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# Important considerations in the development of toothpaste formulations for children

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A number of factors should be taken into account when designing toothpaste formulations for use by children at the different stages of their development. While adult toothpaste formulations may provide caries prevention benefits for children at risk of caries, these formulations may also contain higher levels of abrasive in order to address the staining needs of the adult population owing to smoking and the consumption of dietary chromogens such as coffee and tea, which are not normally found in the diet of children. While toothpastes formulated for adults are also likely to contain higher concentrations of surfactant and flavour, many children prefer toothpastes with mild flavours and modest foaming characteristics. An ideal children's toothpaste formulation should therefore aim to maximise fluoride availability, with appropriate abrasivity, while still delivering effective cleaning, as well as levels and types of flavour and surfactant to provide an acceptable brushing experience. Selection of toothpaste flavour types for children of different ages should ideally be based directly upon preference data from children. Flavours perceived as pleasant during brushing studies have been linked to increased brushing time, which, in turn, can increase the delivery and efficacy of fluoride from toothpastes. Therefore, manufacturers select tested, child-friendly flavours to maximise compliance, providing a more pleasurable brushing experience and oral health benefits.

***Key words:*** *Toothpaste, formulation, children, fluoride*

## INTRODUCTION

Primary teeth are not 'practice teeth' and much harm can be done in thinking of them in this way, both in terms of efforts to establish good oral care habits and behaviours, and in terms of the real and long-term damage that can result if these teeth are not properly cared for[1–4]. Significant physiological and structural differences exist between the primary and developing permanent teeth of children and between fully matured adult permanent teeth[5–12]. The needs of children and children's dentition as they develop and mature should therefore be taken into account when formulating toothpaste for children.

Previous scientific investigation and discussion around the use and design of toothpaste formulations for children has, for the most part, focused on fluoride and the importance of dose[13–15]. This is not unexpected; it is important to avoid too much fluoride in order to reduce the risk of fluorosis in developing permanent teeth, especially in less deprived, low caries communities and in regions where there is a greater risk of exposure to fluoride from other sources[13,16,17]. It is equally important to ensure a sufficient and available dose of fluoride from the formulation to convey a caries prevention benefit, especially to those at greater risk of developing caries[18]. Aside from work relating to fluoride, the literature covering toothpaste formulations designed for children appears to have been limited to investigations into format preferences[19] and to the visual appeal and the taste of toothpaste[20,21]. This has shown that child-specific flavours and product design encourages usage by children, but other studies have shown that this can pose a risk of increased fluoride intake because of swallowing when compared with a regular flavoured toothpaste[13,16,22–24]. Non child-specific studies have shown that flavour development should also be concerned with the impact that flavour may have on fluoride delivery and retention in the mouth[25].

It is also important to carefully consider the selection of other toothpaste ingredients, even though these have not been investigated with specific reference to formulation design for children. For example, silicas and polyphosphates have been shown to have an impact on fluoride delivery and retention[26–28] and can

have an influence upon cleaning efficacy, abrasivity, dispersability in the mouth and upon the potential to irritate oral soft tissue[29,30].

When taking all these factors into consideration, while children can use adult toothpastes, the oral care needs of children can be better met by using toothpaste formulations that have been developed for their needs, even when the fluoride dose is limited appropriately by using a pea sized amount of adult toothpaste[31]. A more holistic approach to children's formulation design and development is therefore desirable. Such an approach is discussed below, with the pros and cons of various formulation components and ingredients considered and balanced to give the building blocks of formulations that are well suited to the different developmental stages of children and of children's developing dentition.

## FORMULATION DESIGN AND DEVELOPMENT

A typical toothpaste formulation contains a number of ingredients, each with their own purpose and each with the potential to influence the performance and behaviour of the other ingredients in the formulation. These are categorised by purpose and summarised below, along with examples.

## THICKENERS

Thickeners give structure and stability to the toothpaste and have a major effect on toothpaste consistency during application to the toothbrush and afterwards during use. The consistency of the toothpaste should ideally be balanced such that it can be readily squeezed from the tube in a controlled way but then remain relatively firm and cohesive on the brush and not flow or fall off too easily. This is especially true for a children's toothpaste where the child is learning new oral care skills and manual dexterity is developing[32]. Toothpaste consistency can also affect how easy it is to achieve the recommended pea-sized dose; a stringy toothpaste with poor 'cut-off' will be more difficult to dose in a measured way. Thickeners are often used in combination to give an acceptable consistency, with gums such as xanthan or carrageenan being used together with thickening silicas to achieve the desired results.

## HUMECTANTS

Humectants act primarily to help water retention within the toothpaste formulation over time and, as with thickeners, also affect longer-term toothpaste stability and toothpaste consistency during use. Water is one of the main ingredients of most toothpastes and is important for effective fluoride delivery. In addition to this, good water retention will usually give gloss or shine to the formulation and give a more appealing texture to the toothpaste within the mouth. Taking into account the possibility of leaving the cap off of a toothpaste tube, which may dry the paste, prevention of water loss over time is important both functionally and cosmetically. Humectants such as glycerol, sorbitol and polyethylene glycol are typically used to achieve this; all of these have been used for many years in toothpaste formulations for adults and children. These ingredients often also serve other functions in the toothpaste, as most convey some level of sweetness, which is important in compatibility with the flavours for a children's toothpaste.

## SURFACTANTS

Surfactants provide foam during brushing, which helps with wetting of the tooth surfaces, dispersion of the toothpaste in the mouth and with loosening of debris and plaque from tissues of the mouth[33]. Choice of surfactant type and concentration for toothpaste is important so as to minimise any potential for irritation of oral soft tissue[30,34], and to minimise any negative affect on fluoride availability[25,27] (see also fluoride section below). Surfactants typically used in toothpaste are sodium lauryl sulphate (SLS), cocamidopropyl betaine (tego betain) and sodium methyl cocoyl taurate (adinol). Of these, tego betain is a zwitterionic surfactant with no overall charge and as such it is the most suitable for use in a formulation designed for young children as it produces a modest amount of foam when compared with other surfactants. Based on sensory testing, tego betain has a somewhat bitter aftertaste. This may pose a problem for taste acceptability, especially given that young children have been reported to be more sensitive to bitterness than adults[35,36] (see also the section Flavours and Sweeteners below). Combinations of surfactants are often used in order to balance the properties and concentrations of different surfactants in a formulation, so one solution to this problem would be to use tego betain in combination with another surfactant such as adinol or SLS in order to reduce the impact of the bitterness, but still maintain a lower foaming surfactant system appropriate for use with young children.

The relative amounts of foam generated during brushing by formulations containing different surfactants will depend largely upon surfactant concentration and upon the presence or absence of other formulation ingredients that may enhance or inhibit foam formation and duration[37]. Different foam properties can also result from different surfactant combinations based upon their molecular packing within the air–solvent interface. In laboratory testing, a combination of tego

betain and adinol will tend to give a creamier, denser foam whereas a combination of tego betain and SLS will tend to give a more expansive open foam. The choice of which combination to use and in what ratio to combine them will depend on the desired formulation design for any given toothpaste. For younger children, low levels of foam from a mild surfactant system are probably most appropriate, but for older children (about 6–12 years of age) with mixed dentition, having a higher level of foam is more desirable to move them into an adult-type paste.

## ABRASIVES

Much of the physical cleaning action during tooth brushing, including removal of plaque and stained pellicle, comes from the use of the toothbrush in combination with abrasive particles in the toothpaste formulation[38–40]. This cleaning action can vary greatly between different toothpaste formulations and improvements in stain removal, shine and polish can be achieved to a greater or lesser degree depending upon the type, morphology and particle size distribution of the abrasive used[41–44]. Other formulation components, such as surfactants, may also have an abrasive effect, especially on exposed dentine[34]. While many of these cleaning benefits are often desirable in adult toothpastes, they may be much less so in a children's toothpaste formulation and the abrasivity of children's toothpaste should ideally be balanced to give a cleaning benefit while minimising abrasive damage to the developing tooth surfaces. Commonly used abrasive ingredients in toothpaste are various grades of calcium carbonate, silica and alumina. The potential interactions between these abrasives and fluoride are discussed in the Fluoride section below.

Two measures used commonly to assess the abrasivity of a toothpaste formulation are relative dentine abrasivity (RDA) and relative enamel abrasivity (REA), and these are typically assessed using the methodology detailed by Hefferren[45] and recommended by ISO 11609[47] and the American Dental Association[46]. An upper limit of 250 (for RDA) or 40 (for REA) for a toothpaste is considered safe for everyday use in adults but no limit has been established specifically for children (ISO)[47]. In terms of typical values for commercial toothpastes, a study by Schemehorn[44] showed RDA values ranging between 38 and 269 for 26 adult toothpaste formulations. Given the structural differences between primary teeth, newly emerged permanent teeth and matured permanent teeth and the fact that childrens' diets typically do not contain large amounts of chromogenic tea and coffee, it would seem prudent to err on the side of caution and formulate toothpastes for children at a lower RDA. The RDA and REA of a new range of children's toothpaste formulations, developed with these formulation principles in mind, are discussed in greater detail in another part of this supplement[48].

## FLAVOURS AND SWEETENERS

Flavour is used in toothpaste formulations to make the taste and odour of the product appealing during and after use. Different flavour components can give breath-freshening benefits by masking odours and can provide cooling or warming sensations within the mouth during and after brushing. Flavours can also serve to mask the taste of other ingredients in the toothpaste formulation. Sweeteners, such as sodium saccharin, sucralose and xylitol, work together with the flavour system by adding a degree of sweetness to the toothpaste but avoid the use of fermentable sugars. Xylitol likely has anti-caries potential when delivered continuously from chewing gum and confectionary, although when delivered from toothpaste, evidence for this is inconclusive at present[49].

Flavour design for a children's toothpaste is important so as to encourage, rather than obstruct, the development of good oral care habits for life. Perception of flavour is a combination of both taste, smell and trigeminal inputs[50]. Sensitivity to and preference for different basic taste types (salt, sweet, bitter, sour) is known to differ between children of different ages and in comparison with adults. From birth there is generally a preference for sweet tastes, rejection of sour tastes and an indifference to salt and bitter tastes[36,51–53]. Older infants normally develop a higher preference for sweet, salt and sour tastes, along with a heightened sensitivity to and rejection of bitter tastes compared with adults, that typically last until late adolescence[35,36,53–55]. Differences in olfactory development are less well researched to date, but evidence suggests perception of smell to be equally well established in children as in adults[52,56,57].

Flavour development for children's toothpaste should therefore take these physiological differences into account; flavour type, flavour intensity, level of sweetness and masking of any bitter tastes in the formulation should all be considered. Different geographical preferences for flavour type and sweetness level should also be taken into consideration. The choice of flavour type and concentration is important so as to minimise any potential for irritation of oral soft tissue. The preferences of parents should also be considered, although given the age-related taste differences already discussed, any preference by a parent should not be considered in isolation from the child. Where practical, assessment by the child should be included in the evaluation of flavours, as mothers are not always able to correctly predict preferred flavours of their children[58].

The use of toothpastes flavoured for children has received a lot of attention in the scientific literature[13,16,22–24], primarily related to concerns over increased ingestion of these formulations because of their appealing flavours and the risk this may pose to fluorosis of teeth. This was of particular concern for regions where exposure to fluoride from other sources, such as increased water fluoride levels or the use of dietary fluoride supplements, is already relatively high[16,59,60]. The scientific literature has conflicting findings. Several studies have reported an increase in the mean weight of toothpaste ingested for toothpastes flavoured for children[13,16,22–24] while others showed no difference in amount ingested between these and regular flavoured toothpastes[13]. From a more global perspective, these concerns should be balanced against the wider and potentially more harmful problem of children not brushing often enough or for long enough to prevent the onset of dental caries.

## FLUORIDE

Various fluoride salts are used in toothpaste such as sodium fluoride, sodium monofluorophosphate, amine fluoride and stannous fluoride. The main oral health benefit of brushing with fluoride toothpastes is the delivery of fluoride to the mouth and concomitant caries reductions. These reductions have been demonstrated over several decades by toothpastes with numerous combinations of fluoride salts and abrasive systems[61–76].

To deliver anti-caries efficacy, fluoride must be available in the ionic form in the fluids that bathe the teeth, saliva and plaque-fluid[77]. Anything that reduces the availability of ionic fluoride, either by interfering with it or by speeding clearance from the mouth has the potential to affect the anti-caries efficacy of fluoride. Therefore, when designing a new toothpaste formulation, it is of paramount importance to ensure that the fluoride is available, is delivered during brushing and is subsequently active.

Several toothpaste excipients can interfere with the availability of ionic fluoride. One example was observed during an early clinical trial in which the anti-caries effectiveness of supervised brushing with a calcium carbonate-based sodium fluoride toothpaste was investigated[78]. No anti-caries effect was reported, and the main reason was likely to have been a reaction between ionic fluoride released from the sodium fluoride and calcium from the abrasive. This would have yielded insoluble calcium fluoride, 'locking-in' the ionic fluoride, at least for the duration of a typical tooth-brushing event, and not allowing it to enter the oral fluoride reservoirs.

At that point, researchers may have concluded that fluoride was simply not effective when delivered from toothpaste and explored other avenues. However, continued testing produced the first successful caries clinical trial of a fluoride toothpaste, reported in 1955, where stannous fluoride was formulated in a compatible base. Currently, sodium fluoride in a compatible base – generally silica – is widely thought to be the most effective in mass market use[79], although opinions differ[80]. Choice of flavour can have a pronounced effect on oral fluoride retention following brushing, and a relationship of decreasing fluoride concentration in saliva with increasing flavour strength has been reported[25]. Given that even small elevations in salivary fluoride concentrations are linked with substantial reductions in caries[81–83], caution should therefore be exercised with the addition of greater amounts of flavour. Surfactants have also been reported to affect fluoride delivery. Sodium lauryl sulphate, a widely used foaming agent, which has some anti-microbial properties, has been reported to affect fluoride delivery[25,84]. When formulated into toothpastes containing sodium monofluorophosphate, SLS can impair fluoride delivery, possibly by interfering with the phosphatase enzymes in plaque and saliva that facilitate release of ionic fluoride from the monofluorophosphate anion. However, SLS can also lead to elevated saliva fluoride concentration when used in sodium fluoride toothpaste formulations.

This raises the question, 'Why include ingredients that can modify fluoride delivery?'. The answer is that a balance must be maintained between maximising the efficacy of fluoride toothpastes, that is, its potential ability to reduce caries, often measured in well-controlled studies where variables such as brushing-time and fluoride dose can be relatively well controlled, and its effectiveness in use (i.e. actual reductions in caries) observed when individuals use the toothpaste *ad libitum*. In the latter case, one might intuitively expect both flavour and consistency to encourage longer use, more frequent use or both and in fact a significant relationship between perceived taste and consistency has been reported, where subjects brushed for longer when they rated a toothpaste more highly for these attributes[85]. Increased brushing time has been linked to enhanced enamel rehardening *in situ*[86] and fluoride delivery to saliva and plaque fluid[86,87], and while these benefits should ideally be demonstrated in a caries clinical trial, costs and duration have precluded the conduct of such studies. So, in formulating fluoride toothpastes for mass market use a balance is required to maximise efficacy, for example by using fluoride salts that maximise ionic fluoride availability in a compatible abrasive base, with flavours that are pleasant for the age range involved.

## SUMMARY AND CONCLUSIONS

A number of factors should be taken into account when designing toothpaste formulations for use by

children at the different stages of their development. Adult toothpaste formulations have higher abrasive levels to deal with adult diets and habits that are not a consideration in children. Adult toothpastes are also likely to contain higher levels of surfactant and flavour that may not appeal to children. In addition, the fluoride source must be taken into consideration to provide available fluoride from the formulation. An ideal children's toothpaste formulation should therefore aim to maximise fluoride availability, minimise abrasivity and use levels and types of flavour and surfactant that will minimise interference with fluoride delivery and deliver a pleasant brushing experience. Selection of toothpaste flavour types for children of different ages should ideally be based directly upon preference data from children because of the age-related differences in taste perception. A pleasant brushing experience throughout the developing years should aid in the establishment of good brushing habits and good oral health for life.

## Conflict of interest

Authors Stovell, Newton and Lynch are employed by GlaxoSmithKline Consumer Healthcare.

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