Peer-reviewed paper; submitted February 2022; accepted June 2022

An update of the evidence on factors that influence the impact of fluoride toothpaste on dental caries in New Zealand

Kanagaratnam S, Schluter PJ

Abstract

Background: Tooth brushing with fluoride toothpaste is the most common form of caries prevention, and its advantages have been thoroughly documented. New Zealand's use of fluoride guidelines was last updated in 2009. To ensure that the optimal anti-caries benefit of fluoride toothpaste can be promoted to New Zealanders, an evaluation of current research in relation to these guidelines is needed.

Aims: To update the evidence on factors that influence the impact of fluoride toothpaste on dental caries and make recommendations that provide the maximum anti-caries effect and safety of fluoride toothpaste.

Methods: To maximise the benefits and safety of the use of fluoride toothpaste, the evidence available since the publication of New Zealand guidelines was examined. The literature review was carried out using electronic databases and hand-searches of reference lists of articles, reports, and textbooks. Articles used in this review were identified using certain keywords, and the findings organised into common themes based on key modifying factors of the use of fluoride toothpaste.

Findings: After an extensive search of database and grey literature, 59 separate studies or policy documents from 91 papers or reports were extracted and critically examined. Thematic analyses revealed eight themes: use of fluoride toothpaste; fluoride toothpaste formulations; fluoride concentration; fluoride toothpaste amount; frequency of use; brushing time; post-brushing rinsing behaviours; and supervised brushing in children.

Conclusion: Recent evidence suggests that it may be time for the 2009 New Zealand use of fluoride guidelines to be updated and refined. Recommended fluoride toothpaste concentrations and amounts for those with higher and lower risk for caries at different age ranges are now more specific, together with more detail on brushing duration and post-brushing rinsing. Amending the current New Zealand guidelines may help in optimising fluoride toothpaste protection, and ultimately reduces individuals' and society's oral disease burden.

Introduction

Oral diseases are among the most prevalent diseases globally and have serious health and economic burdens, greatly reducing the quality of life for those affected (Peres et al., 2019). Dental caries is one of the most prevalent oral diseases that are largely preventable. Within New Zealand (NZ), oral health has improved considerably over time, but dental caries remains the most chronic disease (Ministry of Health, 2010). Although minimal improvements in early childhood caries have been made over recent years, unacceptably wide inequalities remain (Kanagaratnam and Schluter, 2019). The global decline in the prevalence of dental caries has been mainly attributed to the effective introduction of fluoride in toothpaste in the early 1970s and the awareness and commitment of people to maintaining a high level of oral hygiene throughout life (Einarsdottir and Bratthall, 1996).

Fluoride works primarily via topical mechanisms which include inhibition of demineralization at the crystal surfaces inside the tooth, and enhancement of remineralization at the crystal surfaces, the resulting remineralized layer is resistant to acid attack (Featherstone, 1999). Fluoride also affects the glycolytic pathway of bacteria, reducing acid production and interfering with the enzymatic regulation of carbohydrate metabolism. Because the mode of action of fluorides is predominantly post-eruptive, the prevention of caries requires lifelong exposure. The level of fluoride incorporated into dental minerals by systemic ingestion is insufficient to play a significant role in caries prevention (Featherstone, 1999). The effects of fluoride are dependent on a good supply of saliva. The protective factors, which include salivary calcium, phosphate and proteins, salivary flow, and fluoride in saliva can balance, prevent or reverse dental caries.

It has been over a decade since the NZ guidelines for the use of fluorides have been developed (New Zealand Guidelines Group, 2009). Since that time considerable research has been undertaken and published. Moreover, it has been found that an estimated 6.8% of adults and 6.4% of children in NZ use non-fluoride toothpaste, thereby missing out on the cariostatic benefits of fluoride when tooth brushing (Hobbs et al., 2020). Therefore, it is timely to revisit the appropriateness or otherwise of the NZ guidelines before any oral health promotion of fluoride toothpaste use is re-instigated.

Aims

This study aims to update the evidence on factors that influence the impact of fluoride toothpaste on dental caries and makes updated recommendations that provide maximum anti-caries effect and safety of fluoride toothpaste.

Methods

The primary search undertaken in PubMed was limited to articles published in English between 2009 and 2021. A preliminary literature search was conducted to identify key concepts in the research question; 'what are the modifying factors of fluoride toothpaste's effectiveness and safety?' The key search terms used were: 'fluoride', 'toothpaste', 'fluoride toothpaste', 'effectiveness', 'safety', and 'modifying factors'; medical subject headings (MeSH) were not used. Abstracts and articles from this search were examined for alternative words, phrases, and subject headings. This extended list of key terms was then combined using Boolean operators and, or, and not, and PubMed was researched. Wildcards were used to allow for spelling variants and plurals. Once key search terms were identified, additional search terms were used for each of the key search terms; 'fluoride': 'anti-caries mechanism'; 'toothpaste': 'types'; 'fluoride toothpaste': 'why use?', 'types', 'the use in New Zealand'; 'effectiveness': 'anti-caries action', 'modifying factors'; 'safety': 'dental fluorosis', 'monitoring', 'supervised brushing', 'New Zealand studies', 'recommendations'; 'modifying factors': 'formulations': 'availability', 'anti-caries effects', 'recommendation'; 'concentrations': 'anti-caries effects', 'availability in New Zealand', 'recommendation',; 'amount/size': 'anti-caries effects', 'recommendation'; 'frequency of use': 'different frequencies', 'recommendation'; 'brushing time': 'different brushing times', 'recommendation'; 'post-brushing rinsing': 'anti-caries effect', 'studies', 'recommendation'; and 'supervised brushing': 'studies', 'recommendation'. The search included original articles, reviews, guidelines, and recommendations from the expert groups of Australia, the United Kingdom (UK), and elsewhere, and any relevant literature from NZ. Selection criteria included only refereed articles; articles that were not refereed and 'repeat' articles were excluded. SK searched all the articles and chose those that met the selection criteria. Once the relevant information was analysed and gaps identified, it was organized under each modifying factor and stored. In the secondary search, reference lists of articles, reports, selected textbooks, and other related sources were used to search for more relevant information, which included articles published before and after 2009. Although the primary focus of the review was to look at updated evidence, this evidence is not in isolation and is built over many decades of strong research and studies, which needed judicious contextualisation. After downloading 91 articles from the primary and secondary searches, 32 were excluded, leaving 59. SK then synthesised the papers under each theme, which PJS then evaluated and provided feedback.

Findings

The following factors related to the use of fluoride toothpaste that assist with maximum protection have been updated: (1) use of fluoride toothpaste; (2) fluoride toothpaste formulations; (3) fluoride concentration; (4) fluoride toothpaste amount; (5) frequency of use; (6) brushing time; (7) post-brushing rinsing behaviours; and (8) brushing under supervision. Each of these modifying factors is described below.

1. Use of fluoride toothpaste

There is strong evidence available for the anti-caries effect of brushing regularly with fluoride toothpaste on permanent teeth. A Cochrane review assessing the anti-caries effect of fluoride toothpaste on permanent teeth suggests a 24% average reduction in decayed, missing, and filled tooth surfaces (D(M)FS) (Marinho et al., 2003; Twetman, 2009). The benefit of using fluoride toothpaste in preventing caries when compared to non-fluoride toothpaste is well supported (Walsh et al., 2019). There is some evidence supporting the effect of fluoride on deciduous teeth. A large trial involving 2008 children aged 6 to 9 years reported a substantial reduction in caries increment (37%) in deciduous teeth/surfaces (Cahen et al., 1982). Systematic reviews assessing the efficacy and safety of fluoride toothpaste in deciduous teeth demonstrate that fluoride toothpaste use is effective in caries control (dos Santos et al., 2013; Wright et al., 2014). The European Academy of Paediatric Dentistry (EAPD) strongly endorses the daily use of fluoride as a major part of any comprehensive programme for the prevention and control of dental caries in children (Toumba et al. 2019).

2. Fluoride toothpaste formulations

There have been formulation changes over the years, particularly regarding active fluoride agents in toothpaste. Different formulations such as sodium fluoride (NaF), sodium monofluorophosphate (SMFP), amine fluoride, and stannous fluoride have been used either alone or in combination, of which the most frequently used are NaF and SMFP. When the anti-caries effectiveness of these different formulations was compared, no clear evidence has emerged. A critical review of the relative anti-caries efficacy of NaF and SMFP toothpaste showed that NaF was significantly more effective than SMFP in preventing caries ($p<0.01$) (Stookey et al., 1993). However, a study comparing the anti-caries effectiveness of toothpaste containing fluoride as SMFP, and those containing fluoride as NaF, found no statistically significant and clinically meaningful difference (Volpe et al., 1995). A later two-year study provides additional support to the conclusion that toothpaste formulated with SMFP provides an equivalent level of anti-caries efficacy as those with NaF (Saporito et al., 2000). While all these compounds are effective, it is not easy to establish their relative effectiveness from the literature and confidently recommend one over another (Public Health England, 2021).

3. Fluoride concentration in toothpaste

The effects of fluoride toothpaste increase with higher fluoride concentration (Walsh et al., 2010; Walsh et al., 2019). These reviews concluded that the evidence for the anti-caries effect of different fluoride concentrations is more limited, but some evidence for a dose-response effect was observed for D(M)FS in children and adolescents. The caries preventive effect of fluoride toothpaste in the mixed or permanent dentition increased significantly with higher fluoride concentrations compared with placebo, which was 23% (19% to 27%) for 1000/1055/1100/1250 parts per million (ppm) concentrations rising to 36% (27% to 44%) for toothpaste with a concentration of 2400/2500/2800 ppm), but concentrations of 440/500/550 ppm and below showed no statistically significant effect when compared with placebo (Walsh et al., 2010). Based on these results, it may not be appropriate to recommend the use of 440/500/550 ppm fluoride toothpaste for the prevention of caries in the deciduous dentition, whilst acknowledging that there is considerable uncertainty surrounding the estimates at these levels. The updated Cochrane review concluded that confidence in the effect estimates for many comparisons of different concentrations of the caries-preventive effects is uncertain and could be challenged by further research (Walsh et al., 2019). The decision of what fluoride level to use for children under 6 years should be balanced with the risk of fluorosis.

A systematic review of clinical trials and meta-analyses concluded that there is no evidence to support the use of low fluoride (less than 1000 ppm) toothpaste by pre-schoolers regarding caries and fluorosis prevention (Santos et al., 2013). The Scottish Intercollegiate Guidelines Network (SIGN, 2014) recommends the use of toothpaste in the range of 1000 to 1500 ppm fluoride for children and adolescents up to the age of 18 years. Children aged 10 to 16 years who are at increased caries risk should be advised to use toothpaste at a concentration of 2800 ppm fluoride. The EAPD guidelines recommend using 1000 ppm fluoride toothpaste from the time the first tooth appears until the age of 6 years; 1450 ppm for those over 6 years (Toumba et al., 2019). For children between 2 and 6 years, more than 1000 ppm may be considered based on individual caries risk. There is moderate to high-certainty evidence for the use of a toothpaste containing at least 1000 ppm fluoride up to 7 years and the use of a toothpaste containing 1350 to 1500 ppm fluoride for children at higher risk and those from 7 years upwards (Public Health England, 2021). The strength of the recommendation is conditional, based on low or very low certainty evidence for prescribing 2800 ppm for those 10 years and above with active dental caries and either 2800 ppm or 5000 ppm fluoride toothpaste for those 16 years and above with active dental caries, until dental caries is stabilised and risk is reduced (Public Health England, 2021).

4. Fluoride toothpaste amount

The amount of toothpaste delivered on each occasion is critical to provide optimal effectiveness against caries while minimising excessive ingestion in young children and causing fluorosis in permanent teeth. A positive correlation was found between the amount of toothpaste used and the corresponding fluoride uptake (Reintsema and Arends, 1987, Creeth et al., 2013a). With increased fluoride toothpaste quantity from 0.5 g to 1.5 g when brushing for 45 seconds, surface microhardness recovery (SMHR) increased by 38.4%, and enamel fluoride uptake (EFU) by 51.3% (Creeth et al., 2016). With an increased quantity of fluoride toothpaste from 0.5g to 1.5g, fluoride recovered in saliva after brushing more than doubled, and enamel fluoride uptake increased (Zero et al., 2010). A study evaluated the effects of different tooth brushing routines and different kinds of toothpaste (paste, gel, and foam) on the interproximal fluoride concentration after tooth brushing (Ishizuka et al., 2020). An increase in fluoride concentration of 47.2% was observed when the amount of toothpaste was increased from 1 to 2 cm, 26.8% when increasing the duration from 1 to 2 minutes, and 41.2% when reducing the amount of water used for rinsing from 20 to 10 ml. However, in other studies, no relationship with toothpaste quantity was detected (Duckworth et al., 1989; Sjögren and Birkhed, 1993). Over-dispensing of fluoride toothpaste remains a concern, particularly in young children. The results of a study conducted in the UK, USA, and Germany indicate that, in all three countries, the majority of parents of 3- to 6-year-old children dispense considerably more toothpaste in the course of their child's normal oral hygiene routine than the recommended 0.25 gram (Creeth et al., 2013b). The EAPD guidelines recommend the use of the size of a rice grain up to 2-years of age and a pea-sized amount for children between 2 and 6 years of age (Toumba et al., 2019). Those over 6-years of age may use a size up to the full length of the brush. Use of only a smear of 1000 ppm toothpaste for children under 3 years and a pea-sized amount of 1000 ppm fluoride for children aged 3-6 years is strongly recommended (Public Health England, 2021). The FDI World Dental Federation (2019) recommends following the respective national authorities for children under 3 years and brushing with a pea-size amount of fluoride toothpaste for children between 3 and 6 years old while being supervised by an adult. Parents must be strongly advised to apply an age-related amount of toothpaste and assist with tooth brushing until at least 7 years of age. The NZ guidelines recommend a smear of fluoride toothpaste until age 5 and a pea-sized amount from age 6 years (New Zealand Guidelines Group, 2009).

5. Frequency of brushing with a fluoride toothpaste

In children, brushing with fluoride toothpaste needs to be started as soon as the teeth erupt (SIGN, 2014; Clark et al., 2020; Public Health England, 2021; American Dental Association Council on Scientific Affairs, 2014). Children who brush their teeth at least once a day with fluoride toothpaste will have fewer carious lesions (Marinho et al., 2003). Brushing twice a day with fluoride toothpaste lowers an individual's risk of developing dental caries by 14% compared with brushing once a day (Chesters et al., 1992). A three-year double-blind study in adolescents revealed that the reported brushing frequency with fluoride toothpaste and the post-brushing rinsing method was found to be strongly correlated with caries experience and caries increment (Chestnutt et al., 1998). A systematic review conducted by Kumar and colleagues (2016) found that people who reported brushing their teeth infrequently were at higher risk for the incidence of new caries than those who brushed frequently. Tooth brushing with fluoride toothpaste should take place at least twice daily (SIGN, 2014). The NZ guidelines recommend brushing twice a day with fluoride toothpaste (New Zealand Guidelines Group, 2009). After meals, food remnants are retained for a longer period in interproximal areas compared to occlusal surfaces or cervical portions of teeth. Despite the lack of clear evidence as to the optimal time for tooth brushing (before or after meals) brushing is mostly recommended after meals. This would eliminate both bacterial plaque and food impaction and shorten the duration of sucrose impact. In addition, brushing after meals will enhance the maintenance of high fluoride levels in the oral cavity for a long time, particularly at night with the lessened salivary flow during sleeping. Eating immediately after brushing reduced the salivary fluoride level by about 12-15 times compared with brushing alone (Sjögren and Birkhed, 1994). Leaving the fluoride on the teeth, and avoiding eating or drinking for 10 minutes or more after brushing is encouraged. An evidence-based toolkit for prevention strongly recommends brushing last thing at night (or before bedtime) and on one other occasion (Public Health England, 2021).

6. Brushing time

A short-term usage study on brushing times of 30, 45, 60, 120, and 180 seconds suggests that both brushing time and toothpaste quantity may be important determinants of fluoride retention in the oral cavity and consequent enamel remineralization (Zero et al., 2010). A longer brushing time increased fluoride concentrations in saliva for at least two hours after the conclusion of brushing, showing that increased contact time promoted fluoride retention in the oral cavity. Although none of the paired comparisons at different brushing times of either percentage of SMHR or EFU was significant, there was a significant positive linear relationship between brushing time and both percentage SMHR ($p=0.048$) and EFU ($p=0.040$) across 30-180 seconds of brushing. Increasing the time of brushing with higher retention of fluoride tends to promote remineralization of very early caries lesions. A study comparing the effects of 40 seconds versus 2 minutes of brushing on saliva and dental biofilm fluid fluoride in children ages 4–5 years over 1 hour showed the fluoride delivery benefits of 2 minutes of brushing in children (Newby et al., 2013). Scotland's Child Smile Programme recommends tooth brushing with fluoride toothpaste for at least two minutes (Scottish Dental Clinical Effectiveness Programme, 2010).

7. Post-brushing rinsing behaviours

When finishing brushing teeth and gums, a mouthful of toothpaste paste slurry forms. Common practice is to avoid the ingestion of the toothpaste slurry and to remove the strong minty taste depending on the toothpaste by rinsing and gargling with water. Several studies in the 1990s showed that post-rinsing with large volumes of water caused the reduction of fluoride levels and thus had less effect on caries prevention (Chesters et al., 1992; Sjögren et al., 1995; O'Mullane et al., 1997; Chestnut et al., 1998; Ashley et al., 1999). Pitts and others (2012) reviewed the evidence on the impact of post-brushing behaviours reducing or enhancing dental caries. They found a lack of high-quality evidence to support any definitive guidance and recommended prioritizing more research. While this study did not find the highest quality evidence, based on plausibility and mechanisms involved, consensus expert opinions state that rinsing with water after brushing with fluoride toothpaste can reduce the benefit of fluoride toothpaste and 'spit don't rinse', or that rinsing with a slurry of fluoride toothpaste and saliva could retain more fluoride and thus be beneficial for caries control at the individual level. Those who actively used a sip of water and the toothpaste slurry left after brushing as a mouth rinse for one minute had a further reduction in caries. The incidence of approximal caries was reduced by 26% in those who used the above method (Sjögren et al., 1995). In a Saudi Arabian 2-year clinical trial (Sonbul and Birkhed, 2010) the test group was provided with fluoride toothpaste and instructed to use a 'modified fluoride toothpaste' technique as follows: brush for two minutes with 2 cm toothpaste; swish the toothpaste slurry around the dentition with active movements of the cheeks, lips, and tongue, forcing the slurry into the approximal area for about half a minute, before spitting it out; and no post-brushing rinsing and no eating/drinking for two hours. The control group was instructed to continue using their regular fluoride toothpaste twice a day with no further instructions. This practice benefited the test group, which had fewer proximal lesions compared with the control group. The EAPD guidelines state that avoiding post-brushing rinsing with a lot of water is good practice (Toumba et al., 2019). An evidence-based toolkit (Public Health England, 2021) and Scottish guidelines (SIGN 14, 2014) strongly recommend spitting out after brushing rather than rinsing. In addition, the Australian fluoride guidelines and the NZ oral health clinical advisory network also recommend the same (Oral Health Clinical Advisory Network, 2019).

8. Supervised tooth brushing in children

A randomised controlled trial in the United Kingdom investigated the efficacy of a supervised tooth brushing programme for the period of 30-months in 5-year-old children (Pine et al., 2007). In this study, the intervention group received supervised tooth brushing once a day at school with 1000 ppm fluoride toothpaste and a home support package encouraging twice-daily tooth brushing. The comparison group did not brush their teeth at school or receive the home support package. Children were examined every 6 months during the trial, then at 6, 18, 30, and 54 months, when the children were aged 12 years. The intervention group developed significantly less dental caries (D3FS caries increment 1.62) in the permanent molars rather than in the non-intervention group (D3FS caries increment 2.65, $p<0.05$). Higher caries reductions (Protected Fraction 23.3%) were recorded in studies with supervised tooth brushing compared with non-supervised (Twetman et al., 2003). There is strong evidence supporting the effectiveness of supervised tooth brushing (SIGN, 2014; Public Health England, 2021; Twetman et al., 2009) and that toothpaste-swallowing and eating/licking habits during tooth development increase fluorosis (Do and Spencer, 2007). For this reason, children under 7 years need to be assisted or supervised with tooth brushing. The NZ guidelines recommend supervising children when brushing with fluoride toothpaste (New Zealand Guidelines Group, 2009).

Table 1. Comparison of the New Zealand guidelines (2009) on fluoride toothpaste with the proposed changes emerging from the updated evidence.

Brushing Habits	Age range	New Zealand guidelines (2009)	Updated evidence	
			Low caries risk	High caries risk*
Toothpaste fluoride concentration				
	0-6 years	Use toothpaste containing at least 1000 ppm fluoride although toothpaste with less than 1000 ppm may be considered for children with low caries-risk	Use toothpaste containing at least 1000 ppm fluoride	May use toothpaste containing 1350 to 1500 ppm fluoride
	7+ years	Use toothpaste containing at least 1000 ppm fluoride	Use toothpaste containing 1350 to 1500 ppm fluoride	
	10+ years			May use toothpaste containing 2800 ppm fluoride
	16+ years			May use toothpaste containing 2800 or 5000 ppm fluoride
Fluoride toothpaste amount				
	0-2 years	Use a smear	Use a smear or rice grain amount	Use a smear or rice grain amount
	3-5 years	Use a smear	Use a pea-sized amount	Use a pea-sized amount
	6+ years	Use a pea-sized amount	May use up to the full length of brush (1-2 cm)	May use up to the full length of brush (1-2 cm)
Brushing duration				
	0+ years		At least two minutes	At least two minutes
Post-brushing rinsing with water				
	0+ years		Spit slurry without rinsing	Spit slurry without rinsing
Brushing frequency				
	0+ years	Twice daily	Twice daily	Twice daily
Brushing assistance/supervision				
	0-6 years	Children should be assisted/ supervised	Children should be assisted/ supervised	Children should be assisted/ supervised
Eating or swallowing toothpaste				
	0+ years	Should be avoided	Should be avoided	Should be avoided

Note: * Should seek the advice of a dental professional before using toothpaste with high fluoride (more than 1500 ppm) concentration.

Table 2. Proposed changes to current fluoride toothpaste guidelines based on updated evidence.

Age range	Fluoride concentration		Amount	Instructions
	Low caries risk	High caries risk*		
0-2 years	Use toothpaste containing at least 1000 ppm fluoride	Use toothpaste containing at least 1350 ppm to 1500 ppm fluoride	Use a smear or rice grain amount	Commence brushing with fluoride toothpaste as soon as they erupt and continue brushing regularly. Brush all surfaces of teeth twice daily with fluoride toothpaste for at least 2 minutes after dinner, before bedtime, and once more, preferably after breakfast. Parent/caregiver brushes the teeth Teach: not to swallow, spit out the slurry, and not rinse with water.
3-6 years			Use a pea-sized amount	Brush all surfaces of teeth twice daily with fluoride toothpaste for at least 2 minutes after dinner, before bedtime, and once more, preferably after breakfast. Parents/caregivers supervise brushing and assist. Do not swallow; spit out the slurry; do not rinse with water.
7+ years	Use toothpaste containing 1350 ppm to 1500 ppm fluoride		May use up to the full length of brush (1-2 cm)	Brush all surfaces of teeth twice daily with fluoride toothpaste daily for at least 2 minutes after dinner, before bedtime, and once more, preferably after breakfast. Do not swallow; spit out the slurry; do not rinse with water
10+ years		May use a toothpaste containing 2800 ppm fluoride		
16+ years		May use a toothpaste containing 2800 or 5000 ppm fluoride		

Note: *All children, adolescents, and adults with high caries risk should seek the advice of a dental professional before using toothpaste with high fluoride (more than 1500 ppm) concentration. Toothpaste with 2800 ppm fluoride toothpaste is not available in New Zealand.

Dental professionals need to advise the public to choose a fluoride toothpaste with recommended levels of fluoride labelled in ppm.

Continue studies on the prevalence of dental fluorosis in children and the total intake of fluoride in different age groups at regular intervals.

Discussion

The evidence has developed to warrant an update to the NZ guidelines, with respect to recommended fluoride toothpaste concentrations and amounts for those with low and high risk for caries at different age ranges, together with more detail on brushing duration and post-brushing rinsing. It is time for oral health promotion to include the best evidence-based refinements to ensure maximum protection against caries.

An NZ study conducted via an online sample of parents and caregivers of pre-schoolers showed that only 19% of the pre-schoolers in the sample used the full-strength type of toothpaste (Li et al., 2016). The findings of this survey highlight the need for advice on toothpaste choices for preschool children. Several brands of imported toothpaste are available in NZ; with and without fluoride; fluoride toothpaste with varying levels of fluoride; and toothpaste with low levels of fluoride. Packages and/or tubes of a few toothpaste brands marketed in NZ are labelled with ppm fluoride and percentage in small prints. On the packages of some brands, the message 'not to use in children under 6 years' is printed. This makes choosing toothpaste with the recommended levels of fluoride challenging and confusing for the public, particularly for parents and caregivers of young children. To encourage the use of fluoride toothpaste with 1000 ppm fluoride in children, dental professionals should continue to advise the public to choose a fluoride toothpaste that shows the fluoride concentration in ppm on the package and not to use toothpaste with low levels of fluoride, instead to use a smear of toothpaste containing 1000 ppm of fluoride. Medical practitioners, community pharmacies, primary healthcare workers, maternity services, practice nurses, public health nurses, Well Child Tamariki Ora providers, and Community Oral Health Services around the country need to be notified of the recommendation regarding the use of toothpaste with 1000 ppm fluoride in children. Parents and caregivers need to be advised not to use low fluoride toothpaste or non-fluoride toothpaste because of their ineffectiveness in reducing caries. Dental professionals and groups need to lobby the government to increase the excise tax on low fluoride toothpaste and on non-fluoride toothpaste.

The recommendations of the Australian guidelines on the use of fluoride toothpaste are different from those of the NZ guidelines, and those based on updated evidence (Tables 1 and 2) (Do, 2020). The Australian guidelines take into account the levels of fluoride in water; around 89%

of Australians (National Health and Medical Research Council, 2017), compared with slightly more than half of New Zealanders, have access to fluoridated drinking water (Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand., 2014). Fluoride levels in fluoridated water in Australia are within the range of 0.6 to 1.1 mg/L and the levels of fluoride in fluoridated water in NZ are between 0.7 and 1.0 mg/L. In addition to fluoridated water, some Australian drinking water supplies, particularly those relying on bore water, contain naturally occurring fluoride at a concentration of around 0.5 mg/L. The natural fluoride level in NZ water is ~0.1-0.2 mg/L. Further, an increase in dental fluorosis rates in Australia in the 1980s was associated with the addition of fluoride to toothpaste and the use of other fluoride-containing products such as supplements in the form of drops or tablets (National Health and Medical Research Council, 2017). The Australian guidelines recommend no fluoride toothpaste up to the age of 17 months; a small pea-sized amount of toothpaste containing 500-550 ppm fluoride for children aged from 18 months to 5-years; and toothpaste containing 1000-1500 ppm fluoride for those aged 6-years and above (Do, 2020). Unless recommended by a dental professional, toothpaste containing 1000-1500 ppm fluoride is not recommended for children under 6 years of age. These differences underscore the need to have NZ-specific guidelines.

Dental fluorosis is used as the key measure of excess fluoride intake and dental caries as the measure of fluoride adequacy. Excessive exposure to fluoride, while teeth are forming in the first 8 years of life causes dental fluorosis. Studies conducted in NZ showed that the prevalence of diffuse enamel opacities that may be fluoride-related has not increased over time and that all cases recorded were either mild or very mild (Mackay and Thomson, 2005: Kanagaratnam et al., 2009). Furthermore, the national oral health survey found a very low overall prevalence of moderate fluorosis among people aged 8-30 years (Ministry of Health, 2010). The 2021 report of the Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand on the health effects of water fluoridation indicates that there are no adverse effects of fluoride of any significance arising from fluoridation at the levels used in NZ except for minimal fluorosis, and the use of fluoridated toothpaste does not change these conclusions or obviate the recommendations. Similar studies need to check on the prevalence of dental fluorosis due to high ingestion of fluoride at a young age. Young children have relatively poor control over their swallowing reflexes and are likely to swallow toothpaste during tooth brushing. For this reason, children need to be assisted or supervised with tooth brushing. A report on oral health in England concluded that the risk of fluorosis from ingesting too much fluoride is linked more to the amount of toothpaste that is used, rather than to the fluoride concentration in the toothpaste (Public Health England, 2014). With the use of the recommended size and concentration of fluoride toothpaste according to the age group and with supervised brushing, any chances of children swallowing excess toothpaste could be avoided. The evidence that starting the use of fluoride toothpaste in children under 12 months of age may be associated with an increased risk of fluorosis is weak and unreliable (Wong et al., 2010), and the evidence for its use between the ages of 12 and 24 months is equivocal. If the risk of fluorosis is of concern, this should also be balanced with the risk of caries in that individual case before recommending lower than 1000 ppm fluoride toothpaste for young children (under 6 years of age).

An expert working group (Expert Working Group for Fluoride, 2017) estimated the Australian and NZ nutrient reference values for fluoride based on data on water and food consumption and the body weights of various age groups. In setting reference values, an adequate intake level (high enough to prevent dental caries) and an upper level (not high enough to cause dental fluorosis) have been recommended. These levels play an important role in preventing dental caries, fluorosis, and any other health effects. A study by Cressey and colleagues (2010) estimated fluoride intakes from diet and toothpaste use, for NZ sub-groups (6-12-month-old infants, 1-3-year-old toddlers, 4-6-year-old children, 11-14-year-old children, 19-24-year-old males, and adults aged ≥25 years, using existing fluoride concentration and consumption data. The results showed that the estimates of fluoride intake from the diet and toothpaste did not identify any groups at risk of exceeding the upper level of intake, except for infants (6-12 months) living in areas with fluoridated water supplies and using high-fluoride toothpaste. This study further reported that much of the adult population may be receiving insufficient fluoride for optimum caries protection from these sources, as represented by the adequate intake. Infants fully formula-fed on formulae prepared with optimally fluoridated water have a high probability of exceeding the upper level for fluoride and are at an increased risk of dental fluorosis (Creesey, 2010). If there is a concern about the risk of mild fluorosis, low-fluoride bottled water can be used for reconstitution in order to reduce fluoride exposure in this age group. A cross-sectional, multi-centre study among adolescents aged 15-18 years showed that most did not consume the recommended adequate intake of fluoride and no participant consumed more than the upper limit for fluoride (Shahin, 2021). All these studies show that the ingestion of fluoride from toothpaste, food, and water is within safe levels. There is a lack of data on the use of actual fluoride toothpaste and other supplements in NZ. Continuation of studies looking at the average total intake of fluoride from all sources is essential in the future to ensure safety.

While this review was extensive, it nonetheless has weaknesses. Although systematically undertaken, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were not used for reporting. While careful in identifying appropriate literature, the reliance on a single database (PubMed) and the use of non-MeSH terms may have missed some relevant literature. Moreover, relevant articles which are

non-English, non-refereed, and outside of time period, and unidentified grey literature may have been missed. The thematic analysis was framed and initially guided by the Cochrane review and the NZ guidelines – which may have biased/prejudiced some of the themes. Therefore, methodologically, this review might better be characterised as a narrative rather than strictly a systematic review of the literature. Future updates might benefit from adhering to the PRISMA guidelines.

Conclusion

The latest evidence suggests the adoption of additional behaviours such as using the recommended fluoride toothpaste concentrations and amounts for those with a higher and lower risk for caries at different age ranges, together with more detail on brushing duration and post-brushing rinsing, would provide the greatest protection against dental caries. Policymakers may look into this latest scientific evidence and review the guidelines accordingly.

References

American Dental Association Council on Scientific Affairs. (2014). Fluoride toothpaste use for young children *Journal of American Dental Association.* 145(2):190-191. doi: 10.14219/jada.2013.47

Ashley FP, Attrill DC, Ellwood RP, Worthington HV, Davies RM. (1999). Tooth brushing habits and caries experience. *Caries Research.* 33(5):401-402. doi: 10.1159/000016540

Cahen PM, Frank RM, Turlot JC, Jung MT. (1982). Comparative unsupervised clinical trial on caries inhibition effect of monofluorophosphate and amine fluoride dentifrices after 3 years in Strasbourg, France. *Community Dentistry and Oral Epidemiology.* 10(5):238-241. doi: 10.1111/j.1600-0528.1982.tb00386.x.

Chesters RK, Huntington E, Burchell CK, Stephen KW. (1992). Effect of oral care habits on caries in adolescents. *Caries Research.* 26(4):299-304. doi: 10.1159/000261456

Chestnutt IG, Schäfer F, Jacobson AP, Stephen KW. (1998). The influence of tooth brushing frequency and post-brushing rinsing on caries experience in a caries clinical trial. *Community Dentistry and Oral Epidemiology.* 26(6):406-411. doi: 10.1111/j.1600-0528.1998.tb01979.x

Clark MB, Keels MA, Slayton RL. (2020). Section on oral health. Fluoride use in caries prevention in the primary care setting. *Pediatrics*. 146(6):e2020034637. doi: 10.1542/peds.2020-034637

Cressey P, Gaw S, Love J. (2010). Estimated dietary fluoride intake for New Zealanders. *Journal of Public Health Dentistry*. 70(4):327-336. doi: 10.1111/j.1752-7325.2010.00192.x

Cressey P. (2010). Dietary fluoride intake for fully formula-fed infants in New Zealand: impact of formula and water fluoride. *Journal of Public Health Dentistry*. 70(4):285-291. doi: 10.1111/j.1752-7325.2010.00183.x

Creeth J, Zero D, Mau M, Bosma ML, Butler A. (2013a). The effect of dentifrice quantity and tooth brushing behaviour on oral delivery and retention of fluoride in vivo. *International Dental Journal.* 63(Suppl2):14-24. doi: 10.1111/idj.12075

Creeth J, Bosma ML, Govier K. (2013b). How much is a 'pea-sized amount'? A study of dentifrice dosing by parents in three countries. *International Dental Journal.* 63(Suppl2):25-30. doi: 10.1111/idj.12074

Creeth JE, Kelly SA, González-Cabezas C, Karwal R, Martinez-Mier, EA, Lynch RJM, Bosma, ML, Zero DT. (2016). Effect of tooth brushing duration and dentifrice quantity on enamel remineralisation: an *in situ* randomized clinical trial. *Journal of Dentistry.* 55:61-67. doi: 10.1016/j.jdent.2016.10.003

Do LG, Spencer AJ. (2007). Risk-benefit balance in the use of fluoride among young children. *Journal of Dental Research*. 86(8):723-728. doi: 10.1177/154405910708600807

Do LG; Australian Research Centre for Population Oral Health. (2020). Guidelines for use of fluorides in Australia: update 2019. *Australian Dental Journal*. 65(1):30-38. doi: 10.1111/adj.12742

dos Santos AP, Nadanovsky P, de Oliveira BH. (2013). A systematic review and meta-analysis of the effects of fluoride toothpastes on the prevention of dental caries in the primary dentition of preschool children. *Community Dentistry and Oral Epidemiology.* 41(1):1-12. doi: 10.1111/j.1600-0528.2012.00708.x

Duckworth RM, Morgan SN, Burchell CK. (1989). Fluoride in plaque following use of dentifrices containing sodium monofluorophosphate. *Journal of Dental Research*. 68(2):130-133. doi: 10.1177/00220345890680020601

Einarsdottir KG, Bratthall D. (1996). Restoring oral health. On the rise and fall of dental caries in Iceland. *European Journal of Oral Sciences.* 104(4(Pt 2)):459-469. doi: 10.1111/j.1600-0722.1996.tb00113.x

Expert Working Group for Fluoride; Baines J, Foley M, Spencer AJ, Peres M, Mueller U, Do L, Cunningham J, Gnanamanickam E, Amarasena N. (2017). *Australian and New Zealand Nutrient Reference Values for Fluoride: A report prepared for the Australian Government Department of Health and the New Zealand Ministry of Health*. Canberra: Department of Health Commonwealth of Australia.

FDI World Dental Federation. (2019). Promoting oral health through fluoride toothpaste. *International Dental Journal*. 69(1):17-18. doi: 10.1111/idj.12469

Featherstone JD. (1999). Prevention and reversal of dental caries: role of low level fluoride. *Community Dentistry and Oral Epidemiology.* 27(1):31-40. doi: 10.1111/j.1600-0528.1999.tb01989.x

Hobbs M, Marek L, Clarke R, McCarthy J, Tomintz M, Wade A, Campbell M, Kingham S. (2020). Investigating the prevalence of non-fluoride toothpaste use in adults and children using nationally representative data from New Zealand: a cross-sectional study. *British Dental Journal*. 228(4):269-276. doi: 10.1038/s41415-020-1304-5

Ishizuka Y, Lehrkinder A, Nordström A, Lingström P. (2020). Effect of different toothbrushing routines on interproximal fluoride concentration. *Caries Research*. 54(4):343-349. doi: 10.1159/000510181

Kanagaratnam S, Schluter P, Durward C, Mahood R, Mackay T. (2009). Enamel defects and dental caries in 9-year-old children living in fluoridated and nonfluoridated areas of Auckland, New Zealand. *Community Dentistry and Oral Epidemiology*. 37(3):250-259. doi: 10.1111/j.1600-0528.2009.00465.x.

Kanagaratnam S, Schluter PJ. (2019). A review of early childhood caries, risk factors and preventive strategies. *New Zealand Dental Journal.* 115(4):132-150.

Kumar S, Tadakamadla J, Johnson NW. (2016). Effect of toothbrushing frequency on incidence and increment of dental caries: a systematic review and meta-analysis*. Journal of Dental Research*. 95(11):1230-1236. doi: 10.1177/0022034516655315

Li J, Dallas S, McBride-Henry K. (2016). Use of full strength fluoride toothpaste among preschoolers in New Zealand, and factors determining toothpaste choice. *New Zealand Medical Journal*. 129(1436):44-51.

Mackay TD, Thomson WM. (2005). Enamel defects and dental caries among Southland children. *New Zealand Dental Journal.* 101(2): 35-43.

Marinho VC, Higgins JP, Sheiham A, Logan S. (2003). Fluoride toothpastes for preventing dental caries in children and adolescents. *Cochrane Database of Systematic Reviews*. 2003(1):CD002278. doi: 10.1002/14651858.CD002278

Ministry of Health. (2010). *Our Oral Health: Key Findings of the 2009 New Zealand Oral Health Survey*. Wellington: Ministry of Health.

National Health and Medical Research Council (NHMRC). (2017). Information paper – Water fluoridation: dental and other human health outcomes, report prepared by the Clinical Trials Centre at University of Sydney. Canberra: NHMRC.

Newby EE, Martinez-Mier EA, Zero DT, Kelly SA, Fleming N, North M, Bosma ML. (2013). A randomised clinical study to evaluate the effect of brushing duration on fluoride levels in dental biofilm fluid and saliva in children aged 4-5 years. *International Dental Journal*. 63(Suppl2):39-47. doi: 10.1111/idj.12072

New Zealand Guidelines Group. (2009). *Guidelines for the Use of Fluorides*. Wellington: Ministry of Health.

Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand. (2014). *Health Effects of Water Fluoridation: A Review of the Scientific Evidence*. Wellington and Auckland: Office of the Prime Minister's Chief Science Advisor and the Royal Society of New Zealand.

Office of the Prime Minister's Chief Science Advisor. (2021). *Fluoridation: An Update on Evidence.* Auckland: Office of the Prime Minister's Chief Science Advisor. https://www.pmcsa.ac.nz/topics/fluoridation-an-update-on-evidence/ (accessed 31 March 2022).

O'Mullane DM, Kavanagh D, Ellwood RP, Chesters RK, Schafer F, Huntington E, Jones PR. (1997). A three-year clinical trial of a combination of trimetaphosphate and sodium fluoride in silica toothpastes. *Journal of Dental Research*. 76(11):1776-1781. doi: 10.1177/00220345970760110901

Oral Health Clinical Advisory Network (OHCAN). (2019). *Clinical Guidelines for Child and Adolescent Oral Health Prevention*. OHAN. http://nzohcan.org.nz/ (accessed 31 March 2022).

Peres MA, Macpherson LMD, Weyant RJ, Daly B, Venturelli R, Mathur MR, Listl S, Celeste RK, Guarnizo-Herreño CC, Kearns C, Benzian H, Allison P, Watt RG. (2019). Oral diseases: a global public health challenge. *Lancet*. 394(10194):249-260. doi: 10.1016/S0140-6736(19)31146-8

Pine CM, Curnow MM, Burnside G, Nicholson JA, Roberts AJ. (2007). Caries prevalence four years after the end of a randomised controlled trial. *Caries Research*. 41(6):431-436. doi: 10.1159/000104800

Pitts N, Duckworth RM, Marsh P, Mutti B, Parnell C, Zero D. (2012). Post-brushing rinsing for the control of dental caries: exploration of the available evidence to establish what advice we should give our patients. *British Dental Journal*. 212(7):315-320. doi: 10.1038/sj.bdj.2012.260

Public Health England. (2021). *Delivering Better Oral Health: an Evidence-based Toolkit for Prevention* (4th edition). London: UK Government. https://www.gov.uk/government/publications/delivering-better-oral-health-an-evidence-based-toolkit-for-prevention (accessed 31 March 2022).

Reintsema H, Arends J. (1987). Fluoridating efficiency of several fluoride-containing dentifrice systems in vivo. *Caries Research*. 21(1):22-28. doi: 10.1159/000260998

Santos AP, Oliveira BH, Nadanovsky P. (2013). Effects of low and standard fluoride toothpastes on caries and fluorosis: systematic review and meta-analysis. *Caries Research*. 47(5):382-390. doi: 10.1159/000348492

Saporito RA, Boneta AR, Feldman CA, Cinotti W, Sintes JL, Stewart B, Volpe AR, Proskin HM. (2000). Comparative anticaries efficacy of sodium fluoride and sodium monofluorophosphate dentifrices. A two-year caries clinical trial on children in New Jersey and Puerto Rico. *American Journal of Dentistry*. 13(4):221-226.

Scottish Dental Clinical Effectiveness Programme (SDCEP). (2018). *Prevention and Management of Dental Caries in Children* (2nd edition). Dundee: SDCEP. https://www.sdcep.org.uk/published-guidance/caries-in-children/ (accessed 31 March 2022).

Scottish Intercollegiate Guidelines Network (SIGN). (2014). *Dental Interventions to Prevent Caries in Children*. Edinburgh: SIGN. http://www.sign.ac.uk (accessed 31 March 2022).

Shahin A. (2020). *The Fluoride Intake from Diet, Water, and Toothpaste of New Zealand Adolescents*. Dunedin: University of Otago.

Sjögren K, Birkhed D. (1993). Factors related to fluoride retention after toothbrushing and possible connection to caries activity. *Caries Research*. 27(6):474-477. doi: 10.1159/000261583

Sjögren K, Birkhed D. (1994). Effect of various post-brushing activities on salivary fluoride concentration after toothbrushing with a sodium fluoride dentifrice. *Caries Research*. 28(2):127-131. doi: 10.1159/000261633

Sjögren K, Birkhed D, Ruben J, Arends J. (1995). Effect of post-brushing water rinsing on caries-like lesions at approximal and buccal sites. *Caries Research*. 29(5):337-342. doi: 10.1159/000262089

Sonbul H, Birkhed D. (2010). The preventive effect of a modified fluoride toothpaste technique on approximal caries in adults with high caries prevalence. A 2-year clinical trial. *Swedish Dental Journal*. 34(1):9-16.

Stookey GK, DePaola PF, Featherstone JD, Fejerskov O, Möller IJ, Rotberg S, Stephen KW, Wefel JS. (1993). A critical review of the relative anticaries efficacy of sodium fluoride and sodium monofluorophosphate dentifrices. *Caries Research*. 27(4):337-360. doi: 10.1159/00026156

Toumba KJ, Twetman S, Splieth C, Parnell C, van Loveren C, Lygidakis NA. (2019). Guidelines on the use of fluoride for caries prevention in children: an updated EAPD policy document. *European Archives of Paediatric Dentistry*. 20(6):507-516. doi: 10.1007/s40368-019-00464-2

Twetman S, Axelsson S, Dahlgren H, Holm AK, Källestål C, Lagerlöf F, Lingström P, Mejàre I, Nordenram G, Norlund A, Petersson LG, Söder B. (2003). Caries-preventive effect of fluoride toothpaste: a systematic review. *Acta Odontologica Scandinavica*. 61(6):347-355. doi: 10.1080/00016350310007590

Twetman S. (2009). Caries prevention with fluoride toothpaste in children: an update. *European Archives of Paediatric Dentistry*. 10(3):162-167. doi: 10.1007/BF03262678

Volpe AR, Petrone ME, Davies R, Proskin HM. (1995). Clinical anticaries efficacy of NaF and SMFP dentifrices: overview and resolution of the scientific controversy. *Journal of Clinical Dentistry*. 6(Spec No):1-28.

Walsh T, Worthington HV, Glenny AM, Appelbe P, Marinho VC, Shi X. (2010). Fluoride toothpastes of different concentrations for preventing dental caries in children and adolescents. *Cochrane Database of Systematic Reviews*. (1):CD007868. doi: 10.1002/14651858.CD007868.pub2

Walsh T, Worthington HV, Glenny AM, Marinho VC, Jeroncic A. (2019). Fluoride toothpastes of different concentrations for preventing dental caries. *Cochrane Database of Systematic Reviews*. 3(3):CD007868. doi: 10.1002/14651858.CD007868.pub3

Wong MC, Glenny AM, Tsang BW, Lo EC, Worthington HV, Marinho VC. (2010). Topical fluoride as a cause of dental fluorosis in children. *Cochrane Database of Systematic Reviews*. 2010(1):CD007693. doi: 10.1002/14651858.CD007693.pub2

Wright JT, Hanson N, Ristic H, Whall CW, Estrich CG, Zentz RR. (2014). Fluoride toothpaste efficacy and safety in children younger than 6 years: a systematic review. *Journal of the American Dental Association*. 145(2):182-189. doi: 10.14219/jada.2013.37

Zero DT, Creeth JE, Bosma ML, Butler A, Guibert RG, Karwal R, Lynch RJ, Martinez-Mier EA, González-Cabezas C, Kelly SA. (2010). The effect of brushing time and dentifrice quantity on fluoride delivery in vivo and enamel surface microhardness in situ. *Caries Research*. 44(2):90-100. doi: 10.1159/000284399

Author details

Sathananthan Kanagaratnam BDS, DDPHRCS (England), MComDent (Otago), FICD
Dental Public Health Specialist
Corresponding author: Satha.thiru@hotmail.com

Philip J. Schluter BSc (Hons.), MSc, PhD

Kura Mātai Hauora | School of Health Sciences
Te Kāhui Pā Harakeke | Child Well-being Research Institute
Te Whare Wānanga o Waitaha | University of Canterbury
Christchurch, New Zealand

Acknowledgment

We gratefully acknowledge Dr. Pauline Koopu for her advice and support.

The authors contributed similarly to the manuscript and are in agreement with the content of the paper. The authors deny any conflicts of interest related to the study.