ramirez, 1990). Still, many formulas were created and there was competition to increase toothpaste use and sales (Ramirez, 1990). In a quest to see toothpaste use become more pervasive, a successful advertiser, Claude Hopkins set off to find a "trigger that would justify the toothpaste's daily use (Duhigg, 2012 p. 34)." This trigger turned out to be daily use to remove a film on teeth, a step in making one more attractive. The appeal of this was alluring, and toothpaste use is now normative. With many toothpastes available for purchase, companies set their sights on increasing marketing tactics to in turn increase profits. Therapeutically speaking, fluoride stands alone among the ingredients list as having the benefit of fighting dental decay (Ramirez, 1990).

Children's fluoridated toothpastes are supplemented with a number of unnecessary and potentially toxic ingredients that are utilized to increase the appeal of toothpaste among young children. One study found that marketing tactics for children's toothpaste include depicting pictures of fruit on the front of toothpaste tubes as well as use of animated characters, and attractive flavorings that mirror common food items (Basch & Rajan, 2014). In some cases, toothpaste tubes even depicted a full swirl of toothpaste, and image that is in contradiction with the amount of toothpaste recommended to be used by children (Basch & Rajan, 2014). While perhaps not the intent, these depictions could lead consumers (both adults and children) to believe that toothpaste is safe, or even intended to be consumed as if it were a food product. Studies have shown that overconsumption of fluoridated toothpastes among children is associated with health risks such as fluorosis, which causes changes in tooth enamel ranging from spots to stains to deep pitting depending on the severity (Centers for Disease Control [CDC], 2013).

There is an existing research base that focuses on the role of active ingredients in toothpaste to determine their efficacy on reducing dental caries and controlling the viability of bacteria present in dental plaque (Erdal & Buchanan, 2005; Afflitto, Fakhry-Smith, & Gaffar, 1989; Kraivaphan, Amornchat, & Triratana, 2013). However, while fluorosis results from the overconsumption of fluoride, possible risks associated with the chronic consumption of other ingredients present in children's fluoridated toothpaste have not been identified. The addition of unnecessary and potentially toxic ingredients (such as sweeteners, artificial colorings, flavorings and

other additives that facilitate the composition of toothpaste in appearing more like a food product) further increases the likelihood that children will consume more toothpaste than is recommended by the American Dental Association (ADA). It should also be noted that the presence of these unnecessary ingredients do not contribute to a child's improved oral health (Center for Science in the Public Interest [CSPI], 2012; Food and Drug Administration [FDA], 2010).

Currently no studies exist that systematically identify the presence of unnecessary and potentially toxic ingredients in children's toothpastes and use available peer-reviewed literature to describe known contamination risks. Indeed, a recent publication stated that with regard to food products, most individuals are not aware about the source and/or possible risks associated with particular ingredients (Nicole, 2013). The authors estimate that the same holds true for cosmetic and hygiene products. In the United States, for example, the US Food and Drug Administration (FDA) regulates the safety and efficacy of fluoridated toothpaste as used during brushing, however the intent is never for toothpaste to be consumed. Previous research has suggested that young children may swallow up to half of the toothpaste on their brush during any given instance; a significant amount (Rock, 1994). Toothpaste advertised as a food-like substance, used multiple times a day, and often swallowed by young children, poses risks for bioaccumulation (Delorenzo et al., 2008; Ethier et al., 2012). The authors therefore collected data to identify the presence of potentially toxic ingredients in children's toothpaste and subsequently conducted a literature review to describe the purpose of the ingredient as well as the known contamination risks associated with chronic overconsumption. Recommendations for alternatives to promoting positive and safe oral care practices are provided and the crucial role of dental hygienists, health educators, and public health professionals is emphasized.

2. Methods

Ancillary to another study, ingredients from children's fluoridated toothpastes being sold at drug stores and pharmacies in New York City (NYC) were coded (Basch & Rajan, 2014). The coder visited locations until a comprehensive and exhaustive list of children's toothpaste products was compiled. A coding sheet was created to record the amount of fluoride present in each toothpaste product, as well as all additional ingredients. The coder (CB) recorded ingredient information for each toothpaste in the study's sample. It should be noted that the study's sample size represents unique toothpaste products based on the packaging and brand.

A thorough review of current peer-reviewed literature was subsequently conducted to identify the purpose, known contamination risks, and risk for bioaccumulation of each ingredient. The primary search engine utilized was PubMed, however, both Google Scholar and Microsoft Academic Search were used to ensure that no publication was missed. It should be noted that in instances where there were gaps in current peer-review literature regarding ingredient toxicology, Material Safety Data Sheets were consulted to examine ingredient toxicology.

"Necessary" ingredients were defined by the authors as those ingredients used specifically to increase the quality of children's oral health and/or contribute to the production of toothpaste as a paste. "Unnecessary" ingredients were defined by the authors as those ingredients that do not contribute to a child's improved oral health and/or ingredients that help toothpaste taste like a food product. While the authors acknowledge that isolated incidences of toothpaste consumption can and do occur, this study is concerned with chronic toothpaste consumption among young children. Specifically, chronic consumption of toothpaste among children was defined by the authors as swallowing any amount of toothpaste, multiple times a week and for an extended period of time (greater than one year). Finally, and as emphasized earlier, while the ADA recommends that a pea-sized amount of toothpaste be used for brushing, no amount of toothpaste is ever intended to be swallowed (ADA, 2013a). This research was deemed exempt by the Institutional Review Board at William Paterson University.

3. Results

The study's sample size comprised 26 children's fluoridated toothpastes, coded from nine stores in NYC. The sample represented well-known toothpaste companies. All toothpastes included in the sample were fluoridated, with sodium fluoride amounts ranging from 0.13%–0.243%. Nearly the entire sample (92.3% [n = 24]) stated they were flavored toothpastes, with sweet and appealing flavors ranging from strawberry to bubblegum. Table 1 lists the observed unnecessary ingredients among this sample of children's toothpastes, their purpose, and known contamination risks. Table 2 lists the observed necessary ingredients among this sample of children's toothpastes, their purpose, and known contamination risks. Risk for bioaccumulation is indicated in each table, where appropriate.

The authors identified 45 unique ingredients across the entire sample. A comprehensive review of the purpose and toxicology associated with each ingredient demonstrated that 75.6% (n = 34) of these ingredients have

specific and known contamination risks associated with chronic consumption and two of these ingredients have documented risks for bioaccumulation. While 71.1% (n = 32) of the ingredients identified were defined by the authors as those ingredients used specifically to increase the quality of oral health and/or contribute to the production of toothpaste as a paste, the remaining 28.9% (n = 13) ingredients were identified as being unnecessary to improving the oral health of the consumers (Table 1).

Table 1. Purpose and known contamination risks of unnecessary toothpaste ingredients

Ingredient	Ingredient	Purpose	Known Contamination Risks
Sweeteners	Sodium Saccharin	An artificial sweetener (Fitch & Keim, 2012).	Findings are mixed; the use of sodium saccharin as a sweetener is considered safe for consumption (Fitch & Keim, 2012), but recent research suggests it contributes to enamel demineralization (Giacamam, Campos, Munoz-Sandoval, & Castro, 2013).
	Sorbitol	A substitute for sugar used as a sweetening agent (Fitch & Keim, 2012).	The malabsorption of sorbitol has been shown to cause abdominal discomfort, as well as diarrhea (Fernandez-Banares, Esteve, & Viver, 2009).
	Sucralose	A nonnutritive sweetener (Fitch & Keim, 2012).	Recent findings suggest that sucralose is not biologically inert (Soffritti et al., 2016).
Artificial Colorings	FD&C Blue 1 Lake	Functions as a coloring agent (Kobylewski & Jacobson, 2010).	Some research suggests that exposure to this coloring agent results in allergic reactions and the inhibition of nerve-cell development (Kobylewski & Jacobson, 2010).
	D&C Red 30 Lake	Functions as a coloring agent (Environmental Working Group, 2013).	Bioaccumulation of D&C Red 30 Lake over time has been shown to lead to organ toxicity (Environmental Working Group, 2013).
	D&C Red 33	Functions as a coloring agent (Science Lab, 2013c).	D&C Red 33 is known to cause irritation of the skin, eyes, and respiratory tract, as well as skin discoloration (Science Lab, 2013c).
	D&C Red 28	Functions as a coloring agent (National Institute of Environmental Health Sciences [NIEHS], 2000).	Toxicology data demonstrate that this dye contributes to genetic damage via the formation of free radicals (NIEHS, 2000).
	Red 40	Functions as a coloring agent (Kobylewski & Jacobson, 2010).	Red 40 is believed to be a carcinogen and known to cause allergic reactions (Kobylewski & Jacobson, 2010).
Foam and Flavor Booster	Cocamidopropyl Betaine	This substance is added as a foaming agent (Moreau & Kaplan, 2013)	Though relatively rare, research indicates that cocamidopropyl betaine may be a contact allergen (Schnuch, Lessmann, Geier, & Uter, 2011; Jacob & Amini, 2008)
Flavorings	Flavor	Functions as a flavoring agent (Sainio & Kanerva, 1995).	This substance has been shown to cause allergic reactions, including inflammation of the mouth and lips and gingivitis (Sainio & Kanerva, 1995).
	Menthol	Functions as a flavoring and scent for toothpaste (International Programme on Chemical Safety [IPCS], 1999).	No known contamination risks (IPCS, 1999)
	Natural Flavors	Encompass a range of flavorings derived from herbs and fruits and together function as a flavoring for toothpaste (Schrankel, 2004; Smith et al., 2005).	No known contamination risks (Schrankel, 2004; Smith et al., 2005).
	Strawberry Juice	Functions as a natural flavoring for toothpaste.	No known contamination risks (Schrankel, 2004; Griffiths, 2005).

More concerning, these latter ingredients are specifically and solely used to increase their appeal to young children and the majority of these ingredients (69.2% [n = 9]) were found to have known contamination risks. These ingredients are as follows: sweeteners (sodium saccharin and sorbitol), artificial colorings (Blue 1 Lake, D&C Red 30 Lake, D&C Red 33, D&C Red 28, Red 40), a foam and flavor booster (cocamidopropyl betaine), and a subset of flavoring agents distinguished on the toothpaste labeling only as "flavor". Identified health risks associated with these ingredients were found to range from enamel demineralization to abdominal discomfort. Among the entire sample of children's toothpastes, 80.8% (n = 21) contained at least one of and 50.0% (n = 13) contained at least two of these unnecessary ingredients with identified known contamination risks. The risks of fluoride overconsumption have been previously well documented (Erdal & Buchanan, 2005; Heifetz & Horowitz, 1986). This study expands on this knowledge base by also clearly identifying the risks associated with the additional and necessary ingredients currently found in children's toothpaste products (Table 2).

Table 2. Purpose and Known Contamination Risks of Necessary Toothpaste Ingredients

Ingredient	Purpose	Known Contamination Risks
Active Ingredients		
Sodium Fluoride	Fights the formation of dental caries, helps with teeth whitening, and decreases mouth odors (Ten Cate, 2013).	Excess ingestion of sodium fluoride has been linked with dehydration, as well as the possibility of dental and skeletal fluorosis (Erdal & Buchanan, 2005; Heifetz & Horowitz, 1986).
Triclosan	Primarily aids in the prevention of gum disease (gingivitis) (Food and Drug Administration [FDA], 2013; Chen et al., 2012).	Triclosan may affect the formation of thyroid hormone (FDA, 2013; Chen et al., 2012; Johnson et al, 2016).
Synthetic Polymers		
PEG-8	Used to stabilize and keep cosmetics (such as toothpaste) from drying out; also helps to control plaque buildup (Fruijtier-Pölloth, 2005).	Research suggests that PEG-8 may result in delayed allergic reactions (Wenande, Skov, Mosbech, Poulsen, & Garvey, 2013).
PEG-12	Used to stabilize and keep toothpaste from drying out; also helps to control plaque buildup (Fruijtier-Pölloth, 2005).	No known contamination risks (Wenande, Skov, Mosbech, Poulsen, & Garvey, 2013).
PEG-32	Used to stabilize and keep the toothpaste from drying out; also thickens the toothpaste to keep the ingredients from separating (Fruijtier-Pölloth, 2005).	No known contamination risks (Wenande, Skov, Mosbech, Poulsen, & Garvey, 2013).
PEG-1450	Used as surfactant, solvent, and plasticizer (Skaare, Kjærheim, Barkvoll, & Rølla, 1997)	This substance could cause mild irritation to the skin and eyes (Science Lab, 2013d).
PVM/MA Copolymer	Used as a stabilizer and a binder; also helps to fight bacteria (Podariu, Galscan, & Rosianu, 2009).	No known contamination risks (Podariu, Galscan, & Rosianu, 2009; DiLucco et al., 1989).
Carbomer	Used to control the flow of products (such as toothpaste) and keeps the ingredients of the toothpaste from separating (Luo, Wilber, & Guo, 2004).	Though rare, research has suggested that carbomer may be a contact (skin) allergen (Vie, Pons-Guiraud, Dupuy, & Maibach, 1991).
Emulsifiers		
Sodium Lauryl Sulfate	Makes toothpastes thicker, and acts as a foaming agent while brushing (ADA, 2013b).	This substance could cause irritation to the skin and eyes, as well as gastrointestinal irritation (Wilhelm, Surber, & Maibach, 1991; Blondeel, Oleffe, & Achten, 1978).

Sodium Carboxymethyl Cellulose	Used as a toothpaste emulsion stabilizer (CSPI, 2012).	No known contamination risks (CSPI, 2012).
Poloxamer 407	Aids in the process of dissolving other ingredients to create an emulsion (Garala, Joshi, Shah, Ramkishan, & Patel, 2013; Bhardwaj & Bhardwaj, 2011).	This substance could cause irritation to the eyes and renal issues (Spectrum Laboratory, 2007; Dumortier, Grossiord, Agnely, & Chaumeil, 2006). In animal studies, when given parentally, it caused hyperlipidaemia and engorgement of Kupffer cells (Warren, Benseler, Cogger, Bertolino, Le, & Couter, 2011).
Tetrasodium Pyrophosphate	Used to prevent plaque buildup by reducing the amount of calcium and magnesium from one's saliva during brushing (Llena, Forner, & Vento, 2009; Winston, Fiedler, Schiff, & Baker, 2007).	This substance could cause irritation of the nose, skin, eyes, throat, and respiratory passages (CDC, 2011).
Sodium Hexametaphosphate	Aids in extrinsic stain removal (He et al., 2007).	If ingested, excess consumption of this substance could cause irritation of the skin and eyes; respiratory tract irritation; and vomiting, nausea, and diarrhea; lethargy (Lanigan, 2000).
Buffering Agents		
DiSodium Pyrophosphate	Helps to prevent plaque buildup by reducing the amount of calcium and magnesium from saliva (DeLattre, 1999).	Exposure to disodium pyrophosphate could cause severe skin irritation; research suggests that high levels of exposure to this substance may also be hazardous to blood and lungs (Lewis, 1996).
Preservatives		
Propylparaben	Used as a preserving agent; can also reduce yeast and mold growth (National Center for Biotechnology Information, 2013).	Research suggests that propylparaben may be hazardous to one's lungs and could cause skin irritation (Soni, Burdock, Taylor, & Greenberg, 2001).
Sodium Benzoate	Used as a preserving agent (Nair, 2000).	Excess consumption of this substance could decrease the ability of the immune system to function properly and also cause other irritations (Science Lab, 2013e; Munoz, Bellido, Moyano, Alvarez, & Fonseca, 1996).
Sodium Methylparaben	Used as a preserving agent (Golden, Gandy, & Vollmer, 2005).	Excess consumption of this substance includes an increased risk of male infertility, breast cancer, skin cancer (Golden, Gandy, & Vollmer, 2005; Boberg, Taxvig, Christiansen, & Haas, 2010).
Sodium Phosphate	Used as a pH stabilizer and buffering agent (Duke, Reading, & Jackson, 1988).	Acute exposure to sodium phosphate can lead to skin and eye irritation; the chronic effects of exposure to sodium phosphate, however, are not known (Science Lab, 2013f).
Thickening Agent		
Carrageenan	Used as a toothpaste thickener (CSPI, 2012).	Side effects associated with consumption of this substance include gastrointestinal issues (Tache, Peiffer, Millet, & Corpet, 2000; Corpet, Tache, & Preclaire, 1997; Cohen & Ito, 20002).
Cellulose Gum	Used as a toothpaste thickener (CSPI, 2012).	This substance could cause irritation to the skin and eyes (Science Lab, 2013a).
Xanthan Gum	Used as a toothpaste thickener and stabilizer (Becker, Katzen, Puhler, & Ielpi, 1998).	This substance could cause bloating, cold and flu-like symptoms (Daly, Tomlin, & Read, 1993; Sargent et al., 1990).

Calcium Supplement		
Calcium Carbonate	Aids in the removal of surface stains and plaque on the teeth while brushing (Tahmassebi, Duggal, & Curzon, 1994).	Risks associated with consumption of this substance include possible eye pain and irritation, coughing, and sneezing (Medline Plus, 2013).
Whitening/Plaque Removal		
Citric Acid	Aids in removal of dental plaque (CSPI, 2012).	The developmental toxicity associated with chronic consumption of citric acid is not known (Science Lab, 2013b). However other risks associated with consumption of this substance include diarrhea, nausea, and stomach cramps (CSPI, 2012).
Hydrated Silica	Used as an abrasive to assist in plaque and stain removal (Schemehorn, Moore, & Putt, 2011).	Use of silica nanoparticles in vivo poses risks for bioaccumulation (Pohaku Mitchell, Liberman, Kummel, & Trogler, 2012).
Mica	Used as an abrasive to assist in stain removal (Yin, 2012).	No hazards to human health have been identified (Bernard, Osheroff, Hofman, & Mennear, 1989).
Sodium Bicarbonate	Used as an abrasive to aid in plaque and stain removal (de Araújo, Silva, de Jesus Campos, & de Araújo, 2011).	Although rare, reactions such as dizziness, confusion, irritability, memory problems, muscle pain or aches, vomiting, or weakness can occur with excess consumption (Biosciences, 2011).
Titanium Dioxide	Aids in whitening of the teeth (Julie & Lee, 2011).	Research is mixed, however, recent work has suggested that titanium dioxide in higher concentrations may be dangerous (Julia & Lee, 2011). Specifically, chronic health effects include possible harm to one's upper respiratory tract and lungs (Science Lab, 2013g)
Trisodium Phosphate	Aids in plaque removal (Mestres et al., 2013).	Risks associated with consumption could include gastrointestinal issues (Colonial Chemical Solutions, 2010)
Xylitol	Xylitol aids in caries prevention (Fontana & Gonzalez-Cabezas, 2012).	Research supports that xylitol is not carcinogenic (Fontana & Gonzalez-Cabezas, 2012).
Other Ingredients		
Sodium Hydroxide	Sodium hydroxide is a pH stabilizer (Jungbluth, Marending, De-Deus, Sener, & Zehnder, 2011).	The toxicity of sodium hydroxide via toothpaste consumption is unclear, however, at high concentrations sodium hydroxide has been shown to affect the viability of esophageal cells (Malvasio, Ainoedhofer, Ackbar, Hoellwarth, & Saxena, 2012).
Aloe Vera	Used to reduce the amount of bacteria in the mouth (Namiranian & Serino, 2011).	Research supports that aloe vera is not toxic (Sehgal et al., 2013), however, warnings have been issued about extracts (CSPI, 2013).
Glycerine	Glycerine is used to prevent toothpaste from drying out (Furness, Worthington, Bryan, Birchenough, & McMillan, 2011; Self, 2013).	Though generally found to be low-toxic, at high concentrations, glycerine could impair blood circulation (Maes et al., 2012).

Identified health risks were identified in 78.1% (n = 25) of these ingredients and found to range from dehydration to elevated blood sugar levels.

4. Discussion

The findings in this study are noteworthy for three reasons. First, the majority of all the ingredients identified in this sample have specific and known contamination risks associated with chronic consumption (75.6% [n = 34]). Children's fluoridated toothpastes intentionally use artificial colors, sweeteners, foam boosters, and flavorings to

increase their appeal to young children. However, these ingredients do not contribute to the improved oral health of children. The known contamination risks, as documented in Table 1, pose a number of potential health concerns.

Second, all of the toothpaste products identified in this study contained fluoride and nearly all were flavored, presenting the risk that they could be consumed as if they were a food product. Chronic toothpaste consumption among young children is of particular concern since research documents that children under the age of six years often swallow between 25% - 33% of toothpaste during each brushing (Dincer, 2008). In fact, in 2011, the American Association of Poison Control Centers registered 21,513 calls for over ingestion of fluoridated toothpaste (Bronstein, Spyker, Cantilena, Rumack, & Dart, 2012). Marketing toothpaste to children as if it is a food exacerbates this issue. Further, given that toothpaste is a product that is used daily by children, the risk of bioaccumulation stemming from chronic consumption of these toxic substances is worrying.

Third, the majority of all the unnecessary ingredients (69.2%) were found to have known contamination risks, and half of the toothpastes in the sample contained more than one of these ingredients, further compounding the risk. It should be noted that the known contamination risks documented in this study are a heightened issue among children, given their smaller body size in comparison to adults, the way in which they metabolize exposure to chemicals, and because they are physically developing (Bearer, 1995).

In generalizing these findings, one primary limitation of this study should be considered. Specifically, that no one definition of "overconsumption" exists, therefore making it difficult to estimate the specific risk associated with a given amount of toothpaste. This inconsistency in the literature regarding definition highlights an additional area of future research and study. As described earlier, however, no amount of toothpaste is ever intended to be consumed. Therefore, we consider the chronic consumption of children's fluoridated toothpaste (swallowing any amount of toothpaste, multiple times a week and for an extended period of time) to warrant pause and consideration.

The authors recommend that the risk associated with possible chronic consumption of fluoridated toothpaste be lowered by limiting toothpaste manufacturing practices to include only those ingredients that are necessary for improved oral health and care and also only using natural flavorings when needed. Currently, there are brands of all-natural toothpastes that are available and that do not contain artificial flavorings, colorings, or sweeteners. While artificially flavored and colored toothpaste can increase positive oral health habits among children because it has appealing characteristics, there are other alternatives on the market. Dental professionals and health professionals should continue to work with parents to help encourage safe brushing, spitting, and swallowing practices among their children. Additionally, public health professionals should advocate for further regulatory scrutiny of oral health products manufactured specifically for children.

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Competing Interests Statement

The authors declare that there is no conflict of interests regarding the publication of this paper.

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