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Editorial

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What Is Dental Caries – and Why We Need Fluoride

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Dental caries is a widespread disease; it can be assumed that everyone, at some point in their lives, will experience caries. At the same time, it is a preventable disease – it is possible to maintain caries under control throughout the life course, with resources we have available. This apparent contradiction may be based on how we define this disease. This editorial would like to present a conceptual framework to answer the question: Can we define caries in a simple way, from an actionable point of view?

Different visual diagrams defining the caries process have been developed over the decades of studying this disease and its causes [1–3]. The pioneer diagram of Paul Keyes, with the three interconnecting circles representing the host, the microbiota, and the diet [1], is the most well-known and widely used until today. Although it is easily understandable, the Keyes diagram leaves behind one important actor in the caries control saga: fluoride. When we use this diagram to explain caries until today, we miss the opportunity to put fluoride into the important context it deserves: caries epidemiology, all around the world, would be much worse nowadays in the absence of fluoride. Although we know that in the absence of a dental biofilm (the microbiota) and its exposure to sugar (the diet) caries lesions would not develop (i.e., if individuals maintain a strict control of their oral hygiene and sugar consumption they can maintain caries under control), most therapies and approaches to control this disease throughout the life course rely on fluoride [4].

Fluoride's effect on caries was identified more than a century ago, through observations of individuals with fluorotic teeth (known as "mottled enamel" at that time) who had much reduced caries experience [5]. Thirty years passed before the confirmation that the effect on both caries and fluorosis was due to higher levels of naturally present fluoride in the water [6]. Decades of research followed to understand the process through which fluoride reduces caries, and although there is still a reminiscence of the original theory that fluoride would "strengthen teeth" if incorporated into the tooth mineral while teeth are forming, currently it is well recognized that the effect of fluoride is mainly local: it happens anytime fluoride is available in the oral fluids (saliva, dental biofilm fluid), and for everyone with teeth (irrespective of age, or if teeth were formed in the presence of fluoride or not) [7–10]. Systematic reviews of the literature have provided extensive evidence for the anticaries effect of fluoride, used through any delivery system – from community approaches like water fluoridation, to individual use approaches, like toothpastes and rinses, to professional application products such as gels and varnishes [11–16]. Beyond controlled studies, observing epidemiological data of the significant decline

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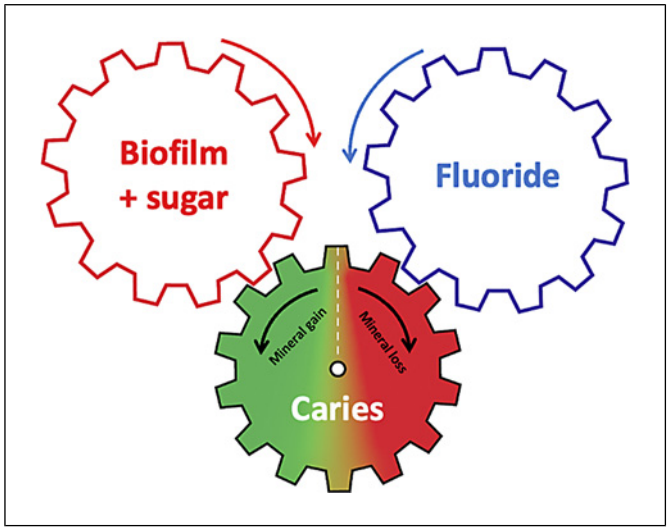

Fig. 1. Defining dental caries with its management in focus, as the result of a balance between dental biofilm exposed to fermentable sugars, and fluoride. The most important factors driving the disease in present days are the patient's diet and exposure to fluoride. Depending on which of these antagonistic processes is predominant, caries lesions will be formed and progress (mineral loss), or caries lesions will be arrested (mineral gain).

in caries since fluoride was introduced in different forms in different populations provides indisputable evidence of its central role in caries control [17–19]. Therefore, it would be extremely helpful if all visual diagrams explaining caries included fluoride.

Dental caries is observable through its signs, the caries lesions; understanding the process of caries lesions formation is very important, because, at any point in time, this process can be modulated into "caries progression" or "caries reversal." This dynamics is critical to understand the disease; it is the basis behind caries activity/risk assessments [7, 20]; it is the basis behind minimum intervention oral care [21], giving support to all the nonoperative treatments for caries management [22, 23], which are considered the best, most conservative approaches for caries control over the life course [4]. In this reversible process involved in a caries lesion development/progression versus arrest, two antagonistic forces can be described (Fig. 1).

1. Biofilm + sugar leading to acid production and mineral loss: dental caries can be defined as a biofilm and sugar-dependent disease, meaning that in the absence of a biofilm, no lesions are formed; if a biofilm is present but there is no dietary sugar to be fermented leading to acid production, no lesions are formed. This represents a "summary" of the diagram designed by Keyes [1], whose studies early on demonstrated the necessity of having both a microbial component and a cariogenic diet for the disease to occur.
2. Some remineralizing agent to reverse the mineral loss, which this editorial proposes we clearly name – fluoride: Whenever fluoride ions are available in the oral fluids, from whichever source, the amount of mineral that is lost is reduced, or the amount that is gained back is enhanced. Fluoride will significantly delay the appearance of early lesions and their progression into advanced lesions, significantly impacting caries prevalence and severity at any given point in time (Fig. 2).

As detailed above, fluoride has been essential for caries control at the individual and population level. Saliva plays a similar and very relevant role, noticeable especially under hyposalivation. Nevertheless, the diagram in Figure 1 proposes the focus to be on main actors and their effects, and others can be added when explaining the process, as needed.

Indeed, the diagram depicted in Figure 1 does not detail other very important factors that influence this complex disease, but they can certainly be incorporated into the same framework.

a. Saliva plays a significant role in the disease process, the most impactful one being observed when there is a drastic reduction in salivary flow. Under hyposalivation, the driving forces for mineral loss, generated by the interaction of biofilm and sugar, will be exacerbated; there will be more sugar available in the mouth, and more acid being generated and not cleared away or neutralized. Figure 1 diagram can be used to explain that under hyposalivation, the mineral loss gear will be moving faster (Fig. 3a).
b. More upstream influences on the disease dynamics can also be depicted with this diagram as the background (Fig. 3a). Caries is a social disease in which access to "oral health" will be significantly impacted by social/economical/cultural/behavioral/etc. factors: Lacking resources to buy a toothbrush and a fluoride toothpaste will drive mineral loss (more biofilm) and reduce mineral gain (less fluoride); prioritizing sugar-rich foods will drive mineral loss (more sugar); lacking access to professionally applied fluoride will reduce mineral gain (less fluoride); eliminating community-based approaches to deliver fluoride, such as water fluoridation, will reduce mineral gain (less fluoride).
c. Disease control can be achieved by interfering with the main drivers for mineral loss, namely biofilm +

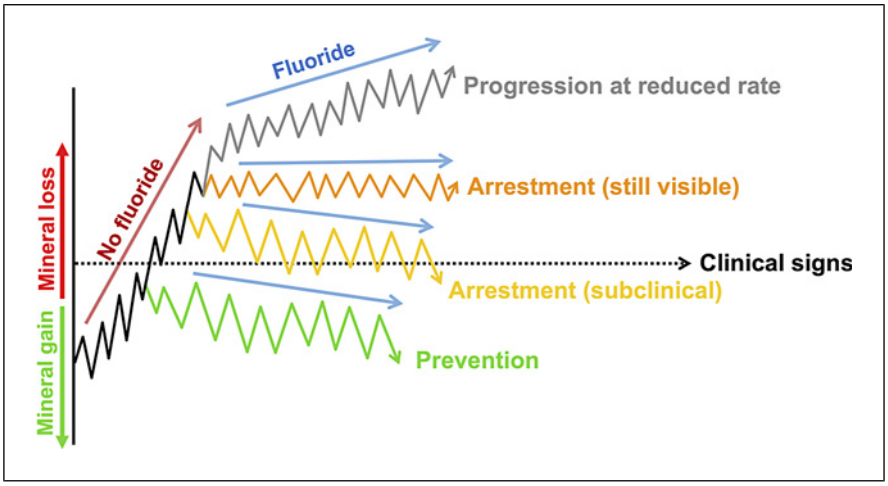

Fig. 2. The role of fluoride on caries prevention or arrestment. Mineral loss happens under a high cariogenic challenge (biofilm+sugar), in which tooth demineralization supersedes remineralization (upward fluctuating line). Fluoride will reduce caries progression by favoring mineral gain over mineral loss. This can result in caries prevention, when mineral loss remains subclinical (green) or early lesions disappear (yellow), arrestment of lesions (orange), or lesions continuing to progress, but at a reduced rate (gray). From Tenuta et al., 2023 [24], with minor modifications.

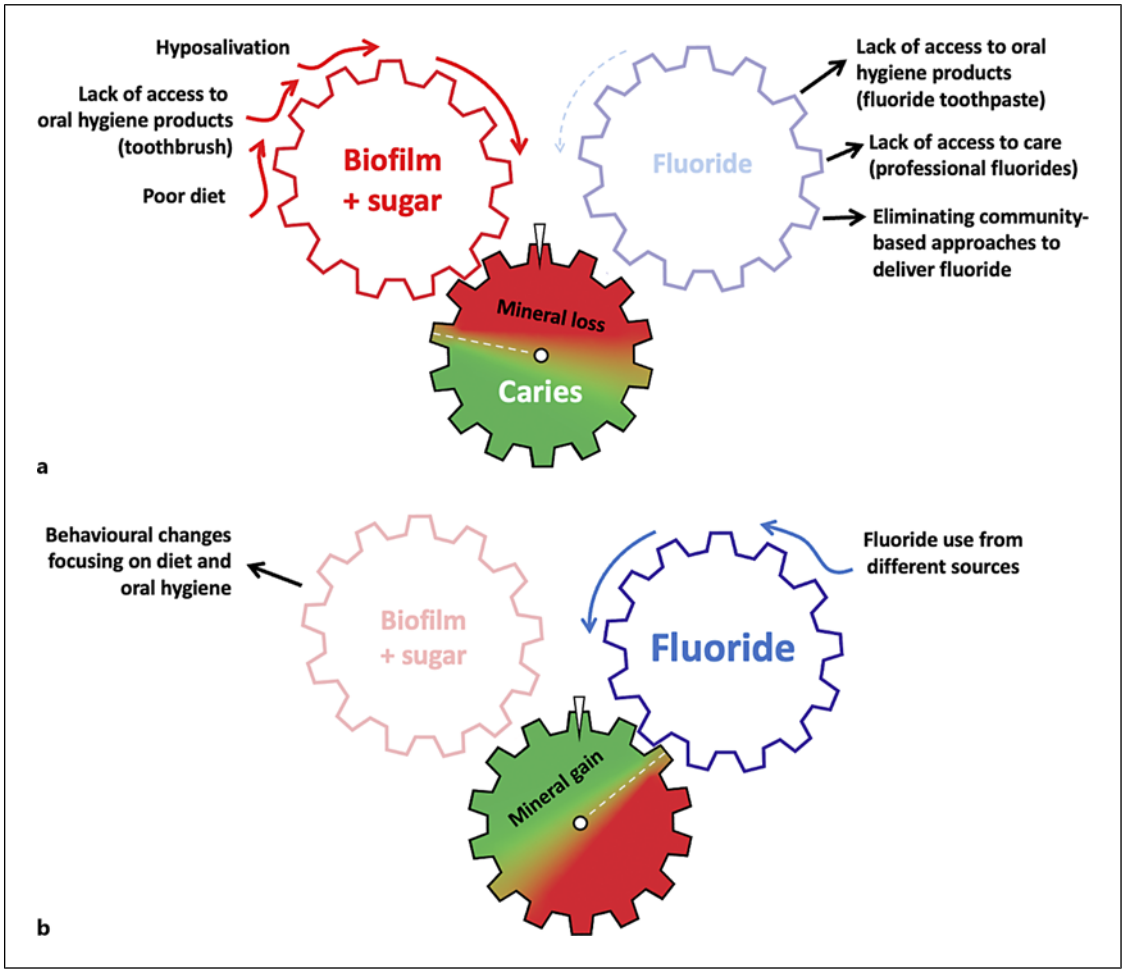

Fig. 3. Using Fig. 1 as a framework to explain different caries outcomes. **a** Drivers of mineral loss (hyposalivation; poor oral hygiene; poor diet; etc.) will accelerate the biofilm + sugar gear. Lack of access to fluoride will reduce mineral gain. **b** Mineral gain will be favored by behavioral changes that reduce the impact of biofilm + sugar, and will be certainly accelerated in the presence of fluoride.

sugar, through behavioral change; nevertheless, access to fluoride will significantly accelerate the process of mineral gain (Fig. 3b).

Although it is true that in a biofilm-free mouth, and/or under a sugar-free diet, caries lesions will not develop, the evidence that caries can be controlled exclusively by dietary interventions or by educating people to meticulously brush their teeth is lacking. Interventions focusing on reducing exposure to sugar and/or improving oral hygiene, at the individual [25, 26], population [27], or global level [28], certainly help. But biofilms form naturally on teeth, and sugar is part of our diet. So unfortunately, although the fluoride gear can be significantly impaired by lack of access to fluoride, there is not much that can be done, with the same strength, to reduce the speed of the biofilm + sugar gear (Fig. 3 a and b).

It is very important to note, however, that fluoride alone is not enough to control caries – or it would be an extinct disease at this point. Depending on the strength of the cariogenic challenge, fluoride will have a different impact on the disease outcome observed through changes in the caries lesions. As shown in Figure 2, fluoride can prevent caries lesions; it can also reduce the speed at which lesions progress, even if caries progression is still observed. More fluoride will be needed when the caries process is advancing quicker [4, 24]; for example, the diagram in Figure 1 can be easily used when describing to a patient with hyposalivation that they might require a higher concentration fluoride toothpaste – mineral loss is advancing quicker in their mouths in the absence of enough saliva, so strengthening the fluoride gear is needed.

Caries is a unique disease and its most well-studied, safe and effective medicine, i.e., fluoride, can be used at different levels – at the community level, by individuals, and by oral health professionals; therefore, we must explain caries with fluoride clearly in the picture, for the benefit of patients, the oral health workforce, and other stakeholders. This editorial aims to address this important gap. We can keep caries under control throughout the life course – but we need to clearly picture how to do it.

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Generative Artificial Intelligence (GenAI) Use: no Generative Artificial Intelligence model was used to create the content or the figures of this Editorial. Parts of the text were revised for grammar and clarity using an OpenAI GPT-5.2 model provided by the University of Michigan (U-M GPT). Figure descriptions (accessibility) were drafted and refined with assistance from U-M GPT, using an OpenAI GPT-5.2 model on March 18, 2026. The author reviewed and edited all AI-generated text and takes full responsibility for the final content.

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Author Contributions

Livia M.A. Tenuta is the sole author.

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