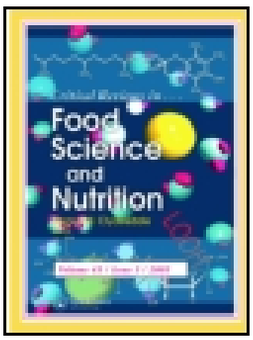

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REVIEW



# Breaking the vicious circle of diet, malnutrition and oral health for the independent elderly

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**ABSTRACT**

Aging impairs senses, mastication, oral status and function, causing nutritional needs and diet insufficiencies. The present needs of independent older adults suggest that health research and oral health care should shift from reductionist disease management to integral and personal treatment plans, including lifestyle, psychological, nutritional and oral health coaching approaches. Dentists and other medical professionals that work in the field of gerodontology should be educated on the macro and micronutrient needs of the elderly and incorporate certain nutritional plans early in the life of their patients with their approval and cooperation, in order to postpone tooth loss and masticatory impairment. Old recipes such as the Mediterranean diet should be kept as a base for all the elderly and be enriched in a customized interpersonal way from the dentist as well as the medical professional according to the specific needs of one's oral and general health status. In this nonsystematic review paper, the basic aspects of the vicious cycle of nutrition and oral health status are discussed and suggestions of major nutrients' influence and needs for independent elders are reported. Based on the scientific data collected, suggestions are made for the food industry for better quality and dosage of foods for this category of individuals. Such strategies can be a whole new area of interest for the food industry in order to obtain better quality of food packaging for the independent OA with accepted texture, odor, colors, macronutrients and micronutrients' consistency and in specific portions.

**KEYWORDS**

Senior oral health; nutritional habits; diet; malnutrition; oral diseases; elderly people

## Introduction

The world's population is getting old. Between 2015 and 2050, the proportion of the world's population over 65 years will nearly double from 12% to 22% (Eurostat 2017). Especially in Greece, one in three people will be aged over 65 by 2050. With 21.3 percent of people over the age of 65, Greece has the second oldest population in the EU, behind Italy (22 percent) and ahead of Germany (21.1 percent). The EU average is 19.2 percent (European Commision 2014). In the European population, women are expected to live 21.3 years more from the age of 65 of which 9.4 years will be healthy ones. Men are expected to live 17.9 years of which 9.4 will be healthy years. From those elderly people, 32.1% live already alone and only 9,5% from those aged 65–74 are still economically active (Eurostat 2017). This picture creates an uncomfortable overview for the national security systems in societies that are expected to overcome the coronavirus COVID-19 economic recession. So far as a consequence of the population's gradual ageing there has been an increase in the percentage of diseases such as cardiovascular diseases, diabetes, chronic renal failure, chronic respiratory failure, cachexia, dementia, osteoporosis, kidney disease, pulmonary infections, neurological lesions, erectile dysfunction and of course the major scourge of cancer (Cullinan and Seymour 2013, Otomo-Corgel et al. 2012). Further, periodontitis is mentioned to be an independent risk factor for certain diseases, including diabetes mellitus, cardiovascular disease and dementia, although there is still place for further scientific support (Meurman, Sanz, and Janket 2004). The elevated prevalence of some of these conditions among the elderly, requires better understanding of the interactions between oral and systemic chronic diseases in order to prevent their onset or worsening and ensure better life quality for the older adults (OA) (Tavares, Lindefjeld-Calabi, and San Martin 2014). Also, the World Health Organization (WHO) has described the main challenges of oral health in the elderly including tooth loss, dental caries, non-caries cervical lesion, periodontal disease, xerostomia, denture-related conditions and oral pre-cancer and cancer (WHO 2019). All these conditions impair quality of life (Petersen and Yamamoto 2005; Sischo and Broder 2011) by causing diet's loss of equilibrium and subsequent malnutrition phenomena which if left unobserved and untreated can lead to a vicious cycle of oral health dysfunction, sarcopenia and finally death. In dentistry, considering the effect of oral health on different aspects of life, including self-esteem, social interaction, speaking and working performance, major efforts have been made in order to develop instruments for the measurement of Oral Health-Related quality of life (Naito

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et al. 2006). It has been already found that there is an association between oral health and Health related Quality of life (HRQoL) (Naito et al 2006) and oral health has been recognized as one of the most important factors of OA's general health (Sischo and Broder 2011; Park, Suh, and Lee 2013). Hence, based on the premise that HRQoL affects one's general well-being and that oral health is an integral component of general health, it can be affirmed that oral health is, in part, responsible for the general state of well-being. Such an important factor of health should then be under the microscope of the food industry. The scope would be to provide the necessary food in well-balanced dosage packets for easy preparation and consumption by leaving alone yet independent OA. This paper provides a nonsystematic review on the basic nutritional aspects for breaking the vicious cycle of malnutrition and bad oral health for these individuals. For purposes of this article, the term *older adults (OA)* refers to individuals age 65 or older.

## Geriatric conditions related to oral health impairment

Concerning food intake there are three entities that may take place while aging: anorexia, food neophobia and obesity; all three are causing some sort of malnutrition of the elderly with certain oral health impairments.

### *Anorexia of aging*

Between the ages of 40 and 70 years food intake reduces by approximately 25% (Nieuwenhuizen et al. 2010) due to differences in satiety signaling (Wysokiński et al. 2015), that results in a declining appetite and gradual malnutrition. The phenomenon is mainly hormonoligally initiated by ghrelin, cholecystokinin, leptin and peptide YY (PYY) that have been observed while aging. Combined actions of the above chemicals convey important anorexigenic signals to hypothalamus (Di Francesco et al. 2007; Chapman 2007). Also, the reduced glucose tolerance and elevated levels of insulin observed during aging may accelerate the indirect development of anorexia through enhancing the anorexigenic signal of leptin to the hypothalamus and hindering the ghrelin stimulus (Di Francesco et al. 2007; Chapman 2007). Altogether, there is a slower gastric emptying in OA associated with a reduced digestive ability in the stomach and a primitive age-related failure of gastric motility induced by chronic gastritis and some drugs (Di Francesco et al. 2006). A slower gastric emptying may decrease the appetite and the food intake by enhancing and prolonging antral distension, as well as modifying the small intestine satiety signals. Additionally, chronic inflammations observed while aging, may modify the response of target brain areas to peripheral stimuli. The circulating levels of cytokines due to these inflammations also reduce food intake and, hence, body weight by several means, contributing to delayed gastric emptying, clampdown of small intestinal motility and differentiated leptin levels, too (Laviano et al. 2005, Yeh, Blackwood, and Schuster 2008). Besides their direct effects on leptin, pro-inflammatory cytokines also stimulate the production of hypothalamic corticotropin releasing factor (CRF), a mediator of the anorexigenic effect of leptin (Morley and Thomas 1999).

To add more, other medical conditions of the body in OA, such as gastrointestinal diseases, malabsorption syndromes, acute and chronic infections, and hypermetabolism (e.g., hyperthyroidism), often cause anorexia and micronutrient deficiencies through increased energy requirements (Morley 2013). Furthermore, OA frequently suffer from diseases that modify the appetite and cause malabsorption or increased metabolism. For example, congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD) and Parkinson's disease are frequently associated with both anorexia and increased energy loss (Morley 2013).

Other common psychological disorders, among which depression is the most known, are often associated with loss of appetite (Stewart et al. 2008). OA seem to suffer more severe appetite and weight loss than younger individuals with depression (Miki et al. 2015) with numerous symptoms and signs including weakness, stomach aches, nausea, and diarrhea (Psaltopoulou et al. 2013; Landi et al. 2016). Loss of appetite and reduced food intake are also frequently observed in OA with cognitive impairment, especially in the later stages of the condition (Insel, Turner, and Ross 2001, Yoshida, Ryo, and Takeshi 2014; Ritchie 2017). Other psychological factors contributing to anorexia are various life events such as loneliness, death of a spouse, lack of social life, estrangement from family, and loss of independence, discussed later.

Polypharmacy is another reason for anorexia (Fávaro-Moreira et al. 2016). OA typically take many prescriptions as well as over-the-counter medications. Several of them can cause malabsorption, gastrointestinal disorders, loss of appetite and ultimately reduced food intake (Morley 2013). For example, extensive use of antibiotics can cause cobalamin deficiency (Rajneesh and Thaiyananthan 2011). Also, the risk of drug-induced anorexia is further increased by polypharmacy, due to the enhanced odds of drug–drug interactions and gastrointestinal problems caused by them (Onder et al. 2014).

Senses deprivation is another main cause of anorexia for the OA. Sight loss is reported to affect 35% of people aged over 75 in the UK (Age UK) and reduced vision can affect food access (Sinclair, Ryan, and Hill 2014) through difficulties with activities such as food preparation, cooking and reading food labels (Jones and Bartlett 2020). Also smell and taste play an important role in making eating and drinking enjoyable. But the sense of smell and taste decreases with age and this contributes to diminished food intake in old age and has a negative impact on the type of food ingested, typically resulting in a less varied and more monotonous diet, consisting mainly of snacks (Ortinau et al. 2013; Leidy et al. 2015; Njike et al. 2016; Larson et al. 2016; Marangoni et al. 2019). It is mentioned that the number of taste buds decreases during the aging process and the remaining buds start to be atrophic (Insel, Turner, and Ross 2001). Also, diseases, medications, smoking, alcohol and some

environmental exposures may worsen the changes observed in the number and functionality of taste buds. Consequently, OA frequently lose salty and sweet tastes first. Hence, they usually choose a more tasteful, yet, unhealthy diet with a lot of salt and sugar.

Furthermore, during aging, the oral mucosa becomes increasingly thin and smooth and loses elasticity. The tongue is reported to show marked clinical changes and to become smoother with loss of filiform papillae. With age, there is a tendency for development of sublingual varices and an increasing susceptibility to various pathological conditions such as *Candidal* infections (especially for those wearing dentures) and a decreased rate of wound healing (Papas, Niessen, and Chauncey 1991). Denture plaque is related significantly with the presence of stomatitis by *Candida albicans* (Schou and Wright 1982). Other common oral pathologies include squamous cell carcinoma, candidiasis, lichen planus, mucosal pemphigoid, pemphigus vulgaris, leukoplakia, burning mouth syndrome, and denture-related lesions (Petersen and Yamamoto 2005; Zegarelli, Woo, and Yoon 2008). These pathologies contribute to pain and general dysanexia in the oral cavity which might be continuous, spontaneous or while chewing, endorsing the vicious cycle of malnutrition.

Furthermore, the decline in saliva secretion during aging causes xerostomia. Saliva is the natural defense mantle of the mouth and related to the textural and overall sensory experience of eating (Xu, Laguna, and Sarkar 2019). Xerostomia reduces the ability of OA to dissolve foods and limit their interaction with taste receptor cells on the tongue (MacIntosh, Morley, and Chapman 2000; Di Francesco et al. 2007). It affects approximately 30% of OA (Ship, Pillemer, and Baum 2002) and adversely affects masticatory function, with a 38% drop of the salivary flow and consequent problems forming the food bolus (Vandenberghe-Descamps et al. 2016). There is a normal, uniform decrease in the acinar content of salivary gland tissue accompanying the aging process (Vissink, Spijkervet, and Amerongen 1996) which causes hypofunctioning. Hypofunctioning of the salivary glands has been reported with Protein-Energy Malnutrition (PEM), which results in a decreased salivary flow rate, a decreased buffering capacity and decreased salivary constituents, particularly proteins. PEM and vitamin A deficiency are on the other hand associated with salivary gland atrophy. The cycle comes with the form of a burning mouth syndrome also induced by other deficiencies such as vitamins B group, iron and zinc (Chouhan, Sharma, and Guleria 2017). Ageing per se does not of course induce salivary dysfunction that is mainly related to other general medical conditions (i.e., Sjögren syndrome, depression, Parkinson's disease, dehydration, anemia, diabetes mellitus, etc.) (Du et al. 2017), xerostomic medications (i.e., antidepressants, antihypertensives, antihistamines, etc.) (Saleh et al. 2015) and head and neck radiotherapy (Ship, Pillemer, and Baum 2002). Another important function of saliva is taste sensitivity (Matsuo 2000), which is often impaired in older ages (Morley 1997), leading also to undernutrition and weight loss.

The abscess of saliva in the oral cavity results in crown and root caries and finally loss of teeth, loss of denture retention and extended traumatic lesions and infections of the oral mucosa. It should also be mentioned that low salivary flow rate or inadequate buffering capacities are factors that exacerbate dental erosion, a phenomenon that diminishes dental hard tissues of the teeth (Antoniadou 2018). Intrinsic acids from vomiting and regurgitation of acid from stomach to oral cavity as well as extrinsic ones from the diet (i.e. citric, phosphoric, ascorbic, malic, tartaric acids and carbonic acids found in fruits and fruit juices, carbonated soft drinks and still, some herbal teas, dry wines and vinegar containing foods) accelerate the process. In an erosive environment no dental plaque can be organized but the phenomenon has phases of energetic evolution when demineralization occurs and others of static development. Dental plaque, on the other hand, accumulates in remineralizing environments and feeds dental caries, well evolved in oral cavities with low pH (Antoniadou 2018).

### Food neophobia

Food neophobia (FN) is a new term, defined as the reluctance or avoidance to eat novel food including unfamiliar functional organic goods, nutritionally modified and genetically modified foods (GMF) (McKie et al. 2000; Bredahl 2001; Siegrist, Stampfli, and Kastenholz 2008; King, Meiselman, and Carr 2010). FN can act as a barrier to the consumption of novel fortified foods or foods that have been specially developed for OA (van den Heuvel, Newbury, and Appleton 2019). Humans naturally display some degree of aversion to new foods (Varzakas and Tzanidis 2016). It is argued that beliefs about risks and benefits of the production and introduction of GMF in the food market, are key in defining consumer acceptance (Varzakas and Tzanidis 2016). FN is related to OA of high age wearing dentures, living alone and with shorter education (King, Meiselman, and Carr 2010; van den Heuvel, Newbury, and Appleton 2019).

### Obesity

Obesity is commonly linked to many detrimental health effects including cardiovascular diseases, hypertension, increased risk of stroke, *o*bstructive sleep apnea (Tuomilehto, Seppa, and Uusitupa 2013), cancer (Wolin, Carson, and Colditz 2010), type 2 diabetes mellitus, dyslipidemia, erectile dysfunction (Tuomilehto, Seppa, and Uusitupa 2013), gastrointestinal and genitourinary diseases (gastroesophageal reflux disease (GERD), erosive esophagitis, acute pancreatitis, gall bladder disease, non-alcoholic fatty liver disease, infection in end-stage liver disease (Premkumar et al. 2015), chronic kidney disease, kidney stones (Taylor, Stampfer, and Curhan 2005) and urinary incontinence (Kramer et al. 2005), degenerative and inflammatory osteoarthritis, back pain (MacFarlane and Kim 2014), shortened lifespan (Kim et al. 2018), frailty, depression (Marmorstein, Iacono, and Legrand 2014), certain infections and decreased response to antimicrobial agents,

antiviral agents and vaccines (rabies, influenza, tetanus, hepatitis A and B) (Genoni et al. 2014; Longo et al. 2013). Not surprisingly, food deprivation also brings its micronutrient deficiencies that are frequently overlooked ("hidden hunger") (Tussing-Humphreys and Nguyen 2014).

## Physical and social factors to malnutrition of OA

### Social factors

All the above-mentioned diet irregularities can lead to malnutrition, sarcopenia, frailty and finally death. In this paper malnutrition will be only on focus.

OA are prone to malnutrition not only due to already mentioned diet irregularities but because of other physical and social factors such as loneliness, poor economic situation, eating by oneself, difficulty in getting foods and lack of cooking skills. The main social factor that contributes to decrease appetite and food intake in old age is socio-economic inequality. Social isolation is also certainly one important factor contributing to the onset of anorexia of aging. Living alone is indeed associated with decreased appetite and energy intake (De Castro 1993; Morley 1997; Ferry et al. 2005; Whitelock and Ensaff 2018). Failure to pay attention to individuals' food preferences and to adequately stimulate a favorable environment to eat, are important factors related to the loss of appetite and reduced food intake among elders. It seems that isolated people are losing gradually their interest in food, sometimes even to the stage of apathy and their main meals consist of snacks. Furthermore, people with hemiplegia, arthritis and reduced vision are experiencing difficulties in buying food and preparing meals. Also, false dietary advices from non-authorized authorities can lead to iatrogenic nutritional deficiencies. It is mentioned that diets followed by pensioners without other financial resources, are generally monotonous, tasteless and bland for purely economic reasons. In the study of Whitelock and Ensaff (2018), "being on your own" influenced participants' eating occasions and was seen to contribute to a diminished effort. This was generally attributed to "being on your own," not having anyone else to cook for and "not being bothered." This lack of motivation to cook has been reported previously in older women who had lost their partner (Bloom et al. 2017) and is pertinent given that motivation is an influencing factor in healthy eating, when cooking for one and eating alone (Hughes, Bennett, and Hetherington 2004). Many participants also reported cooking less frequently and cooking simpler meals in later life compared with previous habits (Lichtenstein et al. 2008). This transition in food choice to incorporate simpler meals that are easy to prepare (including ready meals) is notable, given the potential implications on dietary intake and nutritional risk (Locher et al. 2005). The change mentioned reflects a previous study conducted in Sweden, which found that for some older women now on their own, the importance of providing a complex meal diminished. The preparing and cooking a meal, previously considered like a gift, finally lost its meaning (Sidenvall, Nydahl, and Fjellström 2000). As well as preparing simpler meals, many participants reported a lower appetite and consuming less food in later life with smaller meals as the main associated change to their food practices. Interestingly, many referred to having to request smaller portions when eating away from home, e.g., at family or community centers. The issue of children's portions on menus was notable, with a group of participants having made use of this during a trip (Whitelock and Ensaff 2018).

### Masticatory and dental problems caused by malnutrition

Several reports indicate a bilateral association between nutrition, dietary intake, and oral health (Touger-Decker and Mobley 2013; Huppertz et al. 2017). On one hand, oral health status (particularly natural tooth loss) may have implications for dietary intake and food choice, whereas on the other hand nutrition plays a key role in the etiology of oral diseases such as caries and periodontal disease, which subsequently can cause difficulty in eating, thereby reducing the ability to consume a healthy diet (Kossioni et al. 2018). Other physical factors that worsen the food intake of the elderly are the masticatory and teeth problems. Mastication is an important function that is directly tied to health-related quality of life. In fact, items concerning mastication have been included in representative questionnaires to investigate oral health-related quality of life (Naito et al. 2006; Kandelman, Petersen, and Ueda 2008; Boven et al. 2015; Buset et al. 2016). In addition, mastication is associated with brain activity (Quintero et al. 2013; Ohkubo et al. 2013; Jiang et al. 2015; Banu, Veeravalli, and Kumar 2016) and stress management (Kubo, Iinuma, and Chen 2015). It is said to be essential for good health-related quality of life and to prevent systemic diseases. Moreover, mastication might be a protective factor for cognitive decline, as it is related to increased blood flow in specific brain areas (the cerebral cortex, cerebellum, thalamus, and hippocampus) (Weijenberg, Scherder, and Lobbezoo 2011; Chen et al. 2015). However, the nature of these associations is yet to be determined (Stewart et al. 2008; Batty et al. 2013; Tada and Miura 2017).

Masticatory efficiency is also affected by the presence of teeth, the number of functional teeth, prostheses, and functional decline. Three cross-sectional and longitudinal studies have identified a significant association between oral health status and food intake (Joshipura, Willett, and Douglass 1996; Krall, Hayes, and Garcia 1998; Sheiham and Steele, 2001). Also, several studies have confirmed an association between inadequate dentition and malnutrition (Daly et al. 2003; Nowjack-Raymer and Sheiham 2003). Chewing ability may reflect the comprehensive oral health, including tooth loss, number of functional teeth, fitness of dental prosthesis, oral pain, tooth occlusion and reduced salivary flow (John et al. 2004; Gilbert et al. 2004; Takata et al. 2006; Zhang et al. 2013).

Locker (2002) has reported that there was a marked increase in the number of elderly people reporting chewing problem over a period of 7 years, which suggests an overall decline in oral health among OA. Edentulous OA showed the greatest decline. Cho and Kim (2018) assessed the association between subjective chewing ability and health-related

quality of life (HRQOL) among the elderly. They showed that chewing ability was significantly associated with HRQOL for covariates such as age, gender, economic activity, residence, education, smoking, alcohol, hypertension, diabetes, remaining teeth, denture, CPI, tooth brushing and oral hygiene. Chewing ability was also significantly associated with motor ability, self-care, daily activities, pain and discomfort, anxiety and depression suggesting finally that elderly people with low chewing ability are more likely to have poor health-related quality of life.

Malnutrition may also result from carious problems of teeth due to the pain involved and the dysanexia of the mouth with open cavities (Antoniadou 2018). Despite the rareness of human intervention studies in the field of diet and dental caries, due to mainly ethical reasons, it has been proven that frequency of sugar consumption is undoubtedly an important factor in the etiology of dental caries, but there is also evidence that the amount of sugar consumed influences dental caries development independently of frequency, suggesting that both factors are important. OA like to consume sugar beverages and carbohydrates containing starch, as mentioned earlier. Ground and heat-treated starch can cause dental caries but to a much lesser extent than sucrose. There is little evidence to show that cooked staple foods such as rice, potatoes, and bread are cariogenic when consumed by humans (Guggenheim et al. 2000). It is reported though that manufactured foods, in which starch is heat-treated and hydrolyzed and especially if mixed with sugars, is a potential threat to teeth. On the other hand, less refined starchy foods contain protective factors and it has been suggested that their fibrous nature may aid removal of plaque and food from the exposed teeth surfaces (Grenby and Mistry 2005).

Further, malnutrition can also increase the risk of dental caries by affecting the salivary glands so that the flow rate is reduced and the composition of saliva changed. The salivary flow rates are related to caries directly through oral clearance and in terms of the buffering capacity and the antimicrobial components which in PEM are very low (Chouhan, Sharma, and Guleria 2017). Malnutrition also induces the development of the dental hard tissues. As such, in poorly nourished communities where sugar is available, malnutrition may increase caries risk by causing defective enamel development and salivary gland atrophy. Defective enamel (hypoplasia) appears to derive from hypocalcemia associated with malnutrition and is also caused by vitamin D deficiency and Protein Energy Malnutrition (PEM). PEM and vitamin A deficiency are also associated with salivary gland atrophy, mentioned before, which subsequently reduces the defense of the oral cavity against infection and its ability to buffer the plaque acids. In such a case demineralization occurs and root caries advances especially on the uncovered due to age-recession and gum diseases root teeth surfaces (Antoniadou 2018).

Additionally, periodontal disease evolves more quickly in undernourished populations and low socioeconomic status individuals where oral hygiene is compromised. Malnutrition and bad oral hygiene represent the two important factors that predispose to necrotizing gingivitis (Chouhan, Sharma, and Guleria 2017). Loss of teeth in OA due to periodontitis is probably advancing from earlier stages of life and depends on habits accompanying the person through big periods of time. Of course, changes in structure and function of the mouth during aging may affect the host response to plaque microorganisms influencing the rate of destruction. Gingival recession exposes greater surfaces of teeth to be covered with dental plaque thus explaining the greater amount of plaque recovered in OA (Antoniadou, 2018). Further, exposed cementum of the root surface and dental enamel constitute two unlike types of hard dental tissues with distinct surface characteristics, which may influence the plaque formation rate differently due to the different pH they consist of. Differences in dietary habits, increased flow of gingival exudate from the inflamed gingiva and possible age-related changes in salivary gland secretions, mentioned before, may similarly alter the microflora of the oral cavity inducing proliferation of periodontitis favoring microorganisms (Razak et al. 2014).

Further, missing dentition and ill-fitting dentures cause difficulty in chewing and perception of taste of foods. Although chewing efficiency and nutritional status improve when inadequate dentition or edentulousness is corrected with partial or complete dentures, with these replacements, mastication is less efficient than with intact natural dentition (Razak et al. 2014). Denture status may contribute to dietary changes to soft foods, which are often high in fermentable carbohydrates that may predispose to the development of root caries lesions. Tooth loss also has a direct impact on health-related quality of life (HRQOL) by causing toothache, inaccurate pronunciation, and altered appearance (Yang et al. 2016; Lee et al. 2019). Do and Moon (2020) examined the relationship between oral discomfort and health-related quality of life (HRQOL) in Korean elderly and revealed that toothache, masticatory discomfort, and pronunciation problems caused by oral health conditions were all risk factors for decreased HRQOL. This is so probably due to their impact on self-esteem and physical appearance which are both of vital importance to social life and interpersonal relationships (Kim et al. 2015; Kim et al. 2017).

Generally, objective chewing problems are directly related to fewer numbers of teeth while subjective chewing difficulties, particularly when eating hard food, start when there are fewer than 20 teeth in the mouth (Sheiham and Steele, 2001). The subjective perception of masticatory ability is more optimistic than the objective one (Naka, Anastassiadou, and Pissiotis 2014) but may be more crucial for the individual's dietary choices (Kossioni et al. 2018). Generally, more than three posterior functional teeth are necessary to keep the functional ability of the stomatognathic system in OA (Leake, Hawkins, and Locker 1994). Individuals with fewer than three posterior functional tooth units have a reduced masticatory performance, while partial dentures only partially compensate for the reduced masticatory function (Liang et al. 2015).

Tooth loss is generally a common finding in older age, with wide variation between countries. French subjects aged

between 65 and 74 years have an average of 16.9 missing teeth and 16.3% suffer from being completely edentulous (Kassebaum et al. 2014; Maitre et al. 2020). The global prevalence of edentulousness in people aged 65–74 years in upper/middle-income countries is up to 35%, while the mean number of remaining natural teeth is lower than 20% in most countries, particularly in those over 75 years of age (Maitre et al. 2020).

Several studies have associated tooth loss and denture-wearing with limited consumption of specific food such as meat, fruits and vegetables and increased consumption of sugary products and soft easy-to-chew foods (Hildebrandt et al. 1997; Sahyoun, Zhang, and Serdula 2006; Tada and Miura 2017; Jauhiainen et al. 2017; Zhang et al. 2020). This causes lower intake of specific nutrients, including fibers, vitamins, calcium, and proteins, and higher intake of fats and cholesterol (Landi et al. 2013; Mir, Zafar, and Morley 2013). As it is objectively expected, individuals with self-perceived ill-fitting dentures had lower dietary quality scores, consumed fewer fruits and vegetables, and had a lower variety of foods in their diet as compared with participants with 18 or more teeth (Sahyoun, Zhang, and Serdula 2006). However, those with self-perceived good fitting dentures had diets that were not different from subjects with 18 or more teeth (Sahyoun, Zhang, and Serdula 2006) something also approved recently (Maitre et al. 2020). This is so, probably due to functional adjustments to the masseter muscle neuromuscular activity in order to chew hard (Karkazis and Kossioni 1998) and local culture conditions that affect the subjective evaluation of food intake. For example, Greeks with fewer teeth did not exclude from their diet any food types that were difficult to eat (Anastassiadou and Heath 2002, Kossioni and Bellou 2011) as compared to English study participants (Millwood and Heath 2000). Usually, Greek participants with fewer teeth or edentulous denture wearers used various methods of food preparation which helped them eat most food types such as mincing the meat, cooking vegetables and greens in olive oil, boiling chicken, selecting easy-to-chew fruits (oranges, melons, grapes, and cutting apples into small pieces, etc.) (Kossioni and Bellou 2011). This culture model is also proven in other European elder population (Maitre et al. 2020) and Canadians (Muller, Morais, and Feine 2008) where participants reported that difficulties in chewing hard foods, did not exclude those from their diet. In most cases, foods are cut down into small pieces, raw fruits and vegetables are made into smoothies and meat is pureed (Muller, Morais, and Feine 2008; Maitre et al. 2020) in order to be easily consumed.

A number of cross-sectional surveys in large samples of OA revealed that edentate people and those with few teeth had lower nutritional intake, mainly in vitamins and dietary fiber, while denture wearers have significantly lower serum levels of vitamins C and E, beta carotene, folate, and lutein compared to dentate ones with more than 18 teeth (Sheiham and Steele 2001; Tada and Miura 2017). A systematic review and meta-analysis investigating the association between oral health in individuals older than 60 years and nutritional status has shown that malnourished people presented 0.14 less teeth on average when compared to well-nourished individuals (Toniazzo et al. 2018). Generally, chewing difficulties despite the functional adjustments made to the masseter activity by experienced denture wearers (Karkazi and Kossioni 1998) may lead to lower food intake causing undernutrition and weight loss or to chewing easy-to-chew food, rich in fat and sugars, leading to obesity. This is also reported by the National Diet and Nutrition Survey (NDNS) in independent adults aged 65 and over in the United Kingdom which revealed that having functioning natural dentition of more than 20 teeth increased the likelihood of having a normal Body Mass Index (BMI), while having few natural teeth or being edentulous was associated with a greater risk of being underweight or obese (Sheiham and Steele, 2001). However, the risk of edentulism or using prosthesis did not reveal any differences between malnourished and well-nourished persons (Toniazzo et al. 2018). Other studies revealed limited or no associations between dental status and malnutrition (Anastassiadou and Heath 2002; Liedberg et al. 2004; Gil-Montoya et al. 2008; Kossioni and Bellou 2011; 2012; Maitre et al. 2020). The meta-analysis of a systematic review, in which it was reported that the number of functional tooth units and the number of teeth present in elderly were significantly associated with nutritional status, showed no statistically significant association between malnutrition and edentulism and use of dental prosthesis (Toniazzo et al. 2018). Moreover, another systematic review based on longitudinal studies showed that at present, there is no strong evidence regarding the effect of tooth loss on diet and nutrition because of inconsistent results amongst the few longitudinal studies identified (Gaewkhiew, Sabbah, and Bernabé 2017).

## Effect of alcohol and tobacco on the oral health of OA

Alcohol can be carcinogenic to humans, and heavy use is a major risk factor for the development of both precancerous and cancerous oral lesions (Cogliano et al. 2011). Alcohol independently increases the risk of cancer in the oral cavity by generating free radicals that can damage DNA and proteins through oxidation and metabolization into the toxin acetaldehyde (Cogliano et al. 2011). In addition to the individual carcinogenic properties of alcohol, the frequent concomitant use of alcohol with tobacco yields a greater risk of oral malignancy; the two appear to have a synergistic effect on each other. Alcohol is also a well-known cause of malnutrition, by multiple mechanisms. By providing 7 kcal/g, it decreases the appetite, discouraging caloric intake from food sources, and consequently decreases nutrient intake, especially of proteins and B vitamins (Pflipsen and Zenchenko 2017). Associated symptoms and conditions such as nausea, emesis, anorexia, pancreatitis, and gastritis can further contribute to reduced food intake. Absorption of nutrients is diminished as alcohol causes mucosal erosions and loss of epithelial villi at the stomach and parts of the small intestine (Pflipsen and Zenchenko 2017). Also, chronic alcohol use results in hepatotoxicity, which impairs nutrient metabolism,

especially of protein and vitamin A (Lieber 2003). When the intake of alcohol is excessive, the caloric requirements are covered partly from this source, but with a corresponding reduction in other nutrients. Altogether, nutrient deficiencies secondary to alcohol will result in the oral pathoses dental caries and erosion defects described earlier, in addition to the primary insults from alcohol. Furthermore, nobody could discuss nutritional discrepancies in OA without discussing the problem of smoking. Tobacco use is strongly associated with multiple pathoses, including myocardial infarction, stroke, chronic obstructive pulmonary disease, addiction, and malignancies of various systems (Sato et al. 2020). The wide array of forms of tobacco and frequency of use determine which pathoses manifest and to what extent. However, nearly all tobacco products interface with the oral cavity during use, increasing the risk of oral disease no matter the form of tobacco. It is mentioned that there is a statistically significant association between vitamin B9 and gingival index in smokers compared to nonsmokers (Erdemir and Bergstrom 2006).

Oral manifestations of tobacco use occur in both the dentition and the oral mucosa and range from the cosmetic to the cancerous. Acute necrotizing ulcerative gingivitis, or trench mouth, is a sudden, rapidly progressive polymicrobial infection for which both smoking, and malnutrition are predisposing factors. It manifests as pain, bleeding, and ulceration of the gingiva. Also, the prevalence of periodontitis, nicotinic stomatitis or smoker's palate, leykoplakia or erythroplakia in general is greater in smokers than nonsmokers. Tobacco use can predispose any site of the oral cavity to cancerous growth, including the lips, gingiva, alveolar ridges, buccal mucosa, and floor of the mouth, tongue, and hard palate. Consequent chemotherapy alters the taste and the dysanexia of the oral cavity feeding again the vicious cycle of malnutrition.

## Results of malnutrition in the general health of OA

Parameters discussed above such as age-related changes in life-style, disease conditions, hormone levels and dysfunction, lack of metabolism or malabsorption, medications, impairment of the oral cavity and sight, dysfunction of the salivary glands as well as social and environmental factors along with the use of tobacco and alcohol, have the potential to directly affect dietary behaviors and nutritional status of the elderly leading to malnutrition.

It is referred that micronutrient deficiencies are unexpectedly common both among normal weight and overweight individuals (Kaidar-Person et al. 2008; Via 2012). It is important to mention that a number of epidemiologic studies demonstrated that as body mass index decreases, the risk of tuberculosis also increases (Leung, Lam, and Chan 2007; Lonnroth et al. 2010). This inverse relationship has also been reported in mortality from community-acquired pneumonia. In large population-based studies in different countries, a reduced body weight among less privileged poor people tended to worsen the 30-day mortality rate in patients with pneumonia (Corrales et al. 2011; King et al. 2013; Singanayagam, Singanayagam, and Chalmers 2013). In population studies, the upswing of the mortality curve for underweight subjects is health deficiencies brought on by famine. The association between poverty and infectious diseases has been well documented for centuries (Cegielski and McMurray 2004). Recent data obtained from 1.4 billion Americans between 2001 and 2014 showed that among the poorest 1% in the country, men lived 15 years less and women 10 years less compared with the wealthiest 1% (Chetty et al. 2016).

If malnutrition is diagnosed, a decreased absorption of macronutrients (carbohydrates, proteins, and fatty acids) as well as micronutrient should be expected. It is reported that the usual intake for a large percentage of OA aged 51–70 years and those over 71 years was below the minimum recommended amounts, especially for the nutrient rich food groups. More than 90% of persons aged 51–70 years and 80% of persons aged more than 71 had intakes of empty energy that exceeded the discretionary energy allowances (Krebs-Smith et al. 2010). Compared with younger adults, OA tend to eat fewer high-energy sweets and fast food and eat more grains, fruit, and vegetables. But also, on average, they eat more servings of fruits and vegetables, which might be nutritionally necessary given the change in metabolic processes that occurs in old age (Lichtenstein et al. 2008). Although most adults incorporate at least one serving of fruits and vegetables into their daily diet (85 and 95%, respectively), less than half of OA eat the recommended five servings of fruit and vegetables per day (U.S. Department of Agriculture and Center for Nutrition Policy and Promotion 2007). Major studies have estimated that only 21–37% of men and 29–45% of women aged 65 and older achieve the recommended servings per day (depending on the study methodology) (Serdula et al. 1995). OA tend to score well on the Healthy Eating Index in consumption of total fruit (and whole fruit in particular) and total vegetables but have low scores in consumption of dark green and orange vegetables and fruits. There are also noticeable differences by age among the older adult population as well; elders aged 75 and older are more likely to eat fruit, while elders aged 65–74 tend to eat more vegetables (Federal Interagency Forum on Aging Related Statistics, 2012).

It is very important to mention that the adequate intake for water from food and beverages for OA should be set at a level intended to replace normal daily losses and prevent the effects of dehydration; however, the recommended intake is frequently not met by many OA, especially persons aged over 85 years and institutionalized older adults. Dehydration can result in constipation, fecal impaction, cognitive impairment, functional decline, and even death (World Health Organization 2005, Institute of medicine 2005). As far as it concerns dietary protein, comprehensive short-term nitrogen balance studies suggest that the requirement for it, is not different between apparently healthy younger and OA. For OA the Recommended Dietary Allowance (RDA) of 0.8 g/kg body weight daily is adequate to meet minimum dietary needs (Hooper and Bunn 2015). In the position paper from the PROT-AGE Study Group

(Bauer et al. 2013), a daily intake in the range of at least 1.0–1.6 g protein per kilogram of body weight is required to reduce the loss of muscle mass and strength and prevent the development of frailty (Houston et al. 2008; American Dietetic Association 2009). Approximately 8000 kJ (1900 kcal) is the required calorie requirement for a person 80 years old. However, patients suffering from tissues necrosis or inflammation show an increase in protein turnover and requirements (Razak et al. 2014).

So far, the studies were focused on macronutrients supplementation. Micronutrients, such as vitamins and minerals get much less attention (Shills, Shike, and Ross 2005; Leger 2008; Kaur, Mishra, and Mithal 2015). Although required in minute amounts compared with the macronutrients (carbohydrate, protein, fibers and fat), adequate micronutrient levels are critical for normal or optimal metabolic function (Kaur, Mishra, and Mithal 2015). Studies on micronutrient deficiencies have advanced but they have not been adequately incorporated into practice by the medical community. Micronutrient insufficiency or deficiency should be suspected whenever food intake is seriously diminished (eg. anorexia nervosa, cachexia of chronic disease, neophobia or pathologic obesity) or unbalanced (eg. fat dieting; low socioeconomic status or physical incapacity impacting food access) (Kaur, Mishra, and Mithal 2015). A diet high in calories but low in expensive nutrient-dense foods results in obese individuals with micronutrient deficiencies. Thus, like underweight OA, obese and normal weight individuals need to be fully assessed for micronutrient status.

In many communities where food is inexpensive and easily accessible, favorite food choices are often energy-dense but deficient in vitamins and minerals that are essential for health, including optimal immune function (Kaidar-Person et al. 2008). A growing number of obese individuals worldwide have micronutrient deficiencies, especially among individuals of low socioeconomic status with limited access to fresh fruits and vegetables (Shills, Shike, and Ross 2005; Kaur et al. 2015).

The decreased absorption of micronutrients in the elderly population is significant for cobalamin, calcium, vitamin D, riboflavin, and niacin. Calcium absorption also declines in both sexes in the elderly, and is directly related to vitamin D metabolism. Cobalamin (vitamin $B_{12}$) absorption decreases in the elderly and predisposes them to subacute combined degeneration of the spinal cord. Other vitamin B complexes may also have malabsorption, leading to neuropathies (Insel, Turner, and Ross2001). The elderly has consistently lower levels of vitamin D. In a European study, vitamin D levels are lowest in winter in the elderly (Scragg 2020). This tendency of decreased sun exposure and decreased capacity of the aging kidney to convert vitamin D to active form may reduce endogenous levels of vitamin D (Scragg 2020). Western diets only supply 25–50% of the vitamin D daily requirement; hence, supplementation in the elderly might be crucial (Rajneesh and Thaiyananthan 2011) but only to those with diagnosed deficiency (Scragg 2020). In the review and meta-analysis of Zhao et al. (2017) on papers published on supplementation in calcium or vitamin D and the incidence of fracture, there was no relation between the supplementation and the absence or reduction of fractures in the elderly.

The nutritional deficiencies can affect various parts of the aging spine. Calcium and vitamin D imbalance affecting the vertebral column, vitamin B complexes such as B6 affecting the peripheral nerve conduction, decreased proteins causing paraspinal muscle atrophy, and vitamin B complex deficiency causing dorsal column symptoms are some good examples. Mild forms of malabsorption can also lead to reduced fat absorption, fat-soluble vitamins and vitamin B12 (Landi et al. 2013). On the other hand, warning should be made to clinicians concerning overconsumption of vitamins, specifically vitamin A. Vitamin A is one of few micronutrients that easily lead to intoxication with excess consumption, both acute and chronic (Kim et al. 2018). The most common route of overconsumption is the use of vitamin A supplements containing retinol palmitate, a form of vitamin A that can easily be harmful if taken in excess. The most worrisome adverse effects of vitamin A intoxication in OA are liver abnormalities, and reduced bone mineral density that can result in osteoporosis (Insel, Turner, and Ross 2001).

## Results of malnutrition in the oral health of OA

Certain vitamins and iron preserve oral health while their deficiency compromises it as follows: (1) Apart from its role in healthy vision, vitamin A functions as an important component required to maintain the mucosal membranes, salivary glands, and teeth in OA. The recommended daily dietary allowance for vitamin A is 900 $\mu$g for men and 700 $\mu$g for women. The tolerable upper intake limit of preformed retinol is 2800–3000 $\mu$g per day (Insel, Turner, and Ross 2001). The severity of hypervitaminosis A is dosage dependent. Over-the-counter vitamin A supplements usually contains approximately 2400–3000 $\mu$g of vitamin A per tablet. It is crucial for an individual not to exceed a daily dose of 3000 $\mu$g of vitamin A supplement (Insel, Turner, and Ross 2001). (2) Vitamin D plays an important role in the absorption of calcium, phosphorus, and magnesium from the gut, allowing the proper mineralization of bones and teeth (Kaur, Mishra, and Mithal 2015). Like insufficient vitamin A, a deficiency in vitamin D is associated with enamel and dentin hypoplasia as well as lamina dura and cementum loss that leads to tooth loss as mentioned before. Vitamin D, calcium, magnesium and zinc are interrelated (Uwitonzea et al 2020). Apart from bone strengthening, those nutritional agents actively maintain good status of the dental hard tissues thus avoiding caries and by promoting stronger jawbone (Van der Velden, Kuzmanova, and Chapple 2011). Foods, such as wild-caught salmon and sardines, containing vitamin D, help the body absorb calcium and phosphorus and protect tooth enamel. In addition, foods such as celery, chewing gums, and lemons help stimulate salivary production and reduce cariogenicity (Gondivkar et al. 2019). The lack of enough magnesium, calcium, and phosphorus in the diet is usually associated with loose teeth and premature tooth loss. In magnesium deficiency, the alveolar bone is

fragile, and the gum becomes hypertrophic (Najeeb et al. 2016). (3) Furthermore, vitamin C is required for the synthesis of collagen, which almost exclusively constitutes the protein portion of teeth and bones and serves as the structural scaffolding over which mineralization of these structures occurs. Collagen, and thus vitamin C, is necessary for the creation of dentin, pulp, cementum, periodontal fibers, blood vessels, gingival nerves, connective tissues, and periodontal ligaments. Vitamin C continues to be necessary for the turnover of bone, tooth, and connective tissue throughout the life span. Inadequate intake of vitamin C will eventually manifest as scurvy (Leger 2008). Initial symptoms of scurvy include inflammation of the gingiva. As the deficiency progresses, collagen synthesis is impaired and connective tissues are weakened, causing poor wound healing; inflamed, bleeding gingiva; and loosening of teeth as a result of tissue and capillary fragility (Chapple et al. 2007; Varela-Lopez et al. 2018). Four papers discussed the effect of vitamin C on periodontitis. Two papers (Staudte, Sigusch, and Glockmann 2005; Gokhale et al. 2013) underlined the reduction of gingival bleeding consequent to use of vitamin C in patients affected by chronic periodontitis. The use of fruit or vegetables rich in vitamin C was statistically significantly lower in subjects affected by chronic periodontitis respect to healthy subjects (Dietrich et al. 2004). Serum concentrations of vitamin C, bilirubin, and total antioxidant capacity were inversely associated with periodontitis (Varela-Lopez et al. 2018), the association being stronger in severe disease (Chapple, Milward, and Dietrich 2007).

Except of the role of vitamin C deficiency in periodontitis, vitamin B-complex supplement resulted in statistically significantly superior clinical attachment gains and reduction of inflammatory mediator's respect to placebo in such patients (Neiva et al. 2005). But the use of a standard multivitamin formula provided modest benefits in reducing periodontal inflammation (Harpenau et al. 2011). Also, deficiencies of vitamins A, C, E, as well as folic acid deficiency are related to the production of reactive oxygen species and have been linked to periodontal disease (Varela-Lopez et al. 2018).

Although uncommon in developed countries, vitamin C deficiency can occur in populations with limited food variety like institutionalized elderly people, those who abuse alcohol or drugs, those who follow food fads, and those with a mental illness. A positive correlation between low vitamin C intake and periodontal disease was demonstrated in a study using the NHANES III data (Stewart et al. 2008; Nishida et al. 2000). Consuming foods rich in antioxidant nutrients such as vitamins A, C, and E is therefore important in maintaining periodontal health. Those antioxidants are found in many fruits, vegetables, and grains (Gondivkar et al. 2019). Omega-3 fatty acid–rich foods also reduce periodontitis (El-Sharkawy et al. 2010, Naqvi et al. 2010). (4) Folate (vitamin B9) is a critical component of certain biochemical reactions necessary to synthesize DNA and to power the amino acid metabolism required for cell division. It is an essential vitamin and cannot be created in the human body. 5) Because B vitamins frequently exist in the same foods, they are commonly referred to as the B complex vitamins. A deficiency in one is likely to be accompanied by deficiencies in others (Kennedy 2016). Although they may be accompanied by disparate systemic signs, deficiencies in B2, B3, B6, and B12 will typically manifest in the oral cavity as stomatitis, glossitis, and oral ulcers (Cagetti et al. 2020). Impacts of poor diet and the deficiencies of important macro and micro-nutrients like vitamins and minerals, their association to disturbances in the oral structures, supplementation needed, and food intake sources are mentioned in Table 1. It should be noted that even though evidence is showing the interrelationships among the previous, as mentioned in the systematic and meta-analysis review of Cagetti et al. (2020) there is no clear scientific evidence on the role played by vitamins on oral health. Thus, there is a consensus on the effect of vitamins deficiencies or supplementation on oral health but yet without substantial scientific evidence.

## Diets for the elderly population for better oral and general health

So far it is known that nutritional habits that include overconsumption of salt, low intake of cereals whole grain, fruits and legumes, seafood with a high content of Omega 3 and the overconsumption of poly-unsaturated fatty acids and processed meat are major factors for chronic diseases. A healthy diet packed with vital nutrients can help ward off potential health problems that are common in OA (Cheng, Bohr, and de Cabo 2010; United States Environmental Protection Agency 2016; Pfizer facts. Health status of older adults 2019). There are a lot of suggested diets for the elderly all over the world.

The National Institute on Aging in USA (2019) suggests two options for seniors: (1) **The USDA Food Guide MyPlate Plan.** This plan offers tips for building a healthy, balanced diet, including: (a) half the plate should be fruits and vegetables, (b) at least half the grains should be whole grains, (c) Enjoyment of the meals, but with less portions of food, (d) choice of foods like soup, bread, and frozen meals with less sodium. (2) **The DASH Diet.** The DASH eating plan includes all the key food groups but is designed to help reduce blood pressure and emphasizes foods that are heart healthy. These are recommended daily serving amounts: Grains: 7–8 ounces, Meat and beans: 6 ounces or less of chicken, meat, and fish *plus* 4 to 5 servings of nuts, seeds, and/or dried beans per week, Milk: 2–3 cups, Vegetables: 2–2.5 cups, Fruit: 2–2.5 cups, Oils: 2 teaspoons.

**The Mediterranean Diet.** The above mentioned, as well as all diets worldwide, have elements of healthy eating based on the Mediterranean diet (Kafatos 2018; Vicinanza et al. 2020). The MD with plus a splash of flavorful olive oil and perhaps a glass of red wine — among other components characterizes the traditional cooking style of countries bordering the Mediterranean Sea like Greece. In the study of the seven countries (Greece-Creta, Holland, Finland, Italy, Serbia, Japan and USA participants were followed between the years 1960 and 1995. Although fat consumption was at the same levels between the US and Greece (39% and 37%

**Table 1.** Macro and micro-nutrients deficiencies overview in general and oral health, indicated dosage and physical sources of intake for independent OA with no subsequent pathologies.

| MACRONUTRIENTS | Clinical effects in case of deficiency | Clinical effects in case of balance | Indicated dosage | Food sources |
|---|---|---|---|---|
| **Protein** (Insel, Turner, and Ross 2001; Chernoff 2004; Institute of Medicine 2005; Paddon-Jones and Rasmussen 2009; Bauer et al. 2013) | Hydrogen overload, nitrogen overload, adverse kidney effects | Nitrogen balance | RDA 0.8 g/kg bw, 50 g/ day for women and 63 g/ day for men | Milk and dairy products, fish, meat, legumes |
| **Carbohydrates and fibers** (Bernstein and Munoz, 2012, Insel, Turner, and Ross 2001) | Constipation and diverticulitis, colon cancer, heart disease, abdominal discomfort | Prevention of constipation and diverticulitis, reduction of colon cancer by consumption of complex carbohydrates. Fiber reduces blood cholesterol and heart disease-avoidance of abdominal discomfort | 5 or more servings of fruits and vegetables per day-20-35 g / day | Plain nonfat yogurt, Cereals high in bran, whole grain breads, brown rice, fruits and vegetables (asparagus, broccoli, carrots, green peppers, spinach |
| **Fat** (Insel, Turner, and Ross 2001) | Excess fat leads to obesity hence increasing risk for diabetes, heart disease and cancer, low-fat diet exacerbates insulin resistance, causes elevation of triglycerides, decrease in HDL cholesterol, weight problems. Deficiency of minerals such as calcium, iron and zinc, poor vitamin B12 intake and absorption | Normal cholesterol levels (HDL and LDL), No risk for heart disease, cancer and diabetes | Healthy people with low risk for heart disease max. 30% of daily calories from fat, no more than 10% of calories from saturated fat-300 mg per day cholesterol | Milk, dairy products, red meat, poultry, fish |
| **Water** (World Health Organization 2005, Institute of medicine 2005, Insel, Turner, and Ross 2001) | Difficult cellular metabolism if inadequate intake, dehydration from a decreased thirst response and kidney's reduced concentrating capacity along with diuretics, alcohol and caffeine | Essential to all body functions | 1 ml per kcal of food consumed or 30 ml per kg bw per day | All foods |
| **MICRONUTRIENTS** | | | | |
| **VITAMIN A** (Bloem, de Pee, and Darnton-Hill 1998; Chakravarty 2000; Kim et al. 2018; Cagetti et al. 2020) | Increased susceptibility to infection, cellular damage, impairment of immune response, Impaired mucosal integrity, reduction in the T-helper cell response, impaired immune system, increased deposition of adipose tissue, kidney stones, adverse visual changes including decreased visual acuity, xerophthalmia, hyperkeratosis, loss of taste and smell. Oral cavity: Tooth brittleness, salivary gland degeneration and increased risk of caries, decreased epithelial tissue development, impairment of tooth formation, enamel hypoplasia, bacterial colonization | Reduction in body weight, BMI and total body fat, reduction in measles morbidity and mortality, | 1mg RE (retinol equivalents) | Exceptionally good sources: beef liver, carrots, sweet potatoes, chicken liver. Yellow and orange fruits (bananas, oranges, apples, peaches pineapple, nectarines, leafy greens (broccoli, spinach), yellow and orange vegetables (carrots, peppers, squash, sweet potatoes), whole milk |
| **VITAMIN D** (Mylniec et al. 2015; Zhao et al. 2017; Bruyère et al. 2017; Lucato et al. 2017; Kim et al. 2018, Zadka, Pałkowska-Goździk, and Rosołowska-Huszcz 2018; | Rickets, osteomalacia, osteoporosis, muscle aches and weakness, muscle fasciculation, depression, increased risk of upper and lower respiratory infection, increased risk of autoimmune diseases, associated with incident cardiovascular diseases Oral cavity: Enamel and dentin hypoplasia, lamina dura and cementum loss that leads to tooth loss, periodontitis | Improvement of glucose metabolism and insulin signaling in patients with diabetes or impaired glucose tolerance, Improvement of virologic response when supplemented to conventional therapy of chronic hepatitis C, reduction of hospital readmission due to infection after hip fractures, no relation between supplementation and absence or reduction of fractures in OA (Zhao et al. 2017) | 800 IU (international units) of vitamin D a day (600 IU for adults under 70) or 15× $\mu$g /day (AI: adequate intake) for adults 70 or older | liver, cereals, oily fish (salmon, sardines and tuna), dairy products, egg yolks, orange juice sunlight |
| **VITAMIN E** (Saliha et al. 2014; Cervantes and Ulatowski 2017; Cagetti et al. 2020) | Ataxia, increased risk of cardiomyopathy in patients with ataxia, increased risk of hip fractures, skeletal myopathy, pigmented retinopathy, peripheral neuropathy Oral cavity: Oral tissues will be more vulnerable for bacterial and chemical toxins | Improvement of cardiovascular disease and atherosclerosis, reduction of Alzheimer disease progression, reduction of risk of retinopathy of prematurity, premature hemolysis | 15 mg/day | Wheat germ oil Vegetable and seed oils (safflower, cotton seed sunflower see oils) Nuts, seeds, total cereal |

(*continued*)

**Table 1.** Continued.

MACRONUTRIENTS

| | Clinical effects in case of deficiency | Clinical effects in case of balance | Indicated dosage | Food sources |
|---|---|---|---|---|
| **VITAMIN K (K1, K2)** (Schwalfenberg 2017; Kim et al. 2018; Cagetti et al. 2020) | Causes hemorrhagic disease of newborn and hypoprothrombinemia, Increases risk of hip fractures, increases risk of osteoporosis, Increases disease severity in patients with Crohn's disease. Oral cavity: hemorrhaging gums | Prevention of vascular calcifications and reduction of the risk of congestive heart failure, delay of the deterioration of arterial elasticity, inhibition of the growth of liver cancer, treatment of myelodysplastic syndrome, Helps improve insulin sensitivity, reduction of disease severity in rheumatoid arthritis | 80 $\mu$g/day RDA | Raw turnip greens, cauliflower, cabbage Beef liver soybean oil eggs, tomatoes raw |
| **B2 (Rivoflavin)** (Kim et al. 2018) | Riboflavinosis with manifestations of sore throat, hyperemia of pharyngeal mucous membranes, edema of mucous membranes, cheilosis, stomatitis, glossitis, anemia, and seborrheic dermatitis, anemia of riboflavin deficiency, demyelinating peripheral neuropathy. Oral cavity: Inflammation of the tongue, glossitis, stomatitis, angular cheilosis, ulcerative gingivitis | Improvement of the hematological response, prevention of migraine, improvement of refractory infectious keratitis and non-healing ulcers when combined with ultraviolet A therapy | 1,3 mg/day RDA | Beef liver, chicken liver, yogurt, cornflakes, eggs, mushrooms |
| **Vitamin B1 (Thiamine)** (Kim et al. 2018; Cagetti et al. 2020) | Anorexia and weight loss, Beriberi, Wernicke-Korsakoff syndrome, encephalopathy and mental changes including decrease in short-term memory, apathy, confusion and irritability, Impaired glucose metabolism, enlargement of heart Oral cavity: Cracked lips, angular cheilosis | Improvement of the cardio-metabolism in patients with type 2 diabetes Mellitus, improvement of microalbuminuria, retinopathy, and neuropathy in type 2 diabetic patients | 1,2mg/day RDA | Wheat germ, pork, oatmeal, sunflower seeds, turkey, soymilk, rice, carrots, black beans, salmon, lentils |
| **Vitamin B3 (Niacin)** (Kim et al. 2018; Cagetti et al. 2020) | Pellagra (photosensitive pigmented dermatitis, diarrhea, and dementia; may progress to death), Neurologic symptoms including insomnia, anxiety, disorientation, delusions, dementia, and encephalopathy, Pronounced watery diarrhea and colitis, Cheilosis, angular fissures, atrophy of the tongue, hypertrophy of the fungiform papillae and painful inflammation of the mouth. Oral cavity: Inflammation of the tongue, Angular cheilosis, Ulcerative gingivitis | Improvement of hyperlipidemia, reduction of cardiovascular events and mortality in patients with myocardial infarction, improvement of hyperphosphatemia, dyslipidemia, and proteinuria in patients with chronic kidney disease, reduction of serum free fatty acid, improvement of recovery from central retinal vein occlusion | 16 mg/day RDA | Beff an chicken liver, tuna, salmon, peanut butter, mushrooms, brown rice |
| **Vitamin B5 (Pantothenic Acid)** (Kwok et al. 2017; Kim et al. 2018) | Weight loss, dermatitis, dyslipidemia, neuropathy, muscle cramps, adrenal disorders, acne, paresthesias, irritability, restlessness, sleep disturbances, gastrointestinal disturbances, retarded skin regeneration after wound healing, hypoglycemia Oral cavity: erosion due to vomiting, numbness, | Promotion of wound healing, some pantothenic acid analogs repress the proliferation of Plasmodium falciparum, the major human malaria parasite, reduction of pain in patients with rheumatoid arthritis | 5mg/day $\times$AI | chicken, beef, potatoes, oats, tomato products, mushrooms |
| **Vitamin B6 (Pyridoxine)** (Kwok et al. 2017; Kim et al. 2018; Cagetti et al. 2020) | Seborrheic dermatitis, atrophic glossitis, conjunctivitis, intertrigo, kidney stones and muscular spasms, neurologic symptoms (somnolence, confusion, neuropathy, depression, seizure), sideroblastic anemia Oral cavity: Periodontal disease, sore tongue, burning sensation in the oral cavity | Suppression of pro-inflammatory cytokines in patients with rheumatoid arthritis, improvement of cell-mediated immune response in critically ill patients, lowered plasma homocysteine concentration in patients with renal disease, lowered risks of colorectal and lung cancers, lowered incidence of stroke | RDA 1.7mg/ day for men and 1.5 mg /day for women UL 100 mg/day | Liver, beef, fish, chicken, cereals potatoes, banana, watermelon, sesame and sunflower seeds. |

(*continued*)

**Table 1.** Continued.

| MACRONUTRIENTS | Clinical effects in case of deficiency | Clinical effects in case of balance | Indicated dosage | Food sources |
|---|---|---|---|---|
| **Vitamin B7 (Biotin)** (Cagetti et al. 2020) | Hypotonia, brittle and thin fingernails, alopecia, conjunctivitis, dermatitis, ataxia, unusual distribution of facial fat, neurological symptoms (seizures, irreversible neurosensory hearing loss, optic atrophy, depression, lethargy, hallucination, as well as numbness and tingling of the fingernails) Oral cavity: loosening of teeth | Improvement of fasting glucose and insulin levels in diabetic patients, resolved depression and healing of the rash within a few weeks, modification of hepatic morphology | 30$\mu$g/ day | Egg yolks |
| **Vitamin B9 (Folic Acid)** (Cagetti et al. 2020) | Megaloblastic anemia, risk of cardiovascular disease, cancers, cognitive decline disorders of the gastrointestinal system Oral cavity: inflammations | Low risk of many types of cancer, slowing the decline in hearing with aging | RDA 400$\mu$g/ day | Green leafy vegetables, oranges, beans, nuts, liver and whole grain cereals. |
| **Vitamin B12 (Cobalamin)** (Kennedy 2016; Kim et al. 2018; Cagetti et al. 2020) | Neurologic manifestations (diminished vibratory and position sense and paresthesia, ataxia, spasticity, incontinence), cerebral manifestations (decreased memory, depression, personality changes, psychosis, occasionally delirium), megaloblastic anemia, ineffective hematopoiesis, myelopathy, optic neuritis, visual changes and autonomic dysfunction, unexplained weight loss, transient intestinal malabsorption, skin darkening, reddish hair, nail pigment changes, and impaired bone formation. Oral cavity: angular cheilosis, halitosis Bone loss, hemorrhagic gingivitis, detachment of periodontal fibers painful ulcers in the mouth, pale, smooth and glossy tongue- glossitis | Improvement of gross motor and problem-solving skills | RDA 2.4 $\mu$g/day | Meat, eggs, milk, oysters, liver, caviar, octopus, crab and lobsters, cheese and yogurt, fortified cereals |
| **Vitamin C** (Cagetti et al. 2020) | Impairment of collagen synthesis and disordered connective tissue slowed wound healing, follicular hyperkeratosis and perifollicular hemorrhage, impairment of vasomotor instability, skin and blood vessels disorders. Oral cavity: teeth and collagen formation disorders, scurvy, inflammation of the gingiva, bleeding gums, loosening of teeth due to tissue and capillary fragility, irregular dentin formation, dental pulpal alterations, bleeding gums, delayed wound healing, defective collagen formation, overwhelming acute and chronic bacterial infection. | Reduction of overall mortality, lowered risk of coronary heart disease, slowed atherosclerotic progression when combined with vitamin E32, reduction in prevalence of diabetes, improvement of glucose metabolism or insulin resistance, reduced erythropoietin requirement in hemodialysis patients with iron deficiency, improvement of skeletal muscle oxidative stress and insulin sensitivity in type 2 diabetes mellitus, reduced corneal opacity in infectious keratitis | RDA 90 mg/day | Oranges, grapefruit, mangos, pineapples, strawberries, raspberries, blueberries, watermelon, citrus, tomatoes cauliflower, broccoli, potatoes, leafy greens, green and red peppers and green salads, citrus fruits, mango, papaya, pineapple, strawberries, broccoli, cauliflower |
| **MINERALS** | | | | |
| **Magnesium** (Veronese et al. 2014; Glasdam, Glasdam, and Peters 2016) | Myocardial infarction, cardiac arrhythmia, hypertension, impairment of bone and mineral metabolism, impairment of potassium homeostasis Oral cavity: retarded wound healing | Improvement of insulin resistance, reduction of incidence of hypertension and hyperlipidemia, increase of the function of vitamin D and its activation | 420 mg/day | Cheese, all bran cereals, sesame seeds, almonds, spinach, tofu, yogurt, banana |
| **Iron** (Insel, Turner, and Ross 2001) | Decreases immunity, impairs contractility of human cardiomyocytes, restless syndrome, decreases thyroid hormone synthesis Oral cavity: salivary gland dysfunction, very red, painful tongue with a burning sensation, dysphagia, angular cheilosis, pale, smooth and glossy tongue | Improvement of immune function against infections, Improvement of cognitive function | 10 mg/day | Red meat, egg yolks, dark leafy greens, dried fruits, liver, beans and lentils. |

(*continued*)

**Table 1.** Continued.

MACRONUTRIENTS

| | Clinical effects in case of deficiency | Clinical effects in case of balance | Indicated dosage | Food sources |
|---|---|---|---|---|
| **Copper** (Malavolta et al. 2015; Kim et al. 2018) | Increase of the risk of myocardial diseases including cardiac arrhythmias, increase of the serum cholesterol and glucose intolerance, adult onset peripheral neuropathy, depigmentation Oral cavity: gum inflammations | Promotion of angiogenesis by stimulating endothelial proliferation, prevention of neuro-degeneration such as in Parkinson disease, slowing down aging of the skin by improving skin regeneration | 15mg/day | Oysters, lobster, beef liver, sunflower seeds, hazelnuts, cocoa |
| **Zinc** (Insel, Turner, and Ross 2001; Sharif et al. 2015; Barnett et al. 2016; Kim et al. 2018) | Impairs immune function via lymphopenia, thymic defects, and reduced phagocytosis, Delays healing of wounds, burns, and decubitus ulcers, behavioral disturbances, growth retardation, increases risk of impotence, low appetite regulation Oral cavity: low taste perception | Improvement of immune response against cancer in patients with diabetes and metabolic syndrome, reduction of total cholesterol, LDL, and triglycerides in plasma, reduction of the incidence of respiratory infection, reduction of the incidence of secretory diarrhea, improvement of the cognitive performance and neuropsychological performance, inhibition of aflatoxin B1-induced cytotoxicity and genotoxicity in human hepatocytes | 15mg/day | Oysters, crab, beef, turkey wheat germ, yogurt |
| **Selenium** (Cold et al. 2015; Speckmann and Grune 2015; Mlyniec et al. 2015; Kim et al. 2018; Alehagen et al. 2018) | Increase of pro-inflammatory and pro-fibrotic cytokines in alcoholic, liver cirrhosis, impairment of the conversion of T4 to T3363 Oral cavity: gum inflammations | Reduction of oxidative stress and inflammation in coronary heart, improvement of CD4 cell count, HIV viral load, and quality of life in HIV infected patients, reduction of risks of opportunistic infections in HIV patients, improvement of inflammatory reactions in patients with severe sepsis, prevention of skin aging via UVA-photoprotection, reduction of cardiovascular mortality | 4 55$\mu$g/day | Oysters, tuna, lobster, oatmeal, egg, cottage cheese, corn |
| **Calcium** (Insel, Turner, and Ross 2001; Beto 2015; Bolland et al. 2015; Zhao et al. 2017; Kim et al. 2018) | Osteopenia, decreased bone density and mass, osteoporosis, Oral cavity: tooth mobility and loss (severe periodontal disease), lowered plasma calcium, hypomineralization, compromised tooth integrity, absence of lamina dura, abnormal alveolar bone patterns. | No relation between supplementation and absence or reduction of fractures in OA (Zhao et al. 2017) | 1,200×(AI) mg/day (670 mg/day for women and 830 mg/day for men) | Leafy greens, salmon almonds, brazil nuts, dried beans, milk (whole 2% skim) yogurt, yogurt, cheese, milk, turnips, spinach, soybeans and enriched breads and grains, cheese |
| **Phosphorus** (Insel, Turner, and Ross 2001; Beto 2015; Bolland et al. 2015; Zhao et al. 2017; Kim et al. 2018) | Osteopenia, decreased bone density and mass, osteoporosis, Oral cavity: tooth mobility and loss (severe periodontal disease), lowered plasma calcium, hypomineralization, compromised tooth integrity, absence of lamina dura, abnormal alveolar bone patterns. | Improvement of hard tissues remineralization process | 700mg/ day UL 4 g/day until 70 years and 3g/day for over 70 years | Beef liver, yogurt, sunflower seeds, milk, lentils, almonds |

×RDA: Recommended Dietary Allowances, UL: the maximum level of dairy nutrient intake that is likely to pose no risk or adverse effects. Unless otherwise indicated the UL represents total intake from food, water supplements. AI: Adequate intakes

of total energy intake respectively), the difference was in the consumption of saturated fat which was higher in the US (18%). The world's system for reducing the consumption of saturated fat below 10% came from those measurements of the population in Crete. Fruit and vegetable consumption were also highest in Greece at 654 g/day, followed by the US with 404 g. The consumption of bread and cereals was very similar in Greece (453 g day and in Japan 421 g/day except that Greeks consumed breads with wholegrain flour and minimal salt, while in Japan it had a different composition with ingredients such as rice and with a minimum plant fiber content. The Japanese also had excessive fish consumption beyond the appropriate one which is 300 g/week which may hide disadvantages as they consume large-capfish and even contain polyunsaturated fatty acids which oxidize in the body and produce free roots that are considered carcinogenic. Also, in the USA they consumed meat of approximately 273 g/day and fish 3 g/day while in Greece 35 g/day meat and 39 g/day fish. The results were that Greeks had the lowest land-weight and the lowest mortality rates from ischemic heart disease (heart attack as well as the lowest cancer mortality rates). The second study of 50 years that was carried out between again the population of Crete and residents of the Zutphen region of the Netherlands, proved that the population of Crete had a longer life expectancy of 7 years in comparison to the Dutch. In the same study and in participants of the same age for both countries, the elderly Cretans had lower levels of iron and peroxide fatty acids which are indicators of oxidative stress, while on the contrary they had increased levels of antioxidants such as carotenoids. It is now suggested that following a Med-diet is associated with a reduced risk of cardiovascular mortality as well as overall mortality. The Med-diet is also associated with a reduced incidence of cancer, Parkinson's and Alzheimer's diseases (Krebs-Smith et al. 1995; Figueroa-Méndez and Rivas-Arancibia 2015; Młyniec et al. 2015; Cervantes and Ulatowski 2017; Romagnolo and Selmin 2017; Otten et al. 2020) as well as depression symptoms (Vicinanza et al. 2020) as it may contribute to improve mood and overall wellbeing (Sánchez-Villegas et al. 2013).

Based on the Mediterranean diet, independent OA should maintain normal weight through correct dietary choices daily and rapid physical activity at least 30 min a day (Evans 2004; American Institute for Cancer Research 2017). Foods with a low glycemic load should be selected to prevent the rise of insulin and long-term blood sugar. In this context, it is the choice of whole-wheat bread pasta/bread, brown rice brown rice instead of white, natural sugar-free juices instead of whole grains soft drinks, oatmeal flakes instead of processed fruit breakfast cereals (vibrant colors) and vegetables, fat-free or low-fat milk and cheese, soy or rice milk that is fortified with vitamin D and calcium, fish and whole grains seafood, lean meats, poultry, and eggs, beans, nuts, and seeds. In general, foods to be selected should be foods rich in complex carbohydrates, use only olive oil instead of margarine, saturated fats and seeds, consumed 4–5 fruits and 400 g vegetables per day combined with a restriction on the consumption of salt, sugar and red meat.

While these parts of a healthy diet are tried-and-true, subtle variations or differences in proportions of certain foods may make a difference in the risk of the previous mentioned diseases while aging and the impairment of the oral cavity and should be customized for certain individuals. But most if not all major scientific organizations encourage healthy adults to adapt a style of eating like that of the Med-Diet for prevention of major chronic diseases and avoid foods like sugar-sweetened drinks and desserts and snacks that have added sugars, foods with butter, shortening, or other fats that are solid at room temperature white bread, rice, and pasta made from refined grains.

## Food and nutrients for better oral health

Diet low in fat and sugar are the source of teeth and gums 'good health. More specifically for good gum health there should be use of: (1) Onions because they neutralize oral bacteria, (2) Leafy greens like kale and spinach because they contain vitamins and minerals such as vitamin C which reduces inflammation. Also, leafy greens require more chewing, due to their high fiber content, which is good for the mastication process and the production of saliva. (3) Green tea has specific antioxidants called catechins which help gums fight inflammation. (4) Peppers and citrus fruits like oranges, kiwis, pineapple, and strawberries which are high in vitamin C. (5) Shiitake mushrooms which have lentinan, an antibacterial compound that fights against plaque-building bacteria in the mouth. (6) Celery, carrots and apples, foods that are very crunchy, as they are excellent at scraping away stuck on food and plaque. Crunchy fruits and vegetables also happen to be high in fiber, which, again, means they take longer to chew and generate more saliva. 7) Milk, yogurt and cheese (Gedalia et al. 1991; Lewinstein, Ofek, and Gedalia 1993) (dairy products) are related to lower risk of caries (Pacey, Nancarrow, and Egeland 2010) and reduce caries in the elderly (Yoshihara et al. 2009). They imitate saliva (Gedalia et al. 1991) and are high in calcium. There is also a protein called casein that is found in most dairy products which helps to neutralize oral acids that are produced by bacteria in the mouth and helps strengthening dental hard tissues (Wu, Liu, and Hou 2010). There are dental products which incorporate a phosphopeptide of casein in order to enhance the mineralization of teeth, well suggested to be used in the remaining teeth of OA in order to avoid caries and erosion defects (Antoniadou 2018). Milk also contains calcium, vitamin D, phosphorus, riboflavin, B-complex vitamins, and vitamin A (Bowen et al. 1991) need for oral health. Conversely, because milk is poor in magnesium but rich in calcium and phosphorus, magnesium rich foods such as green leafy vegetables and quinoa, or magnesium supplements, should be consumed at the same time with milk in order to prevent caries and promote tooth mineralization (Yoshihara et al. 2009). However, milk is not a food easily digested and absorbed by all, since there are metabolic diseases and allergies, such as lactose intolerance and cow's milk protein allergy. About 75% of the world's population has symptoms of lactose intolerance (Gallier, Gordon, and

Singh et al. 2012) despite of age. Some OA have experienced this earlier in life and do not consume dairy products (Lomer, Parkes, and Sanderson 2008). Beyond this dysanexia reason, vegans OA constitute another group that eliminates all animal originated food from their diet. For those individuals, plant-based alternative milk could be suggested that has no cow's milk protein (Silva, Marselle-Silva, and Ribeiro 2020) or other protein that can cause allergies (Singhal, Baker, and Baker 2017), no cholesterol (Mridula and Sharma 2015) and no lactose (Mridula and Sharma 2015). The problem is that they contain low micronutrients (Singhal, Baker, and Baker 2017) and protein content (Singhal, Baker, and Baker 2017) and contain antinutrients (phytic acid, trypsin inhibitors, inositol phosphates) (Mäkinen et al. 2016). If such products surpass the low consumer acceptability (Oduro 2018) or neophobia of the OA and incorporate missing nutrients in their content could be promising alternatives for hydration and wetting of the oral cavity plus a mean for micronutrients supplementation. (8) Another innovative field of future research is the one of probiotics. So far it is reported that oral tablets containing probiotics have positive inhibitory effects against oral pathogens, particularly those containing viable probiotics. It seems that probiotics prevent the growth of oral pathogens and improve oral health, providing insights into the antipathogenic efficacy of different probiotic species and their potential role in functional foods that improve oral health (Chen et al. 2020).

## Strategies for the food and nutrition industry

Fortification of the food products with selected ingredients, vitamins, and minerals is another strategy incorporated by the food suppliers (Baugreet et al. 2017). In this context, the need of OA for food products with adequate sensory values and optimal nutritional quality is of crucial importance (Schwartz et al. 2018).

It is well documented that an important nutritional concern is to provide OA with high-quality proteins (Lonnie et al. 2018), while the food industry tries to develop more palatable foods, improving attractive properties such as taste, smell, temperature, color, and texture that positively influence food intake (Aguilera and Park 2016) as proposed by the decline of food chemosensory perception in OA. Thus, highly digestible yet appealing and energy dense foods should be prioritized for OA. High energy density allows for a reduction of up to 20% in food volume whilst maintaining energy intake. Appealing flavors and presentation can also enhance trigeminal stimuli (texture changes, temperature control) as well as visual stimuli (color changes), thus improving appetite and overall food intake (Dermiki et al. 2015).

Hence, another strategy is the increase of food palatability. Van der Meij et al. (2015) highlight the importance of providing a variety of adapted meals and snacks of different colors. In a similar context, Griep, Mets, and Massart (2000) showed that intensely flavored products such as a meat substitute (Quorn) and yoghurt increase food intake in OA. Moreover, an increase in food intake has been observed via flavored additives such as monosodium glutamate (Schiffman 2000; Dermiki et al. 2015), or the natural flavoring of roast beef, bacon, cheese, citrus or pomegranate byproducts and spices such as rosemary, garlic, paprika, and onion (Best and Appleton 2011; Smith, Ameri, and Gadgil 2008).

It seems that there is a need for development of food products with modified texture or rheology, palatable, and nutritious (Aguilera and Park 2016) to help overcome aging related anorexia (Wysokiński et al. 2015). Texture modified foods are processed products with a soft texture or a reduced particle size, as well as thickened liquids (drinks) oriented toward the market segment of OA with eating dysfunctions (Cichero, 2015). Food textures for the OA population should be soft and moist, avoiding sticky and adhesive textures as well as fibrous structures that are not easily disintegrated (Cichero 2016). Preference should be given to soft texture foods due to their easy disintegration and mixing in the mouth, and avoidance of mastication (Ishihara et al. 2013). Under this scope, Laguna et al. (2016) tested the oral processing of foods in OA using gels of different textures (varying in hardness) and reported on the heterogeneity of the food matrix along with texture or consistency (hardness). It seems that oral processing is affected by the physical characteristics of foods, and more specifically the number of chews and time spent in the mouth. Hence, all these are major considerations that should be considered for the design of foods for OA (Lutz, Petzold, and Albala 2019). By this way, OA who have difficulties forming the food bolus, which in some cases leads to a very long time of chewing before swallowing, will not be negatively affected by the sensory experience associated with that food.

Another alternative to offering innovative acceptable foods for OA is to modify the culinary processes used to improve oral comfort when they eat (Wang and Chen 2017). Among these for example, blade tenderization is an effective technique for improving meat texture. It involves meat perforation with sharp edged blades that are closely spaced to cut muscle fibers and ensure tenderness. Vandenberghe-Descamps et al. (2018) demonstrated that easy-to-do culinary processes improve oral comfort, facilitate the formation of a food bolus and ameliorate food texture while eating meat.

### *Reformulation and nutrient profiling*

Nutrient profiling is essential in the reformulation of foods. The WHO defines nutrient profiling as "the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health" (World Health Organisation 2010). Reformulation can target various nutritional aspects, for example, to reduce the amount of nutrients such as sugars, sodium, and saturated fatty acids, to reduce the energy density of the product, to increase the amounts of nutrients such as dietary fiber, and to add vitamins and minerals to address micronutrient deficiencies (Lehmann, Mak, and Bolten

2019). The reduction of sodium and sugars was most targeted by industrial reformulation. Adding whole grain and vitamins were also common reformulation strategies (The Consumer Goods Forum 2017). Products can also be reformulated to improve sensory properties and functionalities such as shelf life, or to reduce E-numbers (van Gunst, Roodenburg, and Steenhuis 2018). van Gunst, Roodenburg, and Steenhuis (2018) have proposed a framework for reformulation that includes the following categories: legislation (e.g., reformulation to achieve better front-of-pack (FoP) labels or nutrition and health claims), food technology (e.g., effects on taste, texture and stability) and consumer perspective: for example, consumer perception, marketing and cost aspects as well as nutrition and health.

New strategies include application of edible coatings as a packaging strategy to extend the shelf life of fresh-cut fruits and vegetables. Moreover, fortification strategies along with new ingredients might offer new solutions for the food industry to increase the nutritional value of end products and offer innovative products to consumers (Varzakas and Kafetzopoulos 2019) including OA.

Additionally, it should be mentioned that there are three major strategies used to combat micronutrient deficiencies: food fortification, food diversification, and supplementation (Bloem, de Pee, and Darnton-Hill 1998; Chakravarty 2000). For the incorporation of vitamins nanofibers are used. Nanofibers are defined as fibers with diameter in a nanometer range. They have numerous applications in food technology, such as filtration, enhancement of mechanical properties of films, and delivery of bioactives. Nanofibers are also preferred because they can be easily and controllably manufactured from natural polymers. Interesting to mention that dextran nanofibers were produced as novel carriers for entrapment of vitamin E.

Furthermore, sugar reduction or removal in confectionary products is an important research objective for the food industry, considering negative press, consumer awareness around civilization diseases and government strategies for sugar reduction in high sugar products (O'Sullivan 2019). Recent research has investigated sugar particle size alteration which affects the physical and sensory properties of chocolate brownies and could be used as a viable approach to reduce sugar in confectionery-type products (Richardson et al. 2018), whereas other studies have examined the use of clean label, novel sweetening ingredients (apple pomace, whey permeate, oligofructose, polydextrose) as possible sugar replacers (Milner et al. 2019). Replacer ingredient strategies have been attempted to achieve the salt/fat reduction objective including reducing the total amount of salt or by (partly) substitution of sodium chloride with potassium, magnesium and calcium chloride, glutamate, glycine and potassium lactate (Alipo et al. 2010a,b; Aaslyng, Vestergaard, and Koch 2014; Fellendorf, O'Sullivan, and Kerry 2015; Fellendorf, O'Sullivan, and Kerry 2016a, 2016b,c, 2017). Research on these matters are ongoing and tremendously promising for better nutrients incorporation in future packaging for all age groups including OA.

## Conclusions

Food intake for OA is a major theme of concern for their general and oral health. Physical and social impairments differentiate oral health status leading to a vicious circle of nutrients deficiency, tooth loss and malnutrition. New strategies in the food industry especially designed for OA can be a whole new area of interest in order to obtain better quality and quantity of food for those individuals. Improving the packaging for independent OA by altering the texture, odor, colors, macronutrients and micronutrients' consistency is also important especially for people living alone. Old recipes such as the Med-Diet should be kept as a base for all OA and enriched in a customized interpersonal way from the dentist and other relevant professionals. Knowledge on the advantages of specific food and nutrients intake is designing a more holistic approach on both oral and general health aspects for elders. The interest, as well as the extended field of this knowledge may suggest the future incorporation of relevant subjects in the educational curriculum of both medical and dental schools worldwide.

In general, the present needs of OA suggest that health research and oral health care should shift from reductionist disease management, to integral and personal treatment plans, including lifestyle and psychological, nutritional and oral health coaching approaches. Dentists and other medical professionals that work in the field of gerontology should be educated on macro and micronutrients needs of the elderly and incorporate certain nutritional plans early in the life of their patients with their approval and cooperation, in order to postpone tooth loss, masticatory impairment and avoid malnutrition.

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