Critical Review
Cariology

Risk factors for dental caries in Latin American and Caribbean countries

Stefania MARTIGNON[(a)]
Angelo Giuseppe RONCALLI[(b)]
Evelyn ALVAREZ[(c)]
Vicente ARÁNGUIZ[(d)]
Carlos Alberto FELDENS[(e)]
Marília Afonso Rabelo BUZALAF[(f)]

[(a)]Universidad El Bosque, Caries Research Unit, Research Department, Bogotá, Colombia.

[(b)]Universidade Federal do Rio Grande do Norte – UFRN, Department of Dentistry, Natal, RN, Brazil.

[(c)]Universidad Científica del Sur, School of Dentistry, Department of Pediatric Dentistry, Lima, Perú.

[(d)]Universidad de los Andes, Faculty of Dentistry, Cariology Unit, Santiago, Chile.

[(e)]Universidade Luterana do Brasil, School of Dentistry, Department of Pediatric Dentistry, Canoas, RS, Brazil.

[(f)]Universidade de São Paulo – USP, Bauru School of Dentistry, Department of Biological Sciences, Bauru, SP, Brazil.

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Corresponding Author:
Stefania Martignon
E-mail: martignonstefania@unbosque.edu.co

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Abstract: Identifying the risk factors for dental caries is vital in epidemiology and clinical practices for developing effective preventive strategies, both, at the individual and collective levels. Different causality/determination models have been proposed to understand the development process of dental caries. In the present review, we designed a model inspired by the world-known social determinants models proposed in the 90s and more recently in the 10s, wherein the contextual factors are placed more externally and encompass the individual factors. The contextual factors included those related to the cultural and societal values, as well as the social and health government policies. The individual factors were classified into the following categories: socioeconomic (social class, occupation, income, and education level), demographic characteristics (age, sex, and ethnicity), behavioral factors (non-use of fluoride dentifrice, sugar consumption, poor oral hygiene, and lack of preventive dental care), and biological factors (recent caries experience/active caries lesions, biofilm retentive factors, developmental defects of the enamel, disabilities, saliva amount and quality, cariogenic biofilm). Each of these variables was addressed, while focusing on the current evidence from studies conducted in Latin American and Caribbean countries (LACC). Based on the proposed model, educational aspects were addressed, and individual caries risk assessment and management decisions were proposed; further, implications for public health policies and clinical practice were described. The identification of modifiable risk factors for dental caries should be the basis for multi-strategy actions that consider the diversity of Latin American communities.

Keywords: Dental Caries; Risk Factors; Socioeconomic Factors; Health Risk Behaviors; Biology

Introduction

A caries risk factor is defined as a factor/determinant, confirmed by temporal sequence and directly associated with an increased probability of caries.[1] The identification of caries risk factors is important in epidemiology and clinical practice for the development of effective preventive strategies at both, the individual and collective levels.

The theoretical assumption of causality and determination is hereby exposed in a model that describes how risk factors interact to pose a greater

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risk for the occurrence of dental caries. Although most factors are well documented in the literature, only description and knowledge of their respective mechanisms of action is insufficient. It is important to discuss the complex interplay among these factors.

Different causality/determination models have been proposed to understand the developmental process of caries. Many of these arise from the authors' theoretical elaborations, scientific literature,[2-5] or statistical and mathematical processes; with the latter, as recently proposed by Foley and Akers[6] who used the causal model based on the Directed Acyclic Graphs that maps the association between variables, creating a causal network. Other models are based on the existing proposals, such as the well-known social determinants model by Dahlgren and Whitehead[7] that employs concentric circles from the most proximal to the most distal factors. Several authors have adapted this model for oral health outcomes[8-11] by changing some variables while maintaining the idea of concentric circles.

In our study, we employed a modified model inspired by different approaches. One approach was the proposal developed by the World Health Organization (WHO)[12] to guide actions focused on the social determinants of health. The social determinants model[7] was also incorporated, recognizing the presence of distal and proximal factors in the determination of dental caries. In this model, the contextual factors are placed more externally, although they encompass the individual factors, not constituting themselves in different dimensions or belonging to the same level of determination. The contextual factors include those related to the cultural and societal values, as well as the social and health policies of the government. The individual factors were classified into the following categories: socioeconomic, demographic, behavioral, and biological factors (Figure 1). Each of these groups was composed of different variables that are discussed later in this article.

Considering the relevance of the consensus papers on caries that was very inclusive within the LACC, we developed the present critical narrative review. An electronic search of the dental literature was conducted in the PubMed, Scopus, LILACS, and SciELO databases, with appropriate keywords and/or phrases; further, a manual search was conducted.

Contextual factors

How are contextual factors usually assessed?

The assessment of the contextual effect on health outcomes is generally performed based on ecological studies, wherein a correlation between the aggregated values at different population levels (cities, states, and countries, in most cases) is analyzed. Since the mid-90s, multilevel models have been used frequently. A limitation of these studies, particularly in the area of oral health, is the poor quality or lack of data on the main problems in oral health, such as dental caries, that are discussed in greater detail in papers 1 and 5 of this LAOHA caries consensus.[13,14] The main repository of WHO-sponsored oral health data, the *Oral Health Country/Area Profile Project* (see at https://capp.mau.se/) maintained by Malmö University presents data from virtually every country in the world. However, these data are quite outdated and have poor accuracy. For some LACC, the most recent information available is > 20 y old, and very few population-based studies are representative of the entire country. However, in spite of these restrictions, the information can be used to assess the global profile of dental caries and the effect of contextual factors.

Databases are more reliable and provide more comprehensive information on socioeconomic variables. Worldwide, numerous researchers have tried to identify the relationship between health and socioeconomic indicators from these databases. In the field of oral health, most of them are based on the comparison of Decayed, Missing, and Filled Teeth (DMFT/dmft) index in different categories of socioeconomic indicators.

Dental caries and contextual factors in LACC

To understand the specificity of the relationship between dental caries and some contextual factors in the 33 countries included in the LACC, we performed an analysis with the data available from the cited sources. Data related to some socioeconomic indicators were gathered from the United Nations Development Programme (UNDP) (http://www.hdr.undp.org/en/data) and the World Bank (https://data.worldbank.org/). Previously collected 12-year DMFT data were

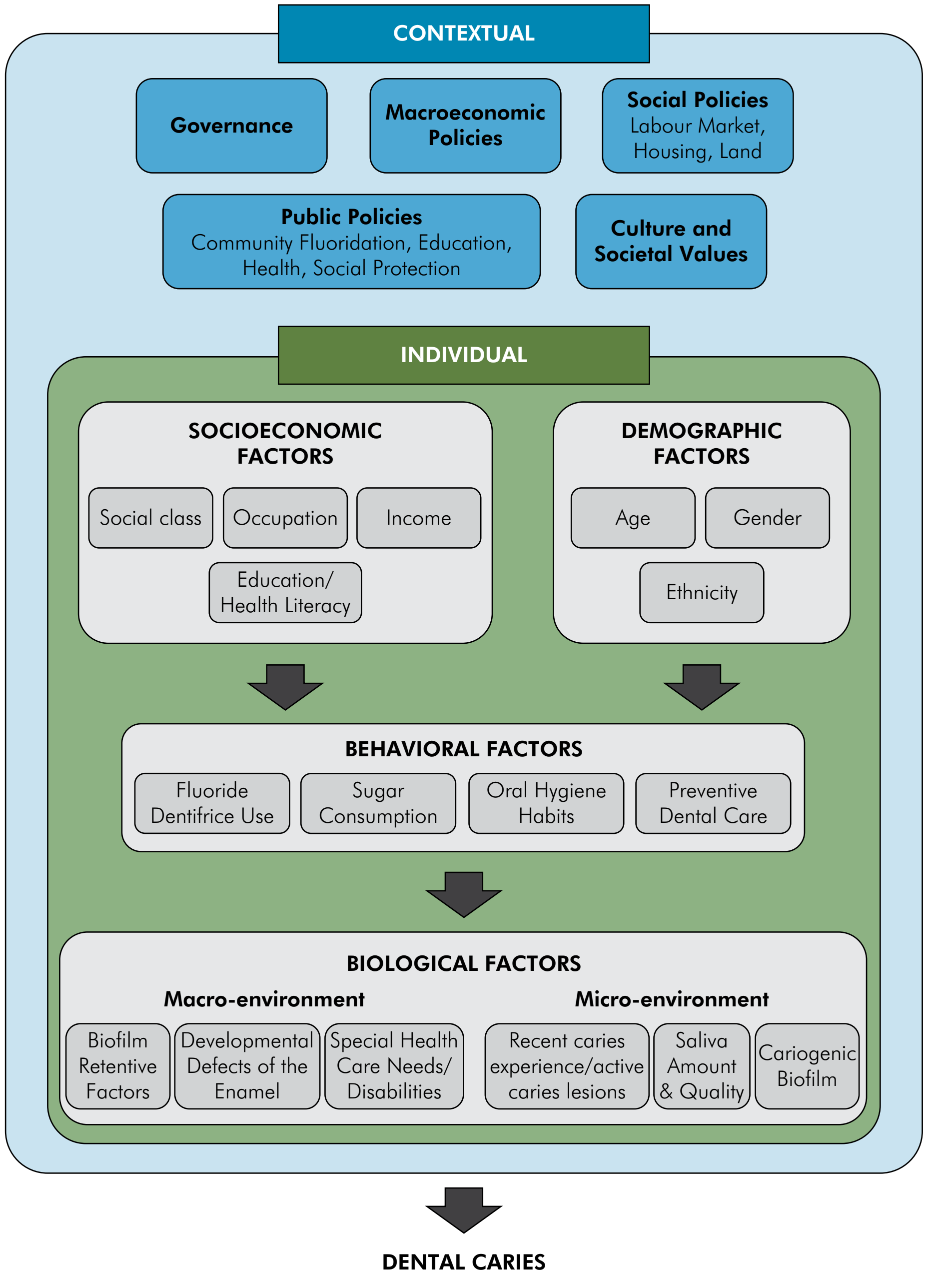
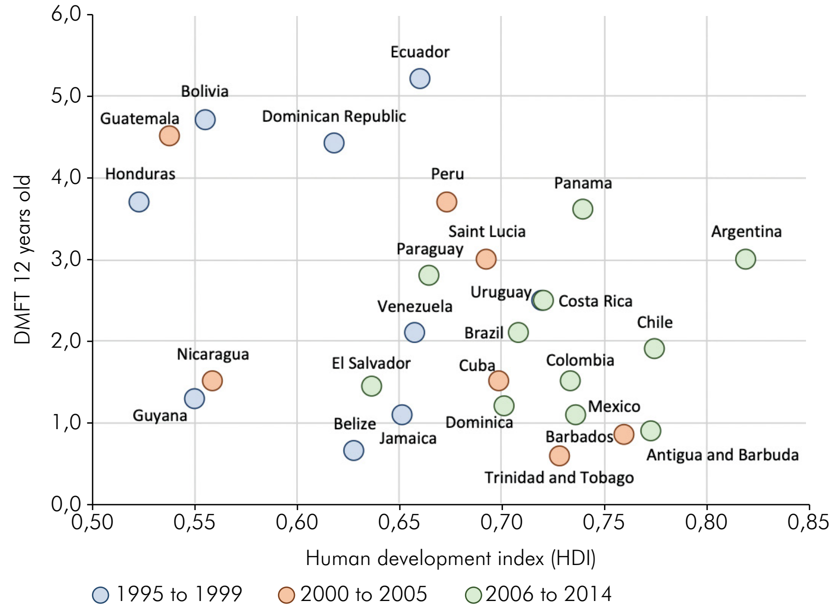


Figure 1. Conceptual framework for the caries risk factors inspired by the WHO Framework[12] and by Dahlgren and Whitehead.[7] Material created by the authors.

obtained from the aforementioned *Oral Health Country/ Area Profile Project* (https://capp.mau.se/). When possible, the database was updated based on a literature search. The reference years in the DMFT database ranged from 1995 to 2014; therefore, we used the socioeconomic data of a year as close as possible. Countries for which data were unavailable for both the variables were excluded from the analysis.

Figure 2 shows the correlation between the DMFT at the age of 12 y and the Human Development Index (HDI), with a weak negative correlation being observed between them; however, the small number of observations rendered no statistical significance and only indicated plausibility.

A similar trend was observed with the Gini index (Figure 3), albeit with a positive relationship; higher



The Human Development Index (HDI) is a statistic composite index of life expectancy, education (Literacy Rate, Gross Enrollment Ratio at different levels and Net Attendance Ratio), and per capita income indicators that are used to rank countries into four tiers of human development. Countries that score higher show greater achievements; Different colors represent the range of years when the data were collected; The circle size is proportional to the population; Pearson correlation only for LACC ($r = -0.345$; $p = 0.078$); Source: Prepared by the authors from the data available at the United Nations Development Programme (UNDP) and the Oral Health Country/Area Profile Project.

Figure 2. Correlation between DMFT in 12-year-old children and the Human Development Index (HDI) in LACC. Material created by the authors.

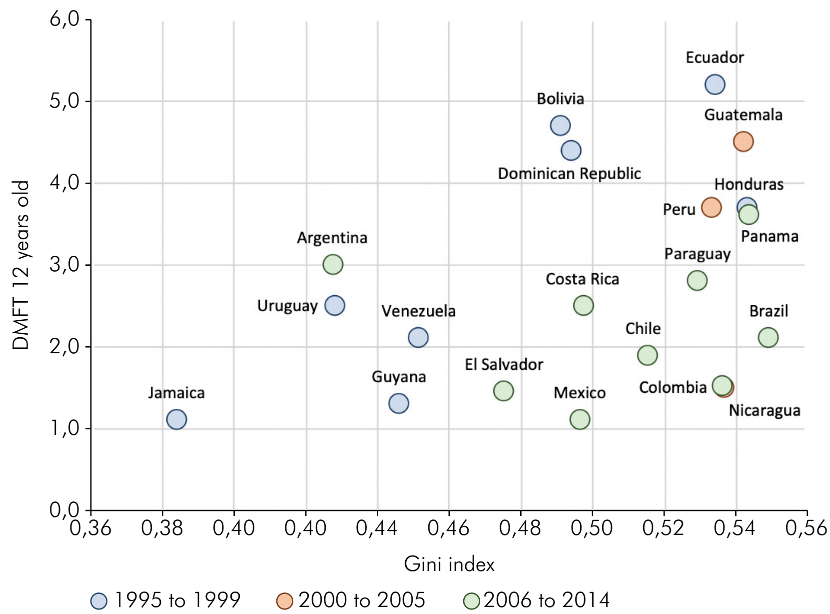
the index, greater the degree of inequality. Countries with lower inequality, such as Uruguay, Jamaica, and Venezuela, and those with greater inequality, such as Ecuador and Guatemala, had lower and higher DMFT values, respectively. This analysis had some limitations, mainly regarding the low extent of the updated data; however, it is important to highlight that this profile was similar to other countries that used more recent information.

As discussed by Roncalli et al.,[15] an association of HDI with DMFT has been observed in Brazil and other countries. Studies using local data, such as the study conducted in Brazil, found a correlation between HDI and oral health outcomes.[16-25] Trials performed in Colombia, Ardila and Agudelo-Suárez[26] showed an association between low HDI and dental pain using a multilevel approach.

The HDI and the Gini index constitute two important aspects of contextual factors because they both represent both a positive characteristic relative to human development index (HDI) and a negative one relative to income inequality, as can be seen in the related Figures 2 and 3 description. This is particularly important because greater indicators of longevity, income, and education are not always associated with greater income distribution; thus, from the viewpoint of the social determination of the disease, these factors have quite different roles.

Bernabé and Hobdell[27] analyzed data from 48 countries and showed an association between the Gini index and previously collected 5 to 6-year dmft values. Only the 22 wealthiest countries were included; therefore, the Gini index presented a significant association, unlike the Gross National Income that showed no association. A significant association between HDI and Gini index was found with a reduction in the incidence of dental caries in Brazilian children when the associated social factors were analyzed.[15]

Another important aspect of contextual factors is the effect of public health and well-being policies. Such analyses are complex, owing to the difficulty of measuring the offered health services. Most studies have analyzed access to health services from an



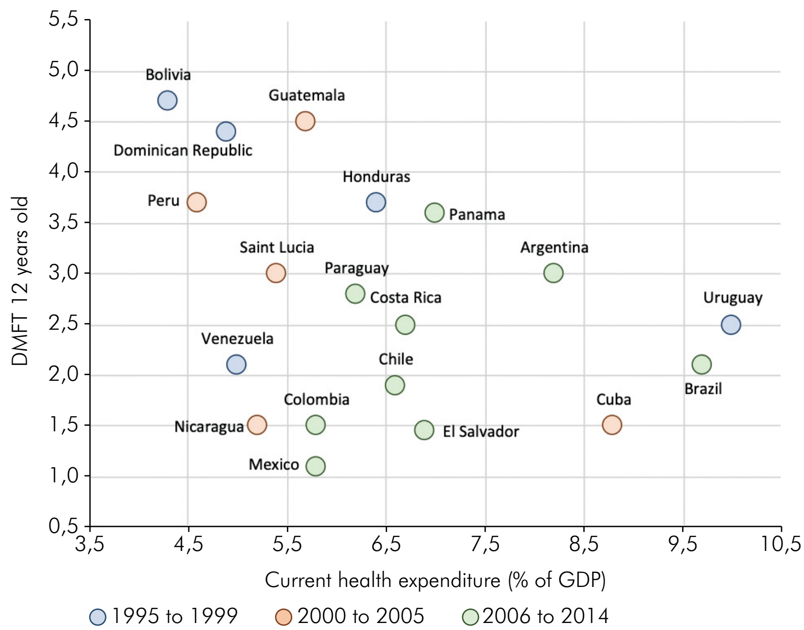
The Gini Index is a measure of statistical dispersion intended to represent the income inequality or wealth inequality within a nation or any other group of people; it measures the inequality among values of a frequency distribution (for example, levels of income). A Gini Index of zero expresses perfect equality, where all values are the same (for example, where everyone has the same income); Different colors represent the range of years when data were collected; Pearson correlation for LACC (r = 0.374; p = 0.103); Source: Prepared by the authors from data available at the World Bank and the Oral Health Country/Area Profile Project.

Figure 3. Correlation between DMFT in 12 years old children and Gini Index in LACC. Material created by the authors.

individual perspective, and in general, based on the use of these services.[22] Guarnizo-Herreño et al.[28] reported the existence of oral health inequalities in adults in all European welfare-state regimes; further, they observed that particular behaviors played a heterogeneous role in explaining these inequalities across the evaluated welfare regimes.[29]

One way of assessing the effect of health policies is to estimate the extent to which countries prioritize health in their public -funding models. Relationships with the workforce, such as the inhabitant/dentist relationship or oral health services coverage is relatively common.[15,19,21,30-33] Most of these studies employ the ecological approach that has intrinsic biases that may interfere with the observation of a genuine effect. One of these biases is attributable to the exposure and outcome being observed at the same time. A given public policy takes a certain amount of time to produce measurable effects, and the best designs to assess them are longitudinal ones or those based on panel data analysis. In any case, ecological studies that aim to evaluate the correlation between the provision of health services and a specific characteristic of the health system, such as financing, are useful because they help generate hypotheses. Figure 4 shows the correlation between these variables. Countries with low investment in health, such as Bolivia, Dominican Republic, and Guatemala, have higher DMFT values. In contrast, countries, such as Argentina, Brazil, Cuba, and Uruguay, that have a higher percentage of investment, have lower DMFT values.

A relevant aspect in this context is the presence of community fluoridation programs. Among these, water fluoridation is the most commonly employed program across the world[34] and is considered the most effective and socially equitable means of achieving community-wide fluoride protection against dental caries.[35] The recommended fluoride water concentration ranges from 0.6 to 1.1 mg/ L,[36] depending on the climate, to achieve a balance between the potential for dental caries reduction and development of dental fluorosis.[35] Water fluoridation programs have an estimated cost of US$ 0.11–4.92/year/capita,[34] and these measures are backed by strong evidence that has demonstrated a



Level of current health expenditure expressed as a percentage of gross domestic product (GDP); estimates of current health; Expenditures include healthcare goods and services consumed during each year; Different colors represent the range of years when data were collected; Pearson correlation for Latin American and Caribbean countries (r =-0.463; p = 0.039); Source: Prepared by the authors from data available at the World Bank and the Oral Health Country/Area Profile Project.

Figure 4. Correlation between DMFT in 12 years old children and current health expenditure (% GDP) in LACC. Material created by the authors.

reduction in the caries prevalence by 26%–35%.[35-36] In contrast, the estimated cost of salt fluoridation is US$ 0.02–0.05/year/capita.[37] The meta-analysis by Yengopal et al. favors it but it states that related available studies are graded as poor-quality.[38] A systematic review[35] suggested that milk fluoridation was beneficial in preventing/reducing caries; however, the quality of evidence was also inferior to that for water fluoridation. The Pan American Health Organization (PAHO) in 1994 launched a multi-year plan to support water and salt fluoridation programs in Central America, South America, and Caribbean countries. It aimed to include more than 400 million people for both the programs by 2010.[39] A table describing the type of community fluoridation and the relevant details in LACC can be found in the "Community interventions and strategies" paper of this LAOHA caries consensus document.[40]

The variable availability of fluoridated toothpaste across countries represents an additional contextual risk factor in Latin America, exposing a large part of the population to an increased risk of dental caries. The legislations of most countries do not ensure that toothpastes have a minimum soluble fluoride concentration so that they exert an anti-caries effect (1,000 ppm of soluble fluoride) mostly because they prioritize the safety of fluoride toothpastes over their anti-caries potential.[41]

Contextual factors are not risk factors per se. They work as modulating elements that must be interpreted as the causes of the causes.[42] In other words, there is no direct way to transport the contextual effects to the individual level. This statement has important implications in the field of dental practice. While it is essential to determine the individual risk factors to guide appropriate interventions, we wish to emphasize that how individuals react to preventive and therapeutic measures depends on the context in which they live. Such reductionism enables an etiological understanding of how ecological exposures affect health; however, it may be counterproductive. In the realm of public health policy and action, contextual factors may serve as the most practical points of intervention in the chain of events.[43,44]

Individual factors

Socioeconomic and demographic factors

This group of caries risk factors comprises social class, occupation, education level, income, sex, age, and ethnicity.

Social class is defined by ownership; it explains how economic inequalities are generated, and how they can influence health.[45] There is a strong association of social and economic conditions with the occurrence of dental caries, indicating that individuals living in low socioeconomic conditions have greater exposure to risk factors that could influence their burden of dental caries.[46,47] A Colombian study demonstrating oral-health inequalities in early childhood found significant associations of caries experience, age, and caregivers' lower educational level.[48]

Occupation is an indicator of the socioeconomic position, determining the individual's place in the societal hierarchy and commonly includes parental occupation as an indicator of a child's socioeconomic position. However, the occupational indicator cannot be assigned to unemployed people; this could underestimate the socioeconomic differences.[45]

Education level is an indicator of the parents' socioeconomic position, determines family income, and is associated with oral health outcomes. Moreover, education provides skills and knowledge that could enable communication; therefore, people become more receptive to oral health information.[49] A systematic review showed that lower parental education was associated with a higher risk of dental caries.[50] In a similar manner, lower maternal educational level was associated with lesser use of dental services, and these children of such mothers with scarce oral health knowledge could have poorer oral health.[51] Oral health literacy has been so far considered in a systematic review as a mediator more than a direct factor for oral conditions, including dental caries.[52]

In addition, income is an indicator of the socioeconomic condition. Family income can be a useful indicator because family expenses are commonly shared by household members.[45] A higher risk of carious lesions has been associated with lower socioeconomic level.[46] In a similar manner, low -income families usually have a diet rich in sugars and fats that in turn led to a higher caries incidence in their children. Family income controls the access to education and oral health services. Therefore, low economic level is associated with scarce preventive care and lowered the prevalence of dental visits.[46]

Sex-based differences have been reported in epidemiological studies with a significant higher prevalence of dental caries in girls than in boys; further, more women use dental health care services.[53,54] A systematic review showed a higher rate of dental caries in Brazilian women.[51] Social and cultural differences between men and women could influence their oral health conditions in different manners.[55]

Race/ethnicity refers to social groups that share ancestry and cultural heritage. It is frequently used for identifying unequal distribution of disease burden, indicating a higher prevalence of dental caries in immigrants or ethnic minorities.[56] Researchers are advised to avoid using race unless the observed differences regarding dental caries cannot be explained by genetics, and the possibility of inadvertently exhibiting racism (individual and structural) should be considered. However, race is not a proxy for racism, but an explanation that should be better studied.[57] However, socioeconomic conditions play an essential role in the association between health and race/ethnicity because oral health problems particularly affect underprivileged people.[45]

Epidemiological surveys have demonstrated an increased prevalence of caries with age, secondary to the cumulative and chronic nature of dental caries. Considerable caries related problems can occur in adults,[58] and older children can have more advance -staged carious lesions than younger children.

Socioeconomic and demographic factors in LACC

In a systematic review,[51] a recent Brazilian population-based study showed that non-white ethnic groups had a higher prevalence of caries in children.[26] Several studies conducted in Latin American indigenous people have shown a rise in the caries prevalence and severity,[45] with a systematic review concluding that sex-based differences and increasing age were associated with a higher caries experience in Guarani and Xavanti groups in Brazil.[59] With respect to the parents' low educational level, an association was found with higher caries prevalence in cross-sectional studies conducted in Colombia,[60] Mexico,[61] and Chile.[62] Further, low socioeconomic status was associated with a higher prevalence of dental caries.[51,63] A national-level study done in Colombia that looked at the association of different socioeconomic-position dimensions and oral health found that those who lacked national-health insurance and those with lower education levels showed the highest oral health problems.[64]

Cross-sectional studies conducted in Chile in 2–4-year-old and 4-year-old children,[65] as well as in Colombia in 8–71-month-old children,[46] and in Mexico in 3–6-year-old children[61] showed that older age was associated with an increased relevance and severity of caries.

Table 1 shows some studies with respect to the socioeconomic and demographic risk factors and caries in Latin America.

Behavioral risk factors

Behavioral risk factors include dietary practices, mainly high intake of free sugars, lack of oral hygiene, inadequate exposure to fluoride with emphasis on non-use of fluoride toothpaste, and irregular preventive dental care.

Dietary practices

The consumption of free sugars (*i.e.*, sugars added to food and beverages and sugars naturally present in honey, syrups, fruit juices, and fruit juice concentrates) is the key factor that governs the occurrence of caries and modulates other factors, such as the dental biofilm.[73,74] There is evidence that the following two characteristics enhance the role of dietary practices in the trajectory of caries incidence: the age at which sugar is introduced and the frequency of sugar consumption. Cohort studies have shown an association between

Table 1. Investigations regarding socioeconomic and demographic risk factors of dental caries in LACC according to age group.

Author	Study design	Country	Age group	Age (months-m /years-y)	Sample size	Main result
Martignon et al., 2018[48]	Cross-sectional	Anapoima, Colombia	Children	8–71 m	316	Older age and caregivers' low-level education associated with caries.
Zaror et al., 2011[65]	Cross-sectional	Chile		2–4 y	301	Older age associated with caries.
Guizar-Mendoza et al., 2019[61]	Cross-sectional	Bajo León, Mexico		3–6 y	292	Older age and parents' low-level education associated with caries.
Feldens et al., 2010[66]	Cohort	São Leopoldo, Brazil		4 y	340	Mothers' low-level education associated with caries.
Montes et al., 2019[67]	Cross-sectional	Curitiba, Brazil		4–5 y	415	Caregiver's oral health literacy associated with caries.
Herrera et al., 2013[68]	Cross-sectional	Nicaragua		6–9 y	794	Age associated with caries.
Brito et al., 2020[26]	Cross-sectional	São Paulo, Brazil		12 y	26,325	Non-white ethnicity associated with a higher caries prevalence.
Freire et al., 2013[69]	Cross-sectional	Brazil		12 y	7,247	Low income and non-white ethnicity associated with a higher caries prevalence.
Solis-Riggioni et al., 2018[70]	Cross-sectional	Costa Rica	Children and Adolescents	2–17 y	201	Socioeconomic factors associated with caries.
Díaz-Cardenas et al., 2010[60]	Cross-sectional	Cartagena, Colombia		4–13 y	243	Parents' low-level education associated with caries.
Casanova-Rosado et al., 2005[63]	Cross-sectional	Campeche, Mexico		6–13 y	1,806	Low socio-economic status, older age and mother's low-level education level associated with caries.
Echevarria-Lopez et al., 2020[62]	Cross-sectional	Chile	Adolescents and Adults	17–18 y	405	Mother's low-level education associated with caries.
Urzua et al., 2012[71]	Cross-sectional	Cartagena, Colombia	Adults and Elderly	35–44 y 65–74 y	1,088	Age, education level and incomes associated with caries.
Álvarez et al., 2013[72]	Cross-sectional	Uruguay		35–44 y 65–74 y	769	Low socio-economic status was associated with caries.

sugar consumption in the first year of life and the occurrence of dental caries in subsequent years.[75] The early introduction of sucrose in the life of an infant promotes the establishment of a cariogenic microbiota and successive colonization of new dental surfaces. Moreover, early exposure to sugar boosts a child's preference for sweets, resulting in higher consumption of sugar in foods and beverages.[76]

Investigations involving different populations have shown the role of high frequency of sugar intake in the occurrence of caries.[66,74,77,78] There is a dose-dependent response between the ingestion of carbohydrates and dental caries in children and adults; with a greater intake of carbohydrates, especially sugar, increasing the risk of caries. This association is established by the repeated production of acids and the maintenance of a very low pH in the dental biofilm; this is observed in children with high food intake, impeding the physiological replacement of minerals in the de-mineralization/ re-mineralization cycle.

Some studies have examined the effect of two specific dietary practices on the occurrence of caries in children. Breastfeeding lowers child morbidity and mortality and appears to exert a protective effect against the occurrence of caries in the first year of life. However, birth cohort studies controlling for sugar intake have shown a greater risk of caries in infants who breastfeed for > 12 months of life and with a high frequency.[79] Moreover, studies have shown that the use of bottles, especially for sugary beverages at night, was associated with dental caries.[66] Increased risk of caries is related to the sugar content (generally sugar-sweetened beverages) and its accumulation on the biofilm on central incisors that are the most affected teeth in younger children. The cariogenicity of both practices is dependent on the frequency of added sugar consumption. Such sugar is usually offered as a pacifier, mainly at night, when the salivary flow is lower.

In children and adolescents, greater consumption of added sugar increases the risk and occurrence of caries.[74] The risk of caries is lower when the daily consumption of free sugars is reduced to < 10% of the total energy. Moderate evidence shows that the amount and frequency of sugar intake are correlated: children and adolescents who eat sugar frequently tend to consume a large amount of sugar.[80]

Oral hygiene and fluoride toothpaste

Oral hygiene measures aim to remove the dental biofilm, the metabolic activity of which can result in the loss of minerals. Therefore, an increase in the risk of caries in children who do not practice tooth brushing is plausible. However, the quality of the disturbance of the biofilm seems relevant, although a recent systematic review does not show any conclusive evidence on the effectiveness of supervised tooth brushing on caries incidence.[81] Biofilm removal could interact with the diet, as shown in an epidemiological study in children where a higher caries risk was associated with increasing levels of biofilm at all levels of sugar intake, suggesting a synergistic interaction between these two behavioral factors.[82] Furthermore, most people do not remove dental biofilm completely during tooth brushing. Thus, the amount of fluoride retained in the biofilm during tooth brushing is involved in caries control.[83]

Brushing is a simple and cost-effective way of constantly supplying fluoride to the oral cavity.[84,85] However, brushing with a non-fluoridated toothpaste is associated with a higher incidence of caries in children, adolescents, and adults.[81,86] Thus, individuals who combine regular tooth brushing with fluoridated toothpaste have a lower risk of dental caries.[87] There is no clinical evidence of a higher reduction in the risk of caries when the brushing frequency is > 2 times a day,[88] while there is a higher reduction in the risk of caries with increased fluoride concentration in the toothpaste.[87]

A recent critical review conducted in Latin America has shown that one of the most common risk indicators for gingivitis is poor oral hygiene,[89] further highlighting the importance of oral hygiene.

Regular preventive dental care

Regular dental care combines individual behavioral factors with public-policy contextual factors (Figure 1). Absence of regular preventive dental care is associated with a higher number of fillings[90] and poor oral health[47] in adulthood.

The behaviour of attending regularly has been linked to keeping teeth healthy.[91] There is a trend to move toward extended recall intervals and individualized preventive care as per the caries risk.[92-94] In this context, periodic application of fluoride varnish (or gel) has a substantial caries-inhibiting effect in both, permanent and primary teeth[95,96]. Although not sufficiently established, the interval of dental visits depends on the risk classification of the patient in addition to age. It can vary from 3 months (in higher caries risk) to 12 and 24 months (in lower caries risk) in children and adults, respectively.[92,93,97]

Behavioral factors in populations from Latin America

Studies conducted in Brazil, Chile, and Colombia show that most children in different Latin American communities have access to foods with added sugars in the first two years of life and consume these foods with high frequencies and quantities during early childhood (Table 2). A study involving a representative, multinational sample of adolescents and adults from eight Latin American countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Peru, and Venezuela) showed a high frequency of excessive added sugar intake, with minimal differences among the countries.[98] In contrast, the practice of brushing teeth with fluoridated dentifrices has been widespread in Latin American countries since childhood.[99-102] However, some studies have suggested that this habit begins later and occurs less frequently among families with lower socioeconomic status.[103-105]

Table 2 shows some trials on the behavioral risk factors and caries in LACC.

Clinical implications

Knowledge on behavioral caries risk factors suggests that delaying the introduction of sugar in the first years of life; reducing the frequency of consumption throughout life; and exposing children, adolescents, and adults to tooth brushing with a fluoridated toothpaste are potential interventions for reducing the burden of this disease. Excess sugar intake is also a risk factor for cardiovascular disease, diabetes, and obesity;[120,121] therefore, reducing its consumption in individuals should be a goal for all health professionals. The adoption of healthier eating habits does not depend only on behavioral change. Eating practices are also influenced by advertising and food availability at supermarkets and schools. In Latin America, Chile, Peru, Uruguay, and Mexico have nutrient warning policies for reducing sugar intake, recognizing it as a threat to human health.[122]

Biological factors

This group of caries risk factors comprises recent caries experience and active caries lesions, saliva, cariogenic biofilm, plaque stagnation areas, and developmental defects of the enamel.

Both, systematic and narrative reviews have reported that caries experience is the best predictor for the development of caries lesions in the future,[123-129] with moderate to good accuracy in preschool children and limited accuracy in school children/adolescents.[123,124] As a single-risk factor, past or active caries has been classified as strong evidence-based recommendation.[127] Further, the highest caries incidence risk in permanent teeth is seen in the first few years after tooth eruption.[130,131]

Saliva is the most important biological factor involved in the protection against dental caries for several reasons, as follows: a) its buffering capacity restores the dental biofilm pH when the bacteria produce acids; b) salivary flow rate removes the acids from the oral cavity; c) it is supersaturated with calcium and phosphate with respect to the enamel mineral, thus promoting dental re-mineralization under favorable conditions; d) salivary proteins are the main components of the acquired enamel pellicle that acts as a semipermeable barrier, reducing the contact of the acids with the teeth.[132,133] Thus, hyposalivation is related to dental caries.[134] Some systemic and metabolic disorders, such as Sjögren´s syndrome, medications, and head and neck irradiation, may cause salivary hypofunction, increasing the risk of caries.[91,135,136]

The oral microbiota on clinically sound enamel surfaces comprises mainly non-mutans streptococci and *Actinomyces*. In this case, acidification is mild and uncommon, and there is an equilibrium between de- mineralization and re-mineralization or a shift toward re-mineralization. With frequent sugar consumption, there is increased acid formation that changes the composition of the microbiota, increasing acidogenic and aciduric bacteria (*mutans streptococci*,

Table 2. Investigations regarding behavioral factors and dental caries in LACC according to age group.

Author	Study design	Country	Age group	Age (months-m /years-y)	Sample size	Main result
Lopez del Valle et al., 1998[105]	Cross-sectional	Puerto Rico	Children	6–47 m	167	Night bottle, persons, F- dentifrice & child's age associated with caries.
Hoffmeister et al., 2016[106]	Cross-sectional	Southern Chile		2–4 y	2,987	Sugary drinks high-frequency bedtime consumption associated with caries.
Ribeiro et al., 2017[77]	Cohort	São Luís, Brazil		2–5 y	388	High frequency of sugar consumption associated with caries.
Macias et al., 2016[107]	Cross-sectional	Colombia		24–60 m	546	Dental visits, treatment, oral hygiene, diet & malnutrition associated with caries.
Feldens et al., 2018[78]	Cohort	Porto Alegre, Brazil		3 y	345	High frequency feeding associated with caries.
Percival et al, 2019[108]	Cross-sectional	Trinidad & Tobago		3–5 y	342	Bottle feeding and high plaque levels associated with caries.
Feldens et al., 2010[66]	Cohort	São Leop., Brazil		4 y	340	High density of sugar associated with caries.
Melo et al., 2019[109]	Cohort	Recife, Brazil		5–7 y	469	Consumption of sweets associated with caries.
Ramón-Jimenez et al., 2016[110]	Cross-sectional	Cuba		5–11 y	300	Poor oral hygiene and dental crowding associated with caries.
Herrera et al., 2013[68]	Cross-sectional	Nicaragua		6–9 y	794	Biofilm and toothbrushing associated with caries.
Cipriano-Martinez; Chipana-Herquinio, 2017[111]	Cross-sectional	Perú		6–12 y	129	Poor oral hygiene associated with caries.
García Pérez et al., 2019[112]	Cross-sectional	Mexico, Mexico		8–12 y	522	More sweets per day associated with caries.
Bedos; Brodeur, 2000[113]	Cross-sectional	Haiti		12 y	322	Dental hygiene and sugar intake associated with caries.
Palacios et al., 2016[114]	Cross-sectional	Puerto Rico		12 y	1,587	Carbohydrates, sugars, sucrose, fructose / inositol intake associated with caries.
Fernandez-Vega et al., 2014[115]	Cross-sectional	Venezuela	Children and Adolescents	12–14 y	240	Scarce brushing and rich-carbohydrate foods ingestion associated with caries.
Arrieta-Vargas et al., 2019[116]	Cross-sectional	Guerrero, Mexico	Adolescents	15 y	1,424	Intake of snacks, sweets, and soft drinks associated with caries.
Carmo et al., 2018[117]	Cross-sectional	São Luís, Brazil	Adolescents and Adults	17–18 y	405	Added sugar consumption associated with caries.
Peres et al., 2016[74]	Cohort	Pelotas, Brazil	Adults	18 y	307	The higher the sugar consumption along adolescence, the higher the caries increment.
Rivera-Cruz et al., 2017[118]	Cross-sectional	Cuba	Adolescents, Adults and Elderly	15–69 y	352	Poor oral hygiene and cariogenic diet associated with caries.
Diaz-Sanchez, et al., 2018[119]	Cross-sectional	Cuba	Elderly	Elderly	166	Poor oral hygiene and cariogenic diet associated with caries.

Only studies with samples ≥ 100 participants were included.

lactobacilli, *bifidobacteria*, and yeasts). The net result is the de-mineralization of enamel.[137]

Plaque stagnation areas increase the accumulation of dental biofilm. Consequently, recently erupted first permanent molars are at higher risk of occlusal caries within the first post-eruption year and second permanent molars within the second and third post-eruption years.[124,138,139] This was confirmed in a study performed in Colombian on the first permanent molars of 6-year-old children and the first and second primary molars of 2-year-old children.[139] In particular, Cortes et al.[140] found an increased caries risk on the distal area of the first primary molar when the neighbor primary molar had a concave proximal-surface.

Developmental defects of enamel (DDE) with areas of enamel loss or incomplete mineralization are considered as risk factors for caries related to dental biofilm stagnation.[141] Systematic reviews have shown an association between DDE and caries in the primary[142] and permanent dentition, respectively.[143]

Disabilities caused by a physical or intellectual deficiency, such as cerebral palsy and Down's Syndrome, respectively, may interfere with an individual's routine functions. They may have special needs for assisted tooth brushing, the lack of which can compromise their oral hygiene, increasing their caries risk.[144] Older age is also related to an increased caries risk because of health deterioration and dependence on other people to perform oral hygiene practices.[145]

Table 3 shows some studies conducted in LACC that have reported an association between dental caries and biological factors.

Individual caries risk assessment

Dental caries is a non-communicable disease with a multifactorial etiology that shares risk factors with other highly prevalent non-communicable diseases, such as obesity, diabetes, and cardiovascular disease; sugar intake is one of these risk factors.[97]

The individual caries risk assessment (CRA) is the clinical process of classifying the probability that caries lesions will appear or progress if the conditions remain the same within a defined period.[1,123] It relates to a patient-centered caries management to reduce the risk of caries.[1] CRA is supported in a scientific causal

Table 3. Investigations regarding biological risk factors and caries in LACC according to age group.

Author	Study design	Country	Age group	Age (months-m / years-y)	Sample size	Main result
Cortes et al., 2018[139]	Cohort	Colombia	Children	2–6 y	352	Erupting primary molars and erupting first permanent molars associated with caries.
Cortes et al., 2018[140]	Cohort	Colombia		3–4 y	52	A concave proximal-surface morphology between primary molars associated with a caries lesion in distal of the 1st molar.
Segovia-Villanueva et al., 2006[146]	Cross-sectional	Campeche, Mexico		3–6 y	1,303	Presence of enamel defects associated with caries.
Velasquez et al., 2019[147]	Case-control	Venezuela		6 y	36	Saliva buffering capacity, calcium/ phosphate associated with caries.
Gambetta-Tessini et al., 2019[148]	Cross-sectional	Talca, Chile		6–12 y	577	MIH and HSPM associated with caries and caries severity.
Casanova-Rosado et al., 2005[63]	Cross-sectional	Campeche,		6–13 y	1,806	Enamel defects associated with caries.
Taboada-Aranza et al., 2018[149]	Cross-sectional	Mexico		6–13 y	194	Erupting first permanent molar associated with caries.
Villanueva-Gutierrez et al., 2019[150]	Cross-sectional	Mexico		8–12 y	506	Moderate/severe MIH associated with cavitated carious lesions.
Acevedo et al., 2009[151]	Cross-sectional	Venezuela	Children and Adolescents	2–19 y	48	Biofilm *S. mutans* in caries-affected/free children not associated with caries.
Lopez-Olvera et al., 2018[152]	Cross-sectional	Mexico		3–15 y	42	*S. mutans* in saliva associated with caries.
Cornejo et al., 2008[153]	Cohort	Cordova, Argentina		5–14 y	46	Phosphorus/calcium levels associated with caries.
Santos et al., 2009[154]	Cross-sectional	Brazil	Children, Adolescents and Adults	2–21 y	65	Cerebral palsy associated with caries.
Martinez-Pabón et al., 2013[155]	Cross-sectional	Colombia	Adolescents and Adults	17–34 y	120	Calcium/phosphate concentration and bacteria associated with caries.
Usuga-Vacca et al., 2020[145]	Cross-sectional	Colombia	Elderly	71–89 y	226	Exposed surfaces and coronal caries associated with root caries.

relationship based on risk models, programs, or single predictors validated via prospective cohort studies.[129] The extrapolation of findings from high-quality predictive studies to the dental practice should be performed cautiously.[123]

Although the best indicator of a patient developing caries in the future is previous caries experience,[123,124] the scientific evidence of standardized CRA is still limited;[123,124,129,130] therefore, multivariate risk assessment models are considered optimal for clinical practice because they overcome assessing dental caries risk with only single predictors. These models consider socioeconomic factors, general health, behavior, diet, oral hygiene, and clinical factors including saliva.[97,123,156-158]

CRA is considered a part of the best practices in caries management decision-making, including recall intervals,[91,97,123,159] with desirable effects mostly overweighting the undesirable effects.[160] The multivariate risk models have shown moderate to good accuracy for early childhood caries and lower accuracy for children, adolescents,[123] and adults.[157,158]

Risk assessment models specifically developed for children aged < 6 y include the Dundee Caries Risk Assessment Model (DCRAM) and MySmileBuddy. Those for older children, adolescents, and adults include the Cariogram (also for younger children), the Caries Management by Risk Assessment (CAMBRA), the National University of Singapore model (NUS), the Caries Risk Tool (CAT), PreViser, the Caries Risk Pyramid, the American Dental Association (ADA) caries risk tool, the DCRAM, and the American Association of Pediatric Dentistry model (AAPD).[123,160,161]

More recently, for individuals off all ages, the CariesCare International (CCI), derived from ICCMS, developed a caries risk assessment model by consensus, taking concepts from Cariogram, ADA, and CAMBRA, among others[97] (Figure 5). The CCI individual risk assessment model considers protective factors, social/medical/behavioral risk factors, and clinical risk factors. Protective factors relate to the use of ≥ 1000 ppm fluoridated toothpaste twice a day, dental preventive care, and accessible community fluoride. Social/medical/behavioral risk factors emphasize as the more relevant risk factor the presence of hyposalivation, followed by a high intake of free sugars, while clinical risk factors consider as a key risk factor a recent caries experience and/or the presence of active caries lesions.

CCI considers active caries lesions between smooth, occlusal and proximal tooth surfaces[128] better reflections the metabolic activity in the biofilm.[124] Active carious lesions can be categorized by using the clinical ICDAS-merged severity and activity criteria as follows: based on their severity - initial (ICDAS 1 and 2; non cavitated), -moderate (ICDAS 3 and 4; microcavity and underlying dentine shadow), and - extensive (ICDAS 5 and 6; cavitated), and based on their activity - active when initial/moderate carious lesions present as whitish/yellowish, opaque, rough to gentle probing, in a plaque stagnation area, and as extensive carious lesions when the dentine feels soft or leathery on gentle probing.[97] Figure 6, depicts the ICDAS-merged severity and activity criteria.[97] CCI classifies the patient into the following two risk categories: "lower caries risk" or "higher caries risk," applying a simplified and practical version following a more ethical path,[129] and highlighting clear best-practice management needs, including homecare, clinical approaches, and risk-based intervals (Figure 5).

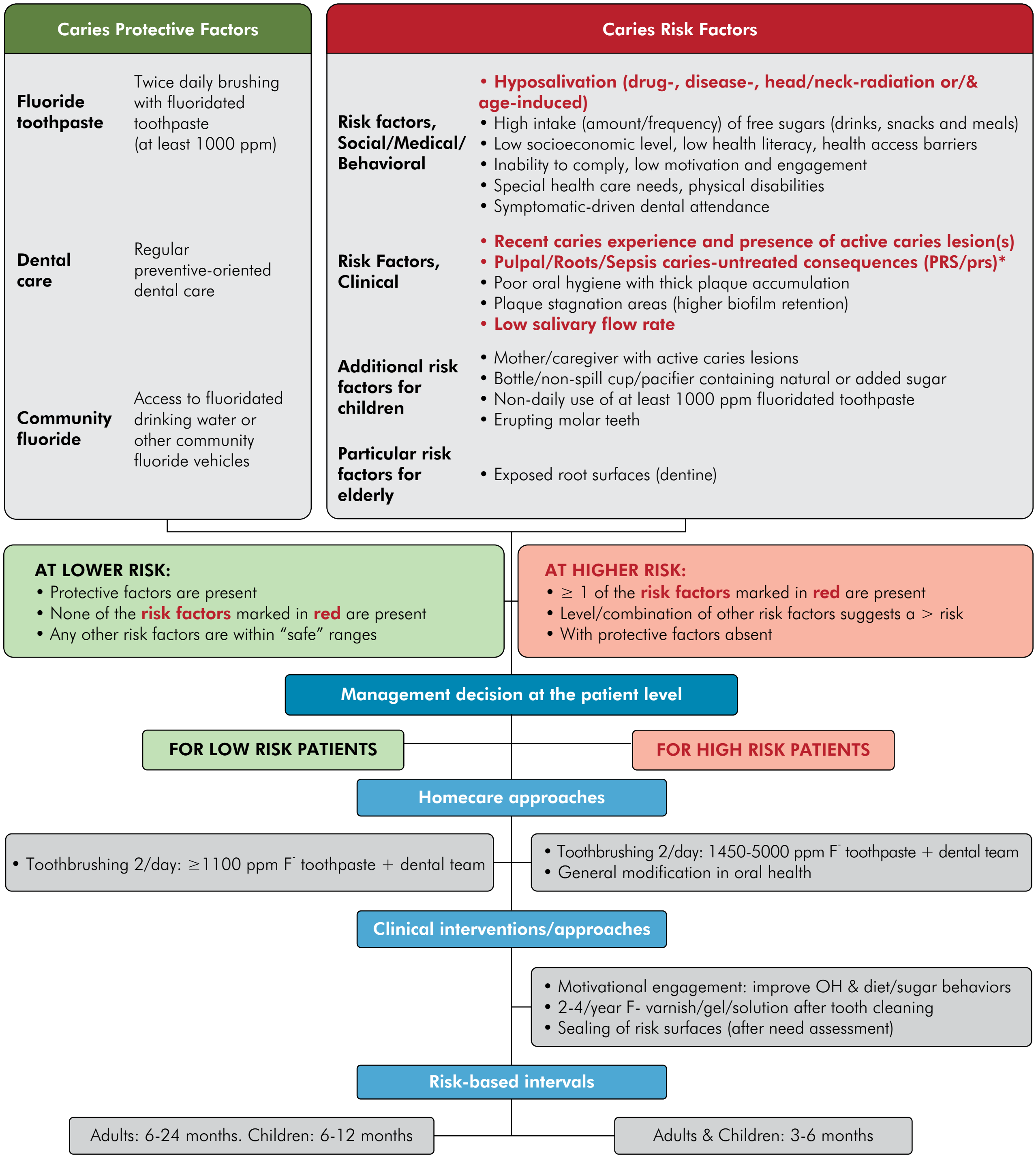
Clinical implications

With regard to ECC, specific protocols focus on the urgency to reduce the risk of dental caries progression, determining the frequency of interventions, and the need to improve primary prevention.[162] In all age groups, high consumption of free sugars should be avoided and brushing teeth twice every day with fluoridated dentifrice of ≥ 1000 ppm F^- should be encouraged.[97]

In the elderly, risk indicators that accurately predict root caries incidence include an increased number of exposed root surfaces and increased root caries experience, gingival recession, poor oral hygiene, and lower socioeconomic level.[146,163,164]

The caries risk status influences the treatment for specific tooth-surface carious lesions in permanent teeth in Colombian dentists, with operative care overruling non-operative care for an initial lesion in the presence of a higher risk of caries.[165]

Age should be considered for the CRA because it is related to individual changes and characteristics at different levels (Figure 3). The caries risk is modifiable

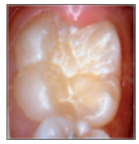
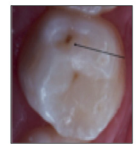


*Pulpal Involvement-Roots-Sepsis Index: clinical consequences of untreated caries. P/p: caries process reached pulp chamber; Roots (R/r): caries process destroyed tooth structures (non-restorable); S/s: pus-releasing tract/tooth-related pus containing swelling.

Material created by the authors.

Figure 5. Individual caries risk assessment, classification, and management decision, adapted from CariesCare International.[90]

by clinical measures and behavioral changes as well as by individual characteristics; therefore, its assessment should be conducted for every patient during the oral health review.[91,97]

		Activity status and signs of ICDAS-merged coronal caries lesions			
		Signs of Likely Active Lesions		Signs of Likely Inactive Lesions	
ICDAS-merged caries stages	Initial (ICDAS 1-2) and Moderate (ICDAS 3-4) Caries Lesions	 Initial  Moderate (Underlying dentine shadow)	• Enamel surface: whitish/yellowish. • Opaque with loss of luster, feels rough to gentle probing across the surface. • Lesion is in a plaque stagnation area. • The lesion may be covered by thick plaque prior to cleaning.	 Initial  Moderate (Microcavity)	• Enamel surface: whitish/brownish/ black. • Enamel may be shiny, feels hard & smooth to gentle probing across the surface. • Smooth surfaces: lesion typically located at some distance from the gingival margin. • Lesion may not be covered by thick plaque prior to cleaning).
	Extensive (ICDAS 5-6) Caries Lesion	 Extensive	• Dentine feels soft or leathery on gentle probing.	 Extensive	• Dentine is shiny and hard on gentle probing.

Material created by the authors.

Figure 6. Activity status and signs of ICDAS-merged coronal caries lesions, adapted from CariesCare International.[96]

Risk assessment and management provides an opportunity to communicate with patients to enable them to adhere and reduce their caries risk, puts oral health into general health, and reinforces the oral health record legally.[97]

Dental educational aspects related to CRA

CRA in the core curriculum of dental students qualifies as a significant competency and is considered an essential component in the decision-making process for correct individual dental caries management. This implies a careful linkage between the teaching and learning processes of caries risk assessment, diagnosis, and synthesis domain, in both, the clinical decision-making and the non-operative and the operative care domains[166]. Evidence-based teaching in dentistry should permeate all aspects of the curriculum. In Spanish-speaking Latin American dental schools, Martignon et al.[167] reported that while 87% dental schools teach caries risk assessment and preventive strategies, only 43% link both of these in the clinic.

In Colombia, after a consensus was achieved in cariology teaching for undergraduate students in 2012 among most dental schools (94%), CRA was designated as a learning objective.[168] This was also the case with the 100% consensus being achieved among 15 dental schools in the Caribbean region, 12 in the Dominican Republic, and 1 each in Puerto Rico, Jamaica, and Trinidad and Tobago.[169] In Brazil, information about caries risk is disseminated via Public health and Integrated seminars, risk factors, and determinants[170] and taught in a theoretical manner in most dental schools (94%).[171] In Chile, all universities teach CRA theoretically,[172] with clinical application being taught at only 40% of all dental schools.[173]

Other data show that students exhibit relatively lower response to the usefulness of a CRA tool, such as Cariogram in the planning of treatments linked to the relatively low knowledge of part-time faculty in using this tool.[174] Calibration training for both, teachers and students may help resolve this issue.[175,176]

General Implications for public health policies

The correct identification of risk factors for dental caries has a direct implication in the implementation of public policies. It allows the organization of oral health services directed at the population that needs it the most. Thus, health policies based on the principles of equity in health care are required. Unfortunately, LACC do not have universal health systems, and oral health, in turn, is offered in most cases through private health care facilities.

In countries with more consolidated public health systems, oral health policies must use the concept of risk factors beyond the individual level. Ideally, caries risk factors should be embedded in a broader context that includes other preventive strategies in an inter-sectorial perspective. The strategy of common risk factors[42] indicates the need of articulating health education policies for different areas of health. Oral diseases share risk factors with other systemic diseases, such as obesity, diabetes, and cancer; therefore, the adoption of collaborative strategies becomes more rational. In paper 3 of this LAOHA caries consensus, Ricomini-Filho et al. discusses oral public health alternatives in more detail.[40]

General Implications for clinical practice

Considering the available scientific evidence and best practices, caries management at the individual level relates to patient-centered practices wherein risk-based care is highlighted.[93] Despite a low-to-moderate evidence of CRA models and the difficulties in the extrapolation of studies, advantages overcome the disadvantages. There is an agreement for risk assessment, with preference of a multi-factor model over a single factor assessment, involving protective and risk factors, putting oral health into general health, considering the common risk factors' strategy, and leading caries risk management to homecare and in-office approaches with a risk-linked interval recall. More recently, there is a trend to simplify the caries risk classification into the following two categories: higher and lower, to facilitate effective management. The involvement of patients in their oral health care is benefited by the dental team-patient communication through CRA; becoming aware of their disease risk increases the patients' adherence and satisfaction with dental care. In paper 4 of this LAOHA caries consensus, Pozos-Guillén et al.[176] discusses individual caries care alternatives at the tooth level in more detail.

Conclusions and recommendations - Perspectives for LACC

Identifying modifiable risk factors for dental caries should be the basis for multi-strategy actions that consider the historical, ethnic, and cultural diversity of LACC communities.

This includes general measures that address social determinants and specific oral health measures such as:

a. increasing the education level;
b. increasing oral health literacy;
c. reducing poverty and inequality;
d. endorsing community fluoridation policies;
e. supporting upstream measures that promote the reduction of sugar intake, such as policies on advertising, availability, and taxation of sugary products;
f. encouraging healthy dietary practices and discouraging the consumption of free sugars from childhood to adulthood;
g. promoting tooth brushing with ≥ 1000 ppm fluoride-containing toothpaste for all children, adolescents, and adults;
h. promoting patient-centered and risk-based caries care;
i. promoting integrated actions among the dental team and other health care professionals.

Integrated actions among dentists, other health professionals, and policymakers represent the only option for effectively combating the common risk factors to reduce the burden of dental caries and other non-communicable diseases. Moreover, there is a need to conduct higher -quality studies in LACC to achieve a better understanding in our populations regarding the effect of exposures to caries risk factors on dental caries, within the framework of non-communicable disease related to oral health, general health, and quality of life. Peres et al.,[47] highlighted the need for birth cohort studies, epidemiologic and statistical analyses, observational and nested intervention studies, as well as conforming collaborative group studies.

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Risk factors for dental caries in Latin American and Caribbean countries. Braz Oral Res. 2021;35:e053. https://doi.org/10.1590/1807-3107bor-2021.vol35.0053

p. 2, column 2, last line
Were is read:
DMFT data collected 12 y previously
It should read:
Previously collected 12-year DMFT data

p. 4, column 2, line 9
Were is read:
dmft values from 5-6 y previously
It should read:
previously collected 5 to 6-year DMFT values

p. 9, §2, line 8
Were is read:
for > 2 months
It should read:
for > 12 months

https://doi.org/10.1590/1807-3107bor-2021.vol35.0053.erratum

ERRATUM

Risk factors for dental caries in Latin American and Caribbean countries. Braz Oral Res. 2021;35:e053. https://doi.org/10.1590/1807-3107bor-2021.vol35.0053

Page 9, §2, lines 8 and 9

Where is read:
and with a high frequency[79] of daily sugars' intake.[79]

It should read:
and with a high frequency.[79]

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