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Natural enamel wear – A physiological source of hydroxylapatite nanoparticles for biofilm management and tooth repair?

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ABSTRACT

Dental caries is a widespread chronic disease caused by glucolytic biofilms. Despite considerable success in prophylaxis, there is still a strong demand for biomimetic biofilm management. Reflections on the abraded, but mostly caries-free teeth observed in prehistoric sculls or omnivorous primates, respectively, offer perspectives for developing new approaches in preventive dentistry. It is hypothesized that nano-sized hydroxylapatite crystallites occur in the oral cavity during extensive physiological wear of the hierarchical structured enamel surface due to dental abrasion and attrition. These nano-scaled apatite enamel crystallites might promote re-mineralization and physiological biofilm management at the tooth surface.

Indeed, modern bioinspired nanomaterials in preventive dentistry containing nano-sized hydroxylapatite particles have shown efficacy in reducing oral biofilm formation and yield re-mineralizing effects. Accordingly, they seem to mimic extensive abrasions which do not occur with modern diet.

Introduction

Caries is still the most prevalent infectious disease in modern society [1]. Diet rich in carbohydrates, mature oral plaque biofilms and poor oral hygiene are regarded as chief causes. Especially low molecular carbohydrates are metabolized by glucolytic bacteria such as *S. mutans* or *lactobacilli*. The bacterial metabolites are organic acids de-mineralizing the dental hard tissues. Despite the tremendous progress in dental prophylaxis by mechanical biofilm removal and the application of fluorides, there is no complete success in preventive dentistry until now.

For better understanding of caries it is worthwhile to have a closer look at the process of bioadhesion in the oral cavity as well as at the architecture of the substrate – dental enamel.

After extensive tooth cleaning, a thin proteinaceous layer termed pellicle is formed on all oral hard tissues from the oral fluids [2,3]. The pellicle layer is of high tenacity and composed of proteins and glycoproteins. On the one hand, the pellicle contains several antibacterial components such as sIg A and lysozyme and serves as a barrier and buffer [2]. Furthermore, de- and re-mineralization processes are mediated by the pellicle. On the other hand it is the starting point of bacterial colonization [2]. Many proteins of the pellicle serve as receptors for specific bacterial adherence of pioneer bacteria making it a real conditioning film. Accordingly, this proteinaceous layer has to be considered when analysing preventive approaches [3]. Further bacterial adherence occurs due to co-adhesion and due to interactions with glucans of the biofilm-matrix serving also as receptors [2].

Dental enamel as the main solid substrate of oral biofilm formation is a masterpiece of bioceramics [4]. It is built up in a hierarchical manner, the main structural elements are the so called enamel prisms, highly organized micro and nano – architectural units of nanorod – like calcium hydroxylapatite crystals arranged approximately parallel to each other [5,6]. The mainly anorganic enamel is composed of calcium- deficient carbonate-hydroxylapatite. Human enamel crystallites in their mature stage measure ca. 20–30 nm in thickness, 60–80 nm in width, and approximately 100 up to 1000 nm in length [7,8].

Caries in prehistoric skulls and in primates

In the history of man, caries occurred mainly with sedentism and the beginning of agriculture. However, there was only a moderate increase of caries despite the general change of diet from proteins to carbohydrates [9–12]. This is often attributed to the effect of micro-sized abraded particles from the prehistoric millstones. The decrease of abrasive food was correlated with an increase of caries in history. None the less, the pure macroscopic removal of initial carious lesions or plaque due to these abrasive remnants cannot account for the comparatively low level of caries especially at the proximal sites or at the root surface which are not prone to the abrasive slurry. Omnivorous primates such as adult baboons *(Papio cynocephalus)* show moderate abrasions of the premolars and molars and considerable loss of dental hard tissue at the incisors and canines but also no carious lesions (Fig. 1). They can be

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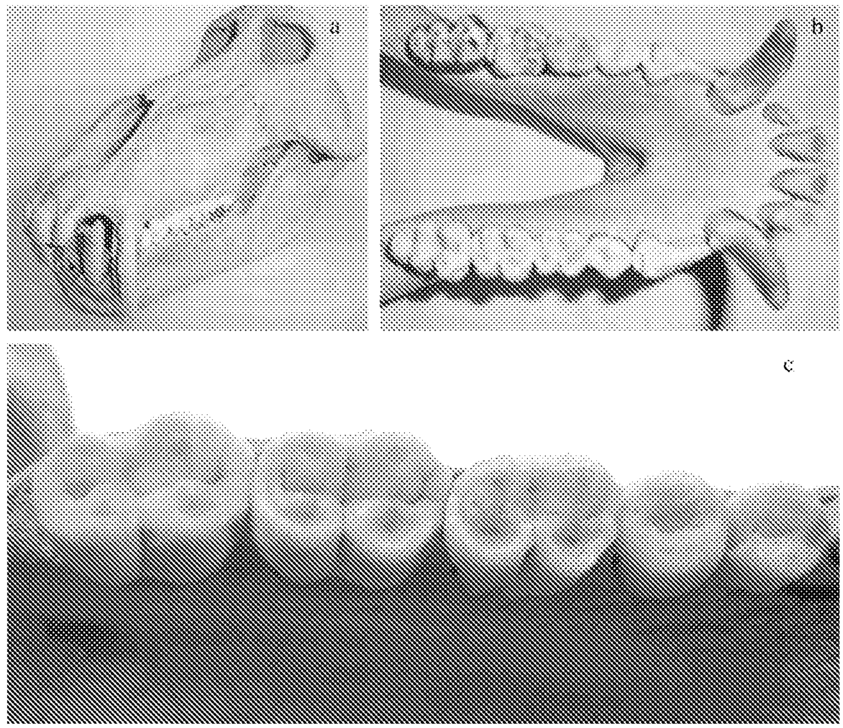

Fig. 1. Skull of a baboon, approximately 10 years old (a) (*Papio cynocephalus*). Please note the abrasions of the premolars and molars in the maxilla (b) as well as in the mandible (c) of the omnivorous primate. These abrasions occur not only on the occlusal surfaces but also on the proximal sites (skull: zoological collection of A. Krause).

regarded as an object of comparison when rethinking physiological biofilm management. Also patients suffering from bruxism often yield few carious lesions. Other than the macroscopic effects of abrasive foods have to be taken into consideration when interpreting these observations. Due to the abrasive process induced by the abrasive food and antagonistic tooth wear nano-sized hydroxylapatite crystallites are presumably present in the oral cavity of primates. The smallest building units of the enamel, fragments of crystallites, break away. It is hypothesized that these abraded nano-crystallites or nano-particles represent some kind of physiological oral health care or biofilm-management lacking nowadays due to non abrasive modern diet [13] (Fig. 2). Recent biomimetic oral health care compounds gave insights in the interactions of suchlike hydroxyapatite nano-particles with the oral biofilm as well as in their impact on re-mineralization [14–16].

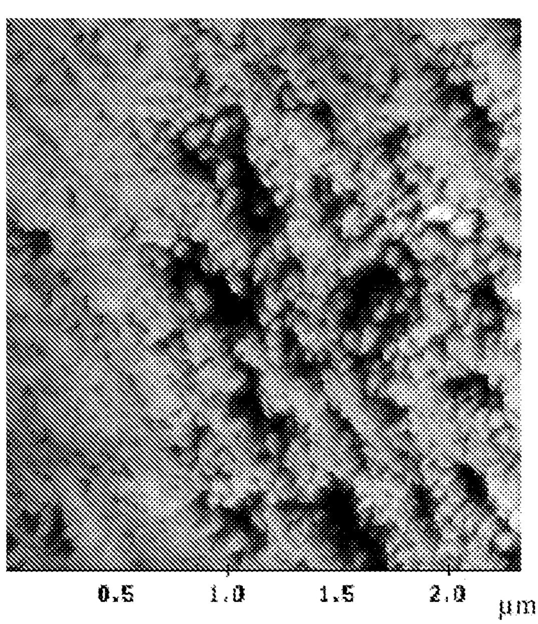

Fig. 2. Enamel surface, atomic force microscopy. The image shows wear and fractures of the enamel at the nano-level. The smallest building units of the enamel, fragments of crystallites, have broken away in some areas.

Modern biomimetic nanomaterials in preventive dentistry

In the last years several oral heath care compounds, tooth pastes and mouth rinses were developed containing nano-sized bioinspired apatite particles in combination with or without proteinaceous additives like caseino-phosphopetides [17,18]. The efficacy of these compounds in dental prophylaxis is attributed to size-specific effects of the apatite nano-particles corresponding to the ultrastructure of the enamel. The nanostructured biomimetic materials expose a large surface to volume ratio and extraordinary physicochemical properties [14]. An example is casein phosphopeptide (CPP) stabilized amorphous calcium phosphate (ACP) [19,20]. These casein phosphopeptides have a high affinity to dental plaque and their incorporation into the oral biofilm provides a reservoir of calcium for re-mineralization [16,21]. CPP–ACP decreases the amount of calcium bridging between the pellicle and adhering bacteria as well as between the bacteria by interaction with calcium binding sites. Furthermore, specific receptor molecules are blocked. This reduces the general bacterial colonization as demonstrated in situ with Germanium surfaces treated with CPP–ACP [17]. However, CPP–ACP does not mimic nano-sized enamel crystallites. Other biomimetic approaches are based on hydroxyapatite-nanocrystals resembling the nanostructure of abraded dental enamel crystallites. Non-aggregated as well as clustered hydroxylapatite nano-crystallite particles ($100 \times 10 \times 5$ nm) adsorb to bacterial surfaces in vitro [22]. The adsorbed nano-sized apatite interacts with the bacterial adhesins, and thus reduces bacterial adherence.

Different types and pharmaceutical forms of nano-hydroxylapatite promote re-mineralization and repair of de-mineralized enamel or micro-sized tooth surface defects [14,23,24].

Typically, these nano-crystallites mimic the size of natural dentinal hydroxylapatite (20 nm) or enamel apatite (100 nm), sometimes aggregated as clusters [14,23,24]. Different forms of the particles such as spheroidal or needle like crystallites have been tested and improved re-mineralization of artificial caries better than sodium fluoride typically contained in tooth pastes [25]. Just like these modern compounds for oral health care based on hydroxylapatite nano-particles, abraded crystallites of human enamel presumably have a high affinity to the tooth surface and to the pellicle yielding comparable effects.

Concluding remark

The hypothesis of the present paper underlines the relevance and necessity of biomimetic oral health care products providing and replacing nano-sized hydroxylapatite-particles in the modern population. These artificial nano-apatites might be supplied during daily oral hygiene measures using tooth pastes, mouth rinsing solutions, chewing gums etc. Further research is necessary to elucidate the re-mineralizing, antibacterial and biofilm preventive effects of nano-sized enamel abrasive.

Conflicts of interest statement

None declared.

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