SLOW-RELEASE FLUORIDE DEVICES: A LITERATURE REVIEW

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ABSTRACT

*A*lthough the prevalence of caries has decreased dramatically over the past decades, it has become a polarised disease, with most of subjects presenting low caries levels and few individuals accounting for most of the caries affected surfaces. Thus it become evident for the need of clinical approaches directed at these high-risk patients, in order to overcome problems related to compliance and low attendance at dental care centres. Slow-release fluoride devices were developed based on the inverse relationship existing between intra-oral fluoride levels and dental caries experience. The two main types of slow-release devices – copolymer membrane type and glass bead – are addressed in the present review. A substantial number of studies have demonstrated that these devices are effective in raising intra-oral F concentrations at levels able to reduce enamel solubility, resulting in a caries-protective effect. Studies in animals and humans demonstrated that the use of these devices was able to also protect the occlusal surfaces, not normally protected by conventional fluoride regimens. However, retention rates have been shown to be the main problem related to these devices and still requires further improvements. Although the results of these studies are very promising, further randomised clinical trials are needed in order to validate the use of these devices in clinical practice. The concept of continuously providing low levels of intra-oral fluoride has great potential for caries prevention in high caries-risk groups.

Key-words: Fluorides. Slow fluoride-releasing device. Dental caries.

INTRODUCTION

Dental caries is caused by acids produced by bacteria in dental biofilms, which slowly but progressively demineralise the enamel. Among various caries-preventive strategies, which include education in oral health, chemical and mechanical control of dental biofilms, the use of fluorides has proved to be the most clinically effective according to a large number of clinical trials, literature reviews and more recently meta-analyses demonstrating the ability of F in controlling dental caries in studies involving the use of rinses, gels, varnishes and dentifrices[29-32]. The ability of fluoride to retard or prevent the development of dental caries appears to involve several mechanisms including a reduction in the acid solubility of enamel, the promotion of enamel remineralisation, inhibition of glucose uptake and utilization by acidogenic bacteria, and possibly bacteriostatic or bactericidal effects[21,24].

Although the increase and the subsequent decline of caries from the 1950's to the early 1990's is common in all economically developed countries, at the same time that dental caries prevalence has diminished it has become strongly polarised, showing a bimodal distribution[39,44]. Data from western countries showed that around 80% of all affected surfaces corresponded to only 25% children and adolescents[23,41,44], implying that the majority of children have no or very little caries to be treated. On the other hand, there is still a fraction of the population in which the conventional fluoride regimens seems to have little or no impact on caries prevalence. In countries in which caries is known to be polarised, there has been a promotion of high-risk strategies, instead of the conventional population-based prevention systems, in an attempt to overcome this problem. However, the effect of such a change remains questionable[44]. The main problem is that regardless of what is performed all prevention methods targeted at high caries-risk groups

eventually fail due to the lack of patient compliance. For countries where it is not possible to promote such high-risk strategies, the picture becomes even worse.

As the current scientific consensus regards a constant supply of low levels of fluoride, especially at the biofilm/saliva/dental interface, as being of the most benefit in preventing dental caries[18,49], it is reasonable to expect a positive effect on caries prevalence of a treatment able to raise intra-oral F concentrations at constant rates, without relying on patient compliance. This concept is reinforced by the findings of Shields, et al.[47] (1987), who showed that irrespective of water fluoridation status, caries-free children had salivary F levels of 0.04 ppm or more whereas those with carious dentitions had 0.02 ppm or less. Other investigators also found salivary F levels of caries-free individuals are higher than those found for caries-active subjects, regardless the exposure to fluoridated drinking water[20,43,54]. Generally, baseline F levels in saliva are known to be around 0.02 ppm or less, dependent on the F level in drinking water and the use of F products[27] and are regarded as adequate for low or medium caries challenge individuals, but not for high caries challenge[19].

Considering that intra-oral levels of F play a key role in the dynamics of dental caries, it has been suggested that the use of controlled and sustained delivery systems – similar to the ones used for birth control, treatment of glaucoma and prevention of motion sickness – can be considered as a means of controlling dental caries incidence in high-risk individuals[35]. Thereafter, a topical system of slow and constant F release started to be investigated in *in vitro*, *in situ* and *in vivo* studies.

TYPES OF DEVICES

The literature describes mainly two types of slow-release F devices: the copolymer membrane type, developed in the United States, and the glass bead, developed in the United Kingdom. More recently, a third type was described, which consists in a mixture of sodium fluoride (NaF) and hydroxyapatite.

Copolymer membrane device

This type of slow-release fluoride device was developed by Cowsar, et al.[15] (1976), consisting of a small pellet which could be attached on or near the tooth surface. This system was designed as a membrane-controlled reservoir-type and has an inner core of hydroxyethyl methacrylate (HEMA)/methyl methacrylate (MMA) copolymer (50:50 mixture), containing a precise amount of sodium fluoride (NaF). This core is surrounded by a 30:70 HEMA/MMA copolymer membrane which controls the rate of fluoride release from the device[35]. When the matrix becomes hydrated, small quantities of granulated NaF are diluted until the matrix itself becomes saturated. The precise water absorption rates by the inner and the outer cores enables the devices to act accurately and reliably as a release controlling mechanism[33]. According to Marini, et al.[33] (2000), hydration of the device leads to fluoride release as indicated by Fick's first law[38]: as the saturation of NaF is 3.3×10^{-4} g/cm^3 and 1.32×10^{-4} g/cm^3,

respectively for the inner core and the outer membrane, F moves spontaneously from the matrix through the membrane and into saliva.

The device is approximately 8 mm in length, 3 mm in width, and 2 mm in thickness[36,37] as shown in Figure 1, and is usually attached to the buccal surface of the first permanent molar by means of stainless steel retainers that are spot welded to plain, standard orthodontic bands[7] or are bonded to the tooth surfaces using adhesive resins[37].

Depending on the amount of F in the inner core, the rate of F release of these devices can be between 0.02 and 1.0 mg F/day for up to 180 days. Salivary F levels were demonstrated to remain significantly elevated throughout a 100-day test period[9,12,36,37].

Glass device

Historically, the glass device was used in animal husbandry to combat pasture and feed deficiencies of various trace elements, such as selenium, copper and cobalt[16]. Due to the association of a number of trace elements with caries inhibition, a variant of this device was developed in Leeds, United Kingdom, for use in dentistry in order to assess its potential use in dental caries control[53]. The F glass device dissolves slowly when moist in saliva, releasing F without significantly affecting the device's integrity.

The original device was dome shape, with a diameter of 4 mm and about 2 mm thick[53-55], being usually attached to the buccal surface of the first permanent molar using adhesive resins, as shown in Figure 2. Due to the low retention rates of the original device, it was further substantially changed to a kidney-shaped device, being 6 mm long, 2.5 mm in width and 2.3 mm in depth (Figure 3), and it was proven to be effective regarding both F release and retention rate[7]. A new modification was introduced more recently, in order to facilitate device handling, attachment and replacement. This new device has been shaped in the form of a disk that is placed within a plastic bracket (Figure 4), so a new device can be easily installed without the need for de-bonding, removing remnants of composite resin and performing a new acid etch and bonding the device (Figure 5)

Preliminary studies were conducted to evaluate the best F concentration to be used in the glass devices, with F concentrations ranging from 13.3% to 21.9%[16]. It was found that devices containing 13.3% F showed a higher rate of F release compared to devices containing higher F concentrations (18.3% and 21.9%); this was explained by the presence of aluminium in the high F concentration devices, which binds to F thus reducing its release rate. Also the glasses had different solubility rates. In contrast to the copolymer membrane device, the glass type has shown a longer life time, releasing F continuous for up to 2 years[43].

Hydroxyapatite-Eudragit RS100 diffusion controlled F system

This is the newest type of slow-release F device, which consists of a mixture of hydroxyapatite, NaF and
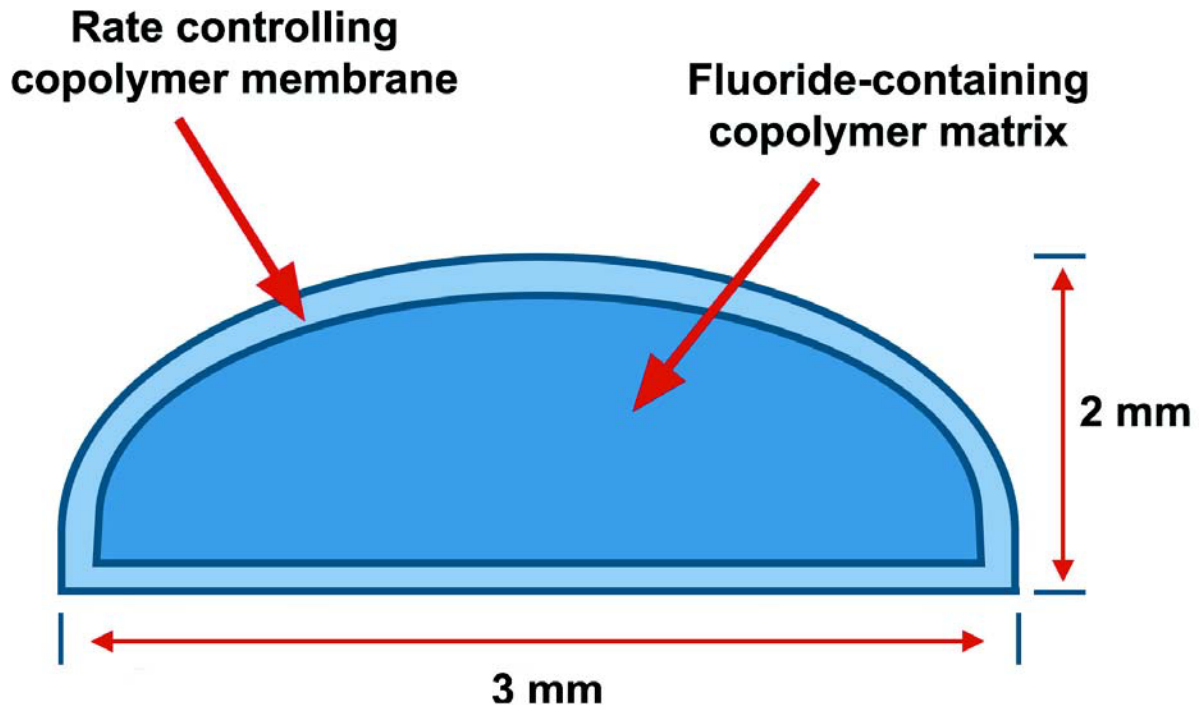
FIGURE 1- Schematic cross-sectional view of the copolymer device, which originally had 8 mm in length, 3 mm in width, and 2 mm in tickness. Modified from Mirth, et al. (1982)

FIGURE 2- Original glass device attached to the buccal surface of the first upper right permanent molar

FIGURE 3- Kidney-shaped device bonded to the upper first permanent molar tooth

FIGURE 4- The latest version of the fluoride glass slow-release device and plastic retention bracket

FIGURE 5- Latest glass device and bracket attached to upper first permanent molar tooth

Eudragit RS100; it contains 18 mg of NaF and is intended to release 0.15 mg F/day. It was demonstrated that the use of this device is able to significantly increase salivary and urinary F concentrations for at least 1 month[6]. However, as there is only one single report in the literature on this device, it will not be further addressed in the present review.

EFFECT ON INTRA-ORAL FLUORIDE CONCENTRATIONS

Several *in vitro* and *in vivo* studies were conducted in order to evaluate the resulting F levels in saliva and dental plaque, which are the sites where the F ion can exert its cariostatic effect during the cariogenic challenge. The results of studies involving the immersion of copolymer devices both in human and artificial saliva suggested an interaction between F released by the devices and calcium from saliva[1], and that F release is directly proportional to the concentration of calcium present in saliva[2]. These laboratory results, however, were not consistent with those obtained in a further clinical trial. After 1 month of placement of a glass device, salivary calcium levels were not significantly different from baseline values[22].

Animal studies also found significant increases in salivary F levels associated to the use of a copolymer device[3,28,36,46], as presented in Table 1. Such increases were further verified in studies involving human subjects, for periods ranging from 270 minutes[35] to 2 years[52] (Tables 2 and 3). As can be observed in Table 3, mean salivary F levels associated to the copolymer membrane device spread a wider range when compared to the glass type.

Significant increases were also found in plaque F concentrations, both for the copolymer membrane and glass devices. In a double-blind crossover study, it was demonstrated that the glass device significantly elevated F levels in plaque (~ ten fold) after 1 month of placement of the bead[22]. Similar findings were obtained in a study employing the copolymer membrane device, also for a period of one month[37], as well as in another study conducted with primates[46].

EFFECT ON CARIES PREVALENCE REDUCTION

After proving that the use of the slow-release F devices was able to significantly increase salivary F levels for prolonged periods of time, the next step was to evaluate the clinical outcomes resulted from such increases. The first studies that aimed to verify the effect of the slow-release devices on caries prevalence were conducted using animal models and the copolymer type. Mirth, et al.[36] (1983) reported a 63% reduction in caries development in the test group (rats using a device releasing 0.15 mg F/day) in comparison to the control group (no treatment) after 1 month. The most interesting finding, however, was that the occlusal surfaces were also protected in that study, since 40% fewer occlusal caries lesions were found in the test group. Another study using a similar protocol also demonstrated that the copolymer device significantly restricted the development of enamel caries on the sulcal-morsal surfaces in rats[45].

The only study involving humans was conducted using the glass device. It was a double-blind clinical trial that evaluated the development of dental caries in 174 children aged 8 years[53]. Children were residents in a deprived area of Leeds, United Kingdom, and used both fluoride (test group) and placebo devices (control group). After 2 years of placement of the devices, it was found that the test group developed 67% fewer new carious teeth and 76% fewer new carious surfaces. In agreement with the findings obtained by Mirth, et al.[36] (1983), there were 55% fewer new occlusal fissures carious cavities, showing that the constant supply of low doses of F is able to protect not only approximal and free surfaces, but also those not normally protected by traditional fluoride regimens. However, as retention rates (discussed in a specific topic on the present review) were low, the results were analyzed on the basis of bead retention rather than an intention-to-treat, which led recent reviews to conclude that the evidence from this study was not strong[10,40]. Thus, although the results from this study provide some evidence on the clinical effectiveness of glass devices on caries control, further investigations on the topic are still necessary.

Studies using *in situ* models also found positive results on F uptake and remineralisation of enamel slabs. Corpron, et al.[12] (1986) demonstrated that enamel can be remineralised within 7 days after the use of a copolymer membrane device, due to the constant release of F ions into the oral environment. The same authors suggested that the low F levels in saliva allow the slow mineral uptake in the base of the carious lesion, and not only on enamel surface, as frequently occurs when high F vehicles are applied[14]. The copolymer membrane device was also shown to be a similar effect on enamel remineralisation and F uptake when compared to a fluoridated chewing gum[56]. In addition, a

TABLE 1- Reported salivary fluoride levels released by copolymer devices in animal studies

Study (year)	Model	Duration	Finding
Lewis, et al.[28] (1977)	Rats	Months	Controlled F release
Adderly, et al.[3] (1981)	Primates	1 month	Elevated salivary F
Mirth, et al.[36] (1983)	Rats	1 month	Elevated salivary F
Shern, et al.[46] (1987)	Primates	1 month	Elevated salivary F

From: Al-Ibrahim NI. Unilateral versus bilateral placement of slow-release fluoride glass device. II. *In vitro* assessment of slow-release fluoride glass device [thesis]. Leeds(UK): University of Leeds; 2007.

TABLE 2- Reported release rates of copolymer devices in clinical studies

Author	Year	Release Rate (RR)
Mirth, et al.[37]	1982	0.5 mg F/day
Corpron, et al.[13]	1991	
Wang, et al.[56]	1993	
Santos, et al.[42]	1994	
Billings, et al.[9]	1998	
Corpron, et al.[12]	1986	0.3-0.4 mg F/day
Kula, et al.[26]	1987	0.1± 0.02 mg F/day
Cain, et al.[11]	1994	0.232 ± 0.07 mg F/day
Alaçam, et al.[4]	1996	0.32 mg F /day
Marini, et al.[34]	1999	0.04 mg F/day

From: Al-Ibrahim NI. I. Unilateral versus bilateral placement of slow-release fluoride glass device. II. *In vitro* assessment of slow-release fluoride glass device [thesis]. Leeds(UK): University of Leeds; 2007.

TABLE 3- Reported salivary fluoride levels released by slow release devices

Study (year)	Device Type	Duration	F salivary level (ppm)
Cowsar, et al.[15] (1976)	Copolymer	30-180 days	Increased
Mirth, et al.[37] (1982)	Copolymer	1 month	1.35
Kula, et al.[26] (1987)	Copolymer	26 weeks	0.645
Bashir[8] (1988)	Glass	Up to 2 years	0.03-0.4
Cain, et al.[11] (1994)	Copolymer	50 days	0.18
Alaçam, et al.[4] (1996)	Copolymer	1 month	0.35
Billings, et al.[9] (1998)	Copolymer	6 months	0.69
Marini, et al.[34] (1999)	Copolymer	6 months	0.46
Andreadis, et al.[7] (2006)	Glass	6 months	0.15 (adults) 0.17 (children)
Kapetania[22] (2004)	Glass	1 month	0.625
Toumba and Curzon[55] (2005)	Glass	2 years	0.11 (0.17 at the beginning of the study)
Altinova, et al.[6] (2005)	RS100	1 month	Increased
Tatsi, et al.[48] (2006)	Glass	3 months	0.06 (F electrode)
Al-Ibrahim[5] (2007)	Glass	6 months	0.096-0.1

From: Al-Ibrahim I. Unilateral versus bilateral placement of slow-release fluoride glass device. II. *In vitro* assessment of slow-release fluoride glass device [thesis]. Leeds (UK). University of Leeds; 2007.

dose-response relationship was verified between F concentration released by the copolymer-type device and enamel remineralisation[11]. Regarding the location of the device, Toumba demonstrated that the glass-type device also was able to increase surface microhardness of enamel slabs, both in the same and the opposite sides of the mouth

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Other studies, using *in situ* and *in vivo* models, also evaluated the potential use of slow-release devices for reduction of orthodontic white spots, dentine sensitivity and prevention of root caries. Marini, et al.[34] (1999) demonstrated that a copolymer device, intended to release F for 6 months, was able to avoid the development of white spot lesions after 1 year of using the devices by patients under orthodontic treatment. Since randomisation procedures were not considered as adequate by a recent meta-analysis[10], care must be taken when analysing these results. The glass device was also proven to be effective for such purpose. After the orthodontic treatment, the group of subjects that used the F releasing device developed 66% fewer white spots lesions when compared to the control group[50].

The use of a F releasing device also proved to be effective for treating dentine sensitivity. Subjects presenting dentine sensitivity both secondary to post-periodontal surgery and primary sensitivity were fitted a copolymer device for a period of 4 months[33]. After 4 weeks of treatment, the symptoms decreased significantly, remaining absent through the duration of the treatment. Regarding root caries, *in situ* studies demonstrated that the use of a slow-release F device was able to increase F uptake in root specimens (with subsurface lesions) to a higher extent when compared to fluoridated mouthrinses and dentifrices[13] and a fluoridated chewing gum[42]. Further clinical studies are still needed in order to test and validate the efficacy of F releasing devices for such purposes.

TOXICITY AND SIDE-EFFECTS

One of the primary concerns about the use of the slow-release fluoride device was the possibility of de-bonding and its subsequent ingestion, which could lead to acute toxic effects. For this reason, since the development of the first device (copolymer type), studies have been conducted in order to verify the degree of safety when using these devices in humans, especially in children.

Using an animal model, Mirth, et al.[35] (1980) demonstrated that no signs of toxicity were verified in dogs after ingestion of devices containing 6 months supply of fluoride (equivalent of 458 mg F). In a further clinical study, the same research group showed no changes in F concentrations in serum and urine of eleven human subjects after fitting copolymer devices[37]. Other investigators also demonstrated that the use of the copolymer device was able to significantly increase salivary and plaque F concentrations without increases in urine or serum, both in primates[46] and in humans[26].

For the glass devices, a pilot study compared F levels in blood plasma of 5 adult volunteers after ingesting either a glass device pellet or a sodium fluoride tablet (2.2 mg NaF) in two separate occasions[16]. While the ingestion of the NaF tablet promoted the increase of plasma F concentrations from 0.01 (baseline) to ~0.1 mg F/mL, returning to baseline levels after 120 min, no changes were verified after the ingestion of the glass device. This demonstrated that if a device is de-bonded or broke, there is no risk of F absorption into the blood stream.

Regarding local side-effects, some authors reported mucosal irritation, erythema and/or small ulcers in some of the subjects[11,37]. On the other hand, a more recent study reported no adverse effects in the oral tissues during the study period[34]; the volunteers did not report discomfort or local irritation, nor found the device bulky. With respect to gingival indices in children and adolescents, Andreadis, et al.[7] (2006) showed no significant differences in the measurements done at days 1, 90 and 180 after the placement of a glass device, although there was a tendency for increased plaque retention on the top of the devices.

RETENTION

Although the use of F releasing devices has been proved to be effective in raising salivary F concentrations at levels that lead to significant reductions in dental caries prevalence, besides the absence of toxicological and side-effects, keeping the device in position has been the major challenge found by the investigators, regardless of the type of the device used. The first studies conducted with the copolymer device showed very low retention rates, even in short-term trials. Mirth, et al.[37] (1982) reported a 65% loss or damage rate after 35 days of placement of the devices. Similar findings were obtained in 50-day[11] and 6-month trials[17,26], which were conducted in order to improve the retention rates.

In 1998, Billings, et al.[9] evaluated new methods for retaining the copolymer devices intra-orally, which consisted of devices with different sizes and shapes combined to different orthodontic-type retainers. After 6 months of evaluation, the retention rate was 85%, of which 100% were still functional. Even better results were obtained in the study conducted by Marini, et al.[34] (1999), in which a new holder called CIPI was tested. This holder was made of a biocompatible elastic alloy designed specifically for orthodontic patients, consisting of a retentive four-wire cage provided with a cannula and a clasp. After 12 months, the retention rate was greater than 98%. The results obtained from both studies show that it is possible to adequately protect and retain the devices in the mouth for prolonged periods of time.

Retention rates for the glass devices were also low in the first clinical trials, although it was reported as 100% in the first pilot studies involving 1 and 4 subjects, for the period of 18 and 7 months, respectively[15]. In the first large clinical trial, Toumba and Curzon[55] (2005) reported only a 48% retention rate using the original "dome-shaped" devices in children. According to the authors, the possible reasons for such a low rate were related to the lower co-operation found in children in comparison to adult volunteers; difficulty in moisture control; incomplete establishment of

children's occlusion in the mixed dentition stage; and a deliberate dislodging of the devices by the child volunteers.

Such low retention rates in children prompted the development of new shapes of glass devices and retention methods that could lead to an increase in such rates. A kidney-shaped glass device with circumferential retentive grooves was evaluated by Andreadis, et al.[7] (2006) for use in children and adults, as shown in Figure 3. After 6 months of placement, the retention rates were 93% and 86%, respectively for children and adults. Such an improvement in the retention was attributed to the large amount of composite resin used for the attachment of the devices, which provided a substantial bulk, which was able to resist both masticatory and brushing forces. Besides, one factor that could explain the success obtained in children was that this new shape device had a shorter height (2.5 mm, against 4 mm for the old shape), which is an important factor when considering that children's molars are usually not fully erupted, so the space available for placement of the device is critical.

The most recent approach was the development of plastic brackets to be used with dome shaped glass beads (Figures 4 and 5). The rationale for this new system is that such brackets would be attached only once, thus facilitating handling and replacement, besides reducing the bulk of the resultant attached device. For adults, 85% of the devices were retained after 6 months of placement, while in children less than 8 years old the retention rates were 60% and 0% after 1 and 6 months, respectively[5]. Thus, this new system for placement and replacement of glass devices seem to be a good alternative for adults, while the kidney shaped type is a good alternative for children with developing occlusions.

FINAL CONSIDERATIONS

Although there are a substantial number of studies addressing the effects of slow-release F devices on intra-oral F levels, as well as its effects on de- and remineralisation processes, the great majority of these were *in vitro* and *in situ* investigations. One recent meta-analysis[10] was conducted in order to evaluate the clinical effect of slow-release F devices on caries prevalence, but only one clinical trial[55] fulfilled the criteria adopted. However, as previously mentioned, the evidence from this study was considered as not strong because the authors did not analyze the data on an intention-to-treat basis. Thus, it is evident that further clinical trials are still needed in order to provide a substantial body of evidence that the use of such devices constitutes an effective and viable measure for the control of dental caries. Future investigators should consider the weaknesses pointed out by the meta-analysis conducted by Bonner, et al.[10] (2006), which mainly included lack of randomisation and/or inadequate study design. Besides the use of these devices in children and other well-known patient groups that are non-compliant, have poor attendance and are mainly from low socio-economic groups, it would be instructive to evaluate their use for the prevention of enamel and root

caries in medically compromised groups, ethnic groups, patients undergoing orthodontic treatment individuals with dentine sensitivity and xerostomia/irradiation patients[52].

In addition, it is worth highlighting that the use of the slow-release devices have been shown to have a very favourable benefit-cost and cost-effectiveness ratios[23]. In the clinical trial conducted by Toumba[51] (1996), the cost-effectiveness of the glass device was 0.72, meaning that the cost for saving one dental surface over a period of two years was £0.72.

According to Featherstone[19] (2006), there is a major anti-caries effect for high caries individuals if a "therapeutic level" of fluoride at a background level of around 0.1 ppm F in saliva can be achieved day and night. Any additional fluoride delivery, such as twice daily brushing with a fluoride toothpaste, would be a bonus. A sustained-release device that functions to provide the same protection as the glass device referred to above should be targeted only in a more acceptable form to the patients. Such a device would overcome compliance problems and could be targeted with success to high caries-risk individuals. It may not eliminate all caries, but would lead to dramatic reductions, and in combination with anti-bacterial treatments could indeed eliminate caries in these individuals.

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