INTERDISCIPLINARY UPDATE

The effect of added sugars on children's health outcomes: Obesity, Obstructive Sleep Apnea Syndrome (OSAS), Attention–Deficit/Hyperactivity Disorder (ADHD) and Chronic Diseases

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ABSTRACT

Increasing attention has been paid to how dietary sugars affect not only tooth decay, but also obesity, Type 2 diabetes mellitus, and cardiometabolic and kidney diseases. Therefore, possible connections of these diseases with oral health and diet are analysed. Healthy approaches to beverage and dietary consumption should be recommended and hopefully established in infancy, with the aim of preventing negative effects on general health in later childhood and adulthood.

KEYWORDS *Added Sugars, Attention-Deficit/Hyperactivity Disorder, Chronic Diseases, Early Childhood Caries, NonAlcoholic Fatty Liver Disease, Obesity, Obstructive Sleep Apnoea Syndrome*

Introduction

Balanced nutrition is very important during childhood, which is a period of increased activity, body growth and development of cognitive ability.

In the last few years dietary sugar has been considered a central risk factor in the development of some important diseases, together with alcohol and tobacco.

Sugars added to foods during processing, preparation or at table, sweeten food and beverage taste, improve their palatability and are used to preserve foods and to confer property such as viscosity, texture and color. They provide sensory enhancement to foods and promote enjoyment but, although they may be required in some clinical situations, they are not a necessary component of the diet in healthy children. In addition to its role in carious disease, for which there is moderate evidence of a direct correlation, increasing attention has been paid to how dietary sugars affect obesity, Type 2 diabetes mellitus, and cardiometabolic and kidney diseases [Fattore et al., 2017].

Carious disease

Dental caries was first described in Miller's chemoparasitic theory in 1890. The caries process can be described as a loss of minerals (demineralisation) of the teeth when the pH of the plaque drops below the critical value of 5.5; reapposition of minerals (remineralisation) occurs when the pH rises. Whether or not a lesion develops, is the outcome of the balance between demineralisation and remineralisation, in which the latter process is significantly slower than the former.

Diet and nutrition may interfere with this mechanism. Sugars and other fermentable carbohydrates, after being hydrolysed by salivary amylase, provide substrate for the actions of oral acidogenic and aciduric bacteria (Streptococci mutans and Lactobacilli especially), which decrease salivary and plaque pH. Otherwise, a diet lower in sugars and fermentable carbohydrates and high in calcium-rich cheese may favour remineralisation.

Studies have confirmed the direct correlation between intake of dietary sugars and carious disease throughout the course of life. The type of food (solid or beverage), exposure time, and frequency of eating also play an important role in the development of carious disease.

Since the first studies, additional factors, besides the diet, have been recognised in the aetiopathogenesis of carious disease that include salivary flow (quality and quantity), the immune system, age, socioeconomic status, level of education, lifestyle behaviours, oral hygiene and use of fluorides [Cianetti et al., 2016].

Early Childhood Caries and added sugar intake

Over the past decades, the American Academy of Pediatric Dentistry introduced the definition of Early Childhood Caries (ECC),

consisting in the presence of one or more cavities, missing or fillings in any primary tooth, in a child under 6 years of age (Fig. 1, 2).

This disease has a widespread diffusion and it has been widely demonstrated that children developing ECC have a diet characterised by high free sugars intake, especially in the form of beverages (fruit juices, soft drinks, etc.). Also the causal role of candies and pacifier dipped in sugar or honey is not negligible [Paglia et al., 2016].

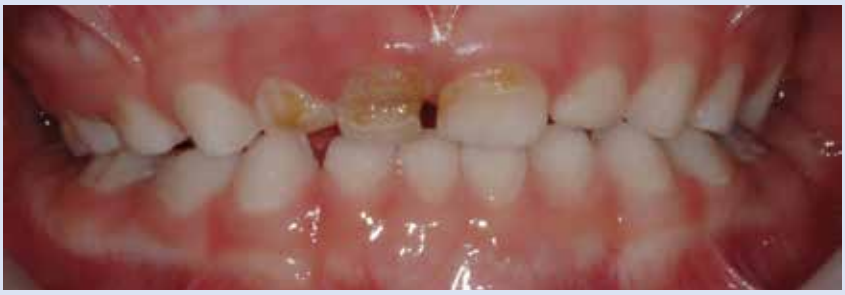
A high incidence of ECC is well documented in Europe [Davies et al., 2001] and Italy [Nobile et al., 2014]. The OMS Collaboration Centre for Epidemiology and Community Dentistry (Milan, Italy) conducted a research in 2004–2005 showing 21.6% decay prevalence in Italian 4-year-old children [Campus et al., 2009].

Generally, children with ECC consume free sugars daily. In particular, sucrose is needed as substratum in the production of extracellular polysaccharides, which in turn facilitate bacterial adhesion to the dental surface and increase the porosity of plaque in close contact with the tooth, with a consequent production of acid on the enamel surface. This condition represents an aggravating factor in carious disease development in primary teeth, due to the thinner and uniform enamel and to the softer dentin in primary teeth than in permanent ones, since dentin tubules have a non-homogenous distribution.

The more frequently free sugars are consumed, the more frequently the pH drops below the threshold value, with consequent difficulty in buffering the general acidity.

The consequences of ECC on a child's health and life quality are numerous and severe: increased risk of malocclusion and development of new decays, in mixed and permanent dentition; increased instances of pain and dental emergencies; risk of bacteremia; possible alteration of a child's development and growth; difficulties in learning with a reduced scholastic performance.

Therefore, it is necessary to apply preventive measures as soon as possible, in children, also considering the possibility of bacteria transmission from mother to child directly through the saliva.



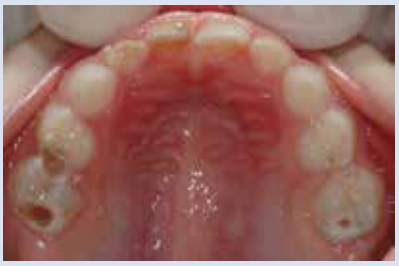


FIG. 1A, 1B Type 2 (moderate to severe) ECC in a 4-years-old girl, frontal and occlusal view: cervical and interproximal areas of yellowish decalcification in maxillary incisors with molars involvement (Photographs courtesy of Dr. Matteo Beretta).

FIG. 2A, 2B Type 2 (moderate to severe) ECC in a 4-years-old boy, frontal and occlusal view: compared to the previous case, carious lesions affect almost all teeth, with crown destruction and consequent permanence of brown black root stumps. Note the presence of fistulas
(Photographs courtesy of Dr. Matteo Beretta).

Does breastfeeding increase risk of ECC?

According to the WHO, "breastfeeding is the normal way of providing young infants with the nutrients they need for healthy growth and development. Exclusive breastfeeding is recommended up to 6 months of age, with continued breastfeeding along with appropriate complementary foods up to 2 years of age or beyond". However, several studies have reported prolonged and unrestricted breastfeeding as a potential risk factor for ECC. On-demand breastfeeding, especially during the night, would seem to cause ECC because milk remains in the baby's mouth for long periods of time. There is lack of evidence that human milk is cariogenic; other factors, such as oral hygiene, may be more influential in caries development than on-demand breastfeeding. Moreover, the biomechanics of breastfeeding differs from those of bottle feeding and milk is expressed into the soft palate and swallowed without remaining on teeth. Indeed we cannot forget that the main factor influencing caries development in infants is the presence of bacteria, Streptococcus mutans, that thrive in a combination of sugars, small amounts of saliva and a low pH [Paglia, 2015]. Further studies with more elaborate methods of assessment are needed to determine the cariogenic nature of breastfeeding. In the meantime, given

the many benefits of breastfeeding, the practice should continue to be strongly encouraged. Dental professionals should encourage parents to start proper oral hygiene with their children as soon as the first tooth erupts, and to limit the consumption of sugary beverages to a minimum.

Chronic diseases and sugar-sweetened beverages

Most chronic diseases are associated with preventable risk factors, such as high blood pressure, high blood glucose or glucose intolerance, high lipid levels, sedentary life and physical inactivity, excessive weight and obesity. The occurrence of intermediate outcomes during childhood increases the risk of disease in adulthood.

Sugar-Sweetened Beverages (SSBs) are known to be significant sources of additional caloric intake, and given recent attention to their contribution in the development of chronic diseases. The consumption of SSBs in children is associated with adverse health outcomes [Fidler Mis et al., 2017].

Children have a strong preference for a sweet taste and early introduction of added sugars in the diet of infants and toddlers may further promote a sweet taste preference. Introduction of SSBs before 12 months of age is associated with an increased likelihood of consuming SSBs ≥1 time/day at 6 years of age. Recent research demonstrating the use of sucrose and glucose, sweeter than lactose (the sugar present in breast milk) in infant formulas, emphasising the importance of new researches on this topic due to the importance of this early period on growth and future obesity and metabolic risk [Tan et al., 2016].

Scientific evidences suggest that during childhood, a crucial phase for the formation of individuals, some eating habits tend to consolidate until adolescence and adulthood.

Added sugar, obesity and cardiovascular disease

Consumption of drinks containing added sugars, fructose in particular, continues to increase and can play an important role in the onset of obesity and cardiovascular disease (CVD). There is, in fact, evidence that a reduction in the consumption of soft drinks is related to a decrease of being overweight and an improvement of sugar metabolism.

A systematic review on the effects of free sugars intake on adiposity development enables to conclude that the decrease or increase of free sugars in diet influences weight in children and young adults [Te Morenga et al., 2012].

In 2015 the World Health Organization (WHO) recommended to further limit free sugars intake to less than 10% of the total energy intake for adults and children, observing that a further reduction of 5% would provide additional health benefits [WHO, 2015]. It is reasonable to recommend that children consume ≤ 25 g (100 cal or 6 teaspoon) of added sugars per day and to avoid added sugars for children < 2 years of age [Vos et al., 2017].

Again in 2015, the American Heart Association (AHA), in collaboration with the American Academy of Pediatrics (AAP), affirmed that "sweetened beverages and naturally sweet beverages, such as fruit juices, should be limited to 4 to 6 ounces per day for children 7 to 18 years old" [Gidding et al., 2005].

Fructose and glucose have similar effect but have significant different metabolic destiny in the human body. After assumption, digestion and absorption, both fructose and glucose are absorbed into the portal circulation and taken up into the liver. The liver has a major role in controlling the amount of glucose that reaches peripheral tissues after a meal. Increased glucose in the portal blood stimulates insulin secretion, leading to increased uptake of glucose into muscles and adipose tissues, increased synthesis of glycogen, increased fatty acid synthesis in the fat, increased amino-acid uptake and induction of lipoprotein lipase into muscles and fat. Fructose does not stimulate insulin secretion to the same measure and is absorbed primarily into the liver where it stimulates de novo lipid synthesis. It is therefore considered responsible for the pathologic conditions previously mentioned [Houston and Minich, 2015; Malik and Hu, 2015].

The form in which added sugars are consumed also may influence the metabolic effects. SSBs provide a lot of calories and are composed almost exclusively of just 2 ingredients: added sugar and water. This makes them a good mean for testing the effect of added sugars with minimal risk of confounding by other nutrients. Several short-term studies have shown that carbohydrates consumed as solids satisfy hunger more than those consumed as liquids and subsequent calorie balance appears to be compensated for by the additional calories, resulting in less body weight gain. In a 6-year longitudinal study of 8–10-year-old children, Olsen et al. [2012] demonstrated a stronger association between liquid sucrose consumption and fat storage in terms of Body Mass Index (BMI) and waist circumference compared with solid sucrose consumption. Moreover, randomised and controlled trials in which children and adolescents switched from SSBs to noncaloric beverages show reductions in their weight. This supports the concept that the association between added sugars and weight gain is mediated by total energy intake, but also it suggests that liquid sugars may uniquely affect body fat distribution. In view of the above, the reduction of all added sugars, SSBs in particular, is recommended as a way to improve long-term cardiovascular health.

Importantly, the associations between added sugars intake and adverse outcomes, in longitudinal and cross-sectional studies, may also be driven by others factors such as: the home environment, a more unhealthy diet and level of activity.

Evidence in both aepidemiological and clinical trials suggests that excessive fructose intake results in increased blood pressure in children and young adults. This effect would seem to be mitigated by urate-lowering therapy based on the hypothesis that the hypertensive effect of dietary sugars is mediated by the induction of hyperuricemia [Nguyen et al., 2009]. Current evidence suggests that added sugars are a source of excess fructose whereas the reduction of fructose (from added sugars) is likely to decrease uric acid, possibly improving blood pressure in children [Vos et al., 2016]. However, further researches are needed to test whether or not a reduction in added sugars results in improved blood pressure in children.

The preponderance of evidence

from the available cross-sectional and longitudinal studiesshows improved triglycerides and HDL values in children with low consumption of added sugars. Although traditionally triglycerides and HDL have not been a primary focus for decreasing CVD risk, newer data demonstrate that a high ratio of triglycerides to HDL predicts smaller dense low-density lipoprotein, an important cardiovascular risk factor [Burns, 2012]. However, even in this case more studies are needed.

Obesity and Obstructive Sleep Apnoea Syndrome

Obesity is a significant risk factor in the pathogenesis of Obstructive Sleep Apnea Syndrome (OSAS), since it alters the anatomy and the collapsibility of the airways as well as it alters the respiratory control. The association between obesity and OSAS has led to increasing attention to the role of weight loss as a potential treatment for OSAS.

Obese children have a greater risk of developing Sleep Disorders Breathing (SDB). Numerous evidences in literature show a correlation between OSAS and obesity, with a prevalence ranging from 13% to 50% of obese children and adolescents with OSAS and a prevalence of 25% polysomnographic alterations in obese children. Redline et al. examined the risk factors for SDB in a group of children between 2 and 18 years of age and found that there is a 4-5 times greater risk of developing RSD in obese children. In particular, for every 1 Kg/m^2 increase in BMI, compared to the mean BMI value for age and sex, the risk of OSAS increases by 12%.

In obese children with OSAS, the reduction of upper air way space is due not only to adenotonsillar hypertrophy, but also to the infiltration of adipose tissue between the neck and the lymphatic structures. In addition, subcutaneous fat in the anterior region of the neck and in the submental region, makes the upper airways more susceptible to collapse when the subject is in a supine position.

The subject with obesity is typically affected by a restrictive respiratory disorder in which visceral fat mechanically reduces lung volumes. Moreover, the increased abdominal adipose tissue, as well as in the thorax, increases the overall respiratory load and reduces the diaphragmatic excursion and the intrathoracic volume, especially in the supine position.

The mechanical role assumed by adipose tissue is not the only feature at the basis of aetiopathogenesis of SDB in obese children. Recent studies show that the abdominal adipose tissue induces a state of chronic inflammation, with increased levels of both C-Reactive Protein (CRP) and cytokines. The adipose tissue is able to produce and release various proinflammatory factors such as leptin and resistin, cytokines (IL-1, TNF-α, IL-6, IL-8, IL-10, VEGF, EGF, MCP-1) and chemokines (adiponectin) that contribute to the development of insulin resistance and predispose to cardiovascular damage.

Type-2 diabetes mellitus, NonAlcoholic Fatty Liver Disease and diet

In a balanced diet, the consumption of fructose naturally contained in foods (fruit, vegetables, flour used for bread, pasta and pizza) has no negative effect. The enemy of children is the added fructose present in syrups and sweetners widely used by industry in various preparations (jam or fruit preserve, drinks, snacks, fruit juices, sweets). A jar of jam has a fructose concentration 8 times greater than the daily requirement; a snack contains on average 45% more of it, while a small bottle of fruit juice contains just over half of the daily requirement.

Fructose is metabolised mainly in the liver. This synthesis process produces energy for the body, but also other derivatives such as uric acid. If the amount of fructose ingested systematically is excessive, its metabolism is altered and too much uric acid is produced. When the body cannot dispose of high concentrations of uric acid in circulation, dangerous mechanisms for health are triggered: oxidative stress increases and insulin resistance and inflammatory processes of the liver cells are activated. These mechanisms are precursors to the onset of diabetes and fatty liver.

Nonalcoholic Fatty Liver Disease (NAFLD) is a disease of lipid metabolism in which an excess of triglycerides accumulates in hepatocytes, thus increasing adiposity, hypertriglyceridemia, and increasing free fatty acid flux to the liver caused by insulin resistance.

NAFLD has increased in the world population to a worrying rate, becoming the most prevalent paediatric chronic liver disease [Berardis and Sokal, 2014]. This disease includes a spectrum of hepatic histological alterations. Diagnosis is made when at least 5% of hepatocytes is characterised by fatty infiltration with no evidence of infection, metabolic or autoimmune disorder, or steatogenic drug or alcohol consumption [Vos et al., 2017].

A relationship between fructose consumption in children and hepatic fat has been suggested [Jensen et al., 2018].

NAFLD in childhood has been demonstrated to have different characteristics from adults, primarily concerning histological findings with a predominant periportal inflammation in the pediatric age. Fructose consumption with consequent hyperuricemia has been shown to induce greater damage in the periportal zone than the perivenous zone [Abdullah et al., 2018].

In children with a liver already compromised, that relationship accelerates the progression of the disease to more severe stages (non-alcoholic steatohepatitis, liver fibrosis, and cirrhosis). Scientific confirmation comes from a study by researches of the area of hepato-metabolic disease of the Bambino Gesù Pediatric Hospital, in Italy, the results of which were published on the Journal of Hepatology. This study including 271 obese adolescents with biopsy-proven NAFLD showed that fructose consumption was significantly higher in patients with NASH (Non-Alcoholic Steatohepatitis) compared with NAFLD, and patients from the first group had significantly higher uric acid levels [Mosca et al., 2017]. However, more studies are needed because NAFLD doesn't occur in isolation and is almost always accompanied by visceral obesity, hypertriglyceridemia, low HDL, high non-HDL cholesterol, and/or insulin resistance [Jin et al., 2012].

SSBs contribute to high dietary glycemic load which leads to

inflammation, insulin resistance and impaired β-cell function. Studies suggest that greater SSBs consumption in childhood or adolescence predict weight gain into adulthood [Nissien et al., 2009; Viner and Cole, 2006]. Obese children are more likely to become obese adults, besides increasing their risk for higher rates of Type 2 diabetes mellitus (T2DM), heart disease and some cancer later in life [Cantley, 2014; Batrina and Rodrigo, 2013].

T2DM is a long-term multifactorial disease that is characterised by high blood sugar, insulin resistance and relative lack of insulin. In adolescents and young adults, T2DM seems to be a more aggressive disease than in middle age subjects, demonstrated by a less response to conventional treatment and a high mortality rate [Constantino et al., 2013].

A recent large cohort study found that a child with obesity has a 4-fold greater risk of being diagnosed with T2DM by age 25 than a counterpart who has normal weight [Abbasi et al., 2017]. Another well powered meta-analysis also found that individuals in the highest quartile of SSBs intake (most often 1-2 servings/day) have a 26% greater risk of developing T2DM than those in the lowest quartile (none/< 1 serving/month). This suggests the independent effect of SSBs intake on T2DM in addition to weight gain. Several high quality-systematic reviews and meta-analysis have assessed the correlation of SSBs with the T2DM incidence. Moreover, it remains unclear whether the association between SSBs and T2DM can be explained by the fructose that these beverages contain. Furthermore, added sugars appear to have a relationship with insulin resistance in overweight children but this findings is not demonstrated in normal-weight children.

Attention-Deficit/Hyperactivity Disorder and sugar intake

Children hyperactivity is a neurodevelopmental condition that is usually diagnosed in childhood and can last into adulthood. Symptoms include excessive motor activity and impulsivity, which lead to distraction and to significant attention deficit.

Diagnosis is made when these symptoms are more severe and persistent than is expected for the child's age and developmental level. Attention-Deficit/Hyperactivity Disorder (ADHD) is 6 to 9 times more common in boys than girls [Yujeong and Hyeja, 2011].

Some correlations between the consumption of sugar and the onset of ADHD have been highlighted, but these must be reconfirmed [Johnson et al., 2011; Del-Ponte et al., 2019]. However, from a physiological point of view, sugar should influence hyperactivity in children because it can quickly enter the bloodstream, making rapid changes in glucose levels and starting adrenaline production. Adrenaline is a hormone produced under stress, capable of providing a short-term energy boost to cope with critical situations. A recent study by paediatric researchers of Yale University confirmed the connection between sugar and adrenaline. The study showed that in a few hours healthy children who took high doses of sugar, on an empty stomach, produced high levels of adrenaline. The variation in the levels of this hormone caused tremor, anxiety, excitement and concentration problems. These reactions were observed only in children and a specialised examination revealed significant changes in their ability to pay attention.

Despite this, no direct association was established between ADHD and sugar consumption, since the study involved ingesting large quantities of sugar on an empty stomach. Thus, it can only be concluded that sugar can cause hyperactivity in children only when taken in large quantities.

We can conclude that it is still controversial whether or not there is an association between ADHD and sugar consumption.

Conclusions

Healthy approaches to beverage and dietary consumption should be established in infancy, with the aim of preventing negative health effects in later childhood and adulthood. Sugar should preferably be consumed as part of a main meal and in a natural form (human milk, cow or sheep milk, unsweetened dairy products, fresh fruits) rather than as SSBs, smoothies, fruit juices and sweetened milk products. Free sugars in liquid form should be replaced by water or unsweetened drink. The choice of fresh vegetables, whole foods, nuts and seeds and proteins with a low content of saturated fatty acids should be promoted. The consumption of added sugars, sugary snacks and drinks, salt and processed meats should be drastically reduced.

The consequences of poor nutrition in children can be permanent. Healthy and varied nutrition during childhood leads to a healthy and long life.

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