A scoping review of epidemiologic risk factors for pediatric obesity: Implications for future childhood obesity and dental caries prevention research

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Abstract

Research Questions: What are the non-modifiable (socioeconomic, genetic) and modifiable factors (physical activity, dietary behaviors) related to childhood (under age 12) obesity? How can this knowledge be applied to oral health professionals' efforts to prevent or manage dental caries in children?
Objectives: Studies have identified risk factors for childhood obesity. The purpose of this scoping review was to develop a conceptual model to identify non-modifiable and modifiable risk factors for childhood obesity and to illustrate how these findings are relevant in developing interventions aimed at preventing obesity and dental caries in children.
Methods: The authors searched PubMed and Embase and limited the study to English-language publications. A total of 2,572 studies were identified. After de-duplication, 2,479 studies remained and were downloaded into a citation-management tool. Two authors screened the titles and abstracts for relevance. Two hundred and sixty studies remained and were retrieved for a full-text review, and 80 studies were excluded, resulting in 180 studies included in the scoping review. An inductive content analytic methods was used to organize all statistically significant obesity risk factors into seven domains, which were classified as non-modifiable or modifiable; then a conceptual model of common risk factors associated with childhood obesity and dental caries was developed.
Results: Non-modifiable obesity risk factors include biological and developmental (e.g., genes, developmental conditions, puberty), sociodemographic and household (e.g., race/ethnicity, socioeconomic status, parent education, unemployment), cultural (e.g., degree of acculturation), and community (e.g., neighborhood composition). Modifiable risk factors included behavioral (e.g., diet, physical activity, weight), psychosocial (e.g., maternal stress, family functioning, parenting practices, child temperament), and medical (e.g., parent smoking, maternal health, child health).
Conclusions: Identifying common risk factors has important implications for future oral health research aimed at preventing childhood obesity and dental caries. Epidemiologic knowledge gleaned from the literature can be used to develop rigorous interventions and programs aimed at preventing these highly prevalent diseases and improving health outcomes for children.

Introduction

There is a global childhood obesity epidemic (1). Based on 2013–2014 National Health and Nutrition Examination Survey data, 17.2 percent of US children and adolescents ages 2–19 are obese [body mass index (BMI) 95th percentile or greater], and an additional 16.2 percent are overweight [BMI 85th to less than the 95th percentile] (2). These rates have increased two and threefold, respectively, since the 1970s (2). While recent data suggest that US childhood obesity rates have peaked, children who are minorities or who are from

families with low incomes continue to be at significantly increased risk (3).

Childhood obesity has well-documented physical, psychological, and life course consequences. Physical consequences include increased risk for endothelial dysfunction, elevated intraocular pressure, non-alcoholic fatty liver disease, cardiovascular and cardiometabolic diseases, obstructive sleep apnea, upper extremity fractures, multiple sclerosis, and diabetes (4-12). Psychosocial consequences include weight-related discrimination, bullying, depression, and low quality of life (13-16). Consequences manifest over the life course as obesity in adulthood, increased demands on the health-care-delivery system, increased health care spending, and early mortality (17-20).

Researchers have explored the relationship between childhood obesity and dental caries. Multiple studies report associations between obesity and caries, implying that obesity is a risk factor for caries (21-23). One study found that larger proportions of underweight or normal-weight children had less active caries than children identified as overweight or obese (24). Two studies reported no associations (25,26). These inconsistencies across studies suggest that it is unlikely that obesity and caries are causally linked. A more plausible explanation is that the two conditions share common risk factors, including those related to diet and socioeconomic status (27). Common risk factors make studies from the vast obesity literature relevant in conceptualizing ways to address both conditions, which is a particularly appealing from a public health perspective, given limited resources and the potential efficiencies gained from such an approach.

The goal of this scoping review is to identify obesity risk factors in children under age 12 and to generate a conceptual model showing factors common to both obesity and dental caries. A common-risk-factors approach is expected to be helpful in identifying epidemiological findings from the extensive childhood obesity literature and in using these findings to develop interventions, policies, and programs aimed at preventing obesity and caries in children (28).

Methods

Search strategy

Article searches were conducted in June 2016 using PubMed and Embase. A comprehensive search strategy was used to maximize the odds of locating all relevant studies (29). The authors searched article titles and abstracts using combinations of the keywords "risk factors," "obesity," and "children." No restrictions were placed on publication dates. Results were limited to English-language studies focusing on children ages under age 12. The search resulted in 2,572 records, which were downloaded into a citation management tool. After de-duplication, 2,479 unique records remained.

Exclusion criteria

Prior to retrieving articles for full-text review, titles and abstracts were screened and 2,219 non-relevant records were removed; then full text of 260 records were obtained, and an additional 80 records were excluded. The final data abstraction and analysis included 180 records (Figure 1).

Data abstraction and analyses

For each study, the following data were abstracted: study country, number of study participants, ages of participants, study design, definition of obesity, statistical methods, and risk factors (Appendix). Statistically significant risk factors ($P < 0.05$) from quantitative studies and all factors from qualitative studies were classified into domains using qualitative inductive content analytic methods (30). The authors used open coding, organized risk factors into higher-order domains, and classified the higher-order domains as non-modifiable or modifiable based on whether the risk factor could be influenced by an intervention. To simplify reporting, the word obesity was used to refer to both obesity and overweight, unless the study specifically examined overweight.

Results

Description of studies

Of the 180 studies, 3 were qualitative (31-33) and 177 were quantitative, 101 of which were cross-sectional (34-134); 55 were retrospective/prospective cohort studies (135-189), 17 were case-control (190-206), 1 was a randomized control trial (207), and 3 were systematic reviews (208-210).

Fifty-one studies were from the United States (33,34,36,39,43,45,46,49,53,60,61,64,66,67,69,76,88,106,110,112,114,117,122,132,134,136,137,139,140,147,150,151,154,156,158,162,164,170,172-175,181-183,185,186,189,190,196,210), 13 from Germany (58,75,108,118-120,125-127,130,138,163,165), 13 from China (37,81,82,84,92,160,161,187,188,194,203,205,206), 9 from the UK (74,98,135,143-145,166,168,177), 8 from Canada (38,50,55,57,85,176,178,180), 6 from Iran (62,71,73,101,192,200), 6 from Greece (54,59,63,70,97,157), 5 from Australia (103,142,184,208,209), 5 from Mexico (52,83,124,131,197), 5 from Portugal (32,48,94,104,105), 4 from the Netherlands (35,148,149,179), 4 from Hong Kong (31,77,141,152), and 4 from Japan (100,169,201,202). The remaining studies were from Asia (42,47,56,65,72,79,86,89,90,107,115,133,193,199), South America (68,109,146,167,198), Africa (44,99,113), and Europe (40,41,51,78,80,87,91,93,95,96,102,111,116,121,123,128,129,153,155,159,171,191,195,204,207).

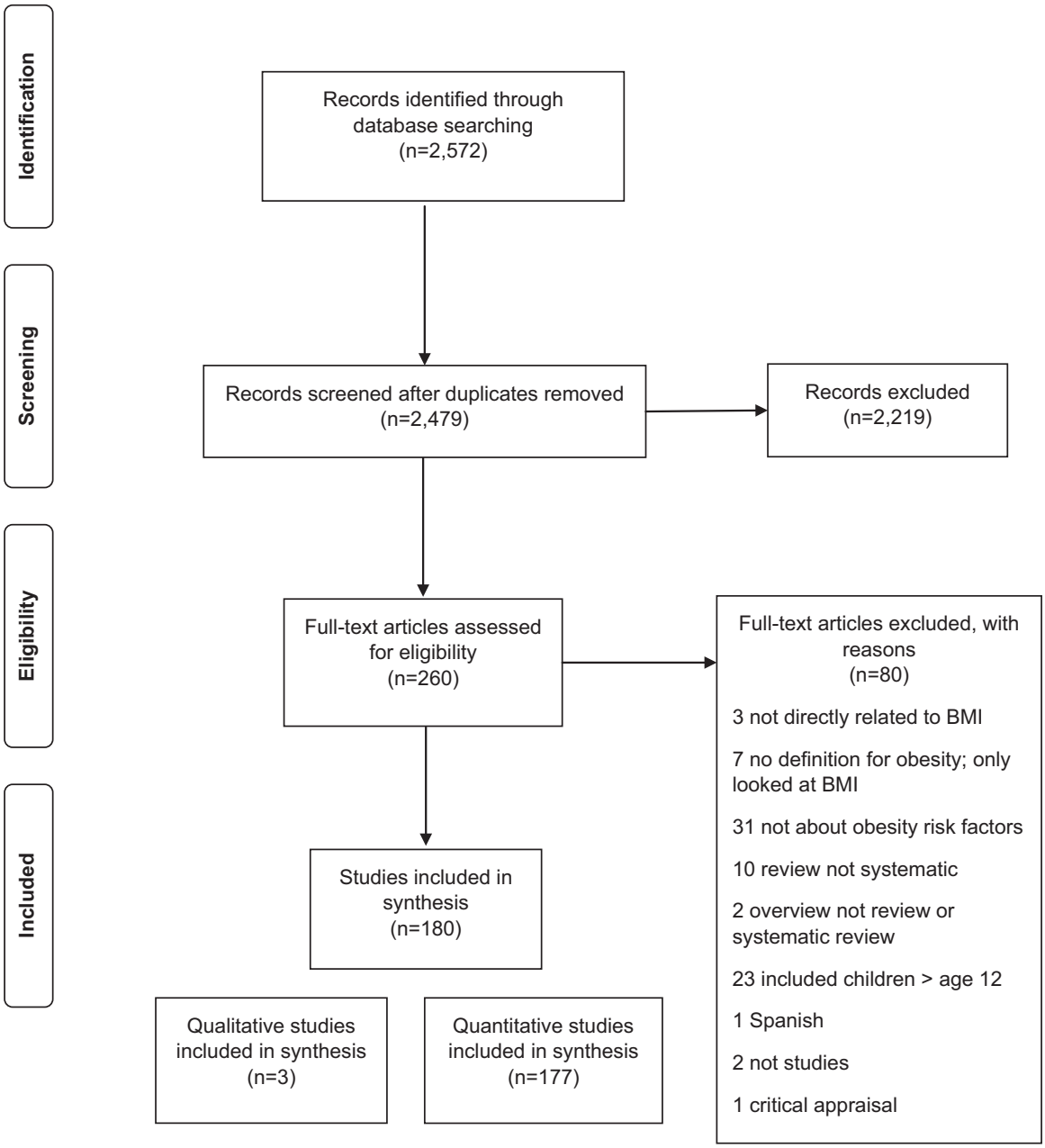

Figure 1 Flow diagram of studies included in scoping review.

Conceptual model

Each risk factor for obesity was organized into one of seven domains, which we classified as non-modifiable or modifiable (Figure 2). There were four domains classified as non-modifiable (biological and developmental factors, sociodemographic and household factors, cultural factors, and community factors) and three domains classified as modifiable (behavioral factors, psychosocial factors, and medical factors).

Biological and developmental factors

Genes and epigenetics

Three studies identified genes and epigenetic factors associated with childhood obesity (90,197,203), including fewer copies of AMY1 genes and children with rs1421085 CC and CT/CC genotypes compared to rs1421085 TT genotypes. A South Korean study (90) found that as sodium intake increased, obesity risk increased in GRK4 A486V

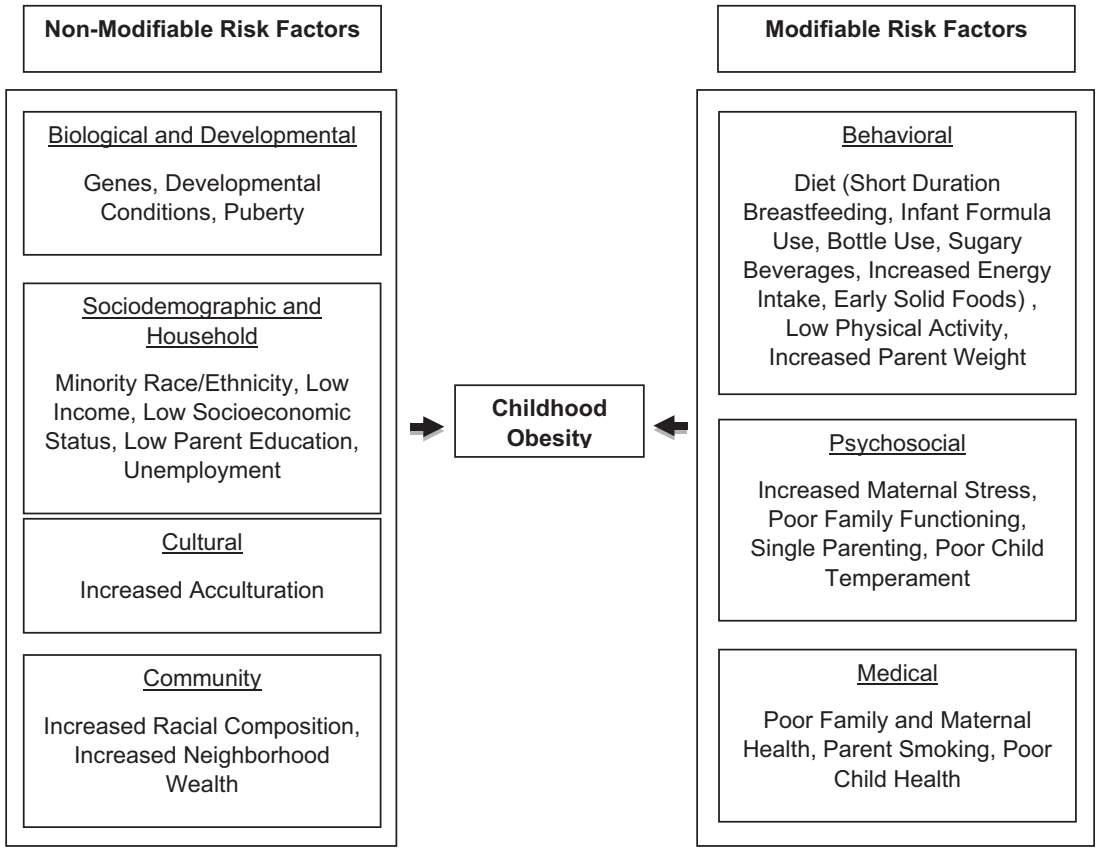

Figure 2 Conceptual model on risk factors for childhood obesity.

heterozygotes and GRK4 A486V mutant homozygotes. Girls with CYP11 β-2 mutant homozygote were also at risk for obesity as sodium intake increased.

Developmental coordination problems

Children with developmental coordination problems were at an increased risk for obesity compared to typically developing children (133). Three studies (171,187,205) reported macrosomia as a risk factor for childhood obesity.

Puberty

In a Hong Kong study, pubescent girls in grade 5 were at greater risk for obesity risk in grade 6 than pre-pubescent girls (152). A US study reported similar findings (106).

Sociodemographic and household factors

Race and ethnicity

Thirteen studies reported race and ethnicity as risk factors for childhood obesity (e.g., Brazilian, Black, Black Caribbean, African, African-American, Asian, multiracial, Hispanic, Latino) (35,39,44,66,76,88,121,122,143,144,147,174,189).

Income and socioeconomic status

Twelve studies reported low income as a risk factor for childhood obesity (35,39,58,85,107,112,116,122,134,143,178,186). Participation in the US Supplemental Nutrition Assistance Program, lower food resource management skills (134), and food insecurity were related risk factors (73,131,134,182). Limited access to household items (e.g., personal car, computer, microwave, washing machine, cell phone, dishwasher) was associated with childhood obesity (73). Three studies (56,65,192) reported that higher income was associated with childhood obesity. Two studies (71,101) reported conflicting findings regarding obesity risk and type of school (private versus public school). Other studies reported the following factors (potential proxies for socioeconomic status) as being associated with childhood obesity: fetal exposure to music (205), living in an Eastern compared to a Western European county (102), living in a grassfield area compared to a forest area in Cameroon (113), exposure to English television (131), and stunted growth (44).

Ethnicity and income interaction

One study (36) reported an interaction between ethnicity and income, whereby Hispanic children from families with low

incomes were at greater risk for obesity than white children from families with high incomes.

Parent education

Lower parent education was identified as a risk factor for obesity (40,84,93,106,143,155). There were inconsistencies for maternal and paternal education, but most studies found lower risk of obesity with higher levels of parent education. Three studies (44,73,192) reported positive associations between maternal education and obesity, and nine studies (35,48,81,87,98,101,104,145,156) reported negative associations. One study (192) reported a positive association for paternal education, and three studies (48,104,206) reported negative associations for paternal education.

Parent unemployment

Both parents being unemployed was a risk factor for childhood obesity compared to one or both parents being employed (106). Four studies reported maternal employment as a risk factor for obesity (74,144,167,192), and one study reported maternal unemployment as a risk factor (35). Two studies (73,192) reported positive associations between paternal employment and obesity.

Maternal age

Two studies (63,190) reported negative associations and three studies (47,106,123) reported positive associations between maternal age and childhood obesity.

Birth order, parity, household size, and household structure

Being first born was a risk factor for childhood obesity (102,104,109,149,199) whereas one study found that lower birth order was associated with obesity (113). Two studies found that having few or no siblings was a risk factor for childhood obesity (106,204). Two studies (44,156) found that smaller household size was a risk factor, whereas another study (51) found the opposite. One study (153) found that parents who lived separately before the birth of child (versus together) were more likely to have a child identified as obese.

Cultural factors

Degree of acculturation

Children in acculturated families were at increased risk for obesity. One study (132) focused on families that spoke Spanish at home (versus English) and a second (76) examined families that spoke English as a second language. A study from Israel (86) found that children born to parents who immigrated >10 years ago (i.e., increased acculturation) were at increased risk for childhood obesity compared to native-born Israelis or new immigrants (immigrated <10 years ago).

Religion

A study from Cameroon (113) found that Christian children were at increased risk for obesity compared to Muslim children. When ecological variables were included in the model, particularly region of country, religion was no longer significant.

Community factors

Urbanicity

Three studies (65,78,115) found that children in urban areas were at increased risk for obesity compared to those in rural communities, whereas another study (73) found the opposite.

Neighborhood racial composition and wealth

Children living in predominantly non-Hispanic black neighborhoods were at increased risk for obesity compared to those living in neighborhoods with a low proportion of non-Hispanic blacks (88). A study from Thailand (65) found that children living in communities with higher wealth concentration had a higher risk for obesity than those living in communities with lower wealth concentration.

Behavioral factors (diet, physical activity, and weight)

Diet

Breastfeeding. Six studies (57,72,125,144,183,191) reported that never-breastfed children were at increased risk for obesity than children breastfed for any length of time. Eight studies, with time periods ranging from 1 to 24 months, reported that shorter duration of breastfeeding was associated with greater risk for obesity (41,44,58,84,135,159,184,186). A US study (190) found that cases had shorter duration of breastfeeding than controls, which was similar to findings from Sri Lanka (199).

Formula use. Infant formula use was associated with obesity (38,67,84,187,200). A study from Europe (207) found that children fed high-protein infant formula were at increased risk for obesity compared to those fed low-protein infant formula.

Bottle use. Children ages 12–36 months who were currently using a bottle were at increased risk for overweight compared to children weaned from a bottle by age 12 months (49). A prospective cohort study from China (187) found that frequently being encouraged to finish bottle contents at age 2

was associated with obesity, compared to rarely being encouraged. This study also found that children who went to bed with a bottle were at increased risk for obesity compared to those who did not.

Sugary beverages. US children who consumed any sugar-sweetened beverages (SSBs) were at increased risk for obesity (164). SSBs were defined as juice drinks, soft drinks, soda, sweet tea, and Kool-Aid. Any SSB consumption during infancy (ages 1–12 months) was associated with obesity, and SSB consumption before age 6 months was a risk factor compared to never consuming SSBs. In addition, children ages 10–12 months consuming SSBs $\geq$3 times/week were at increased risk compared to those who did not consume any SSBs. In two other US studies, juice intake $\geq$9 oz/day was a risk factor for obesity (183), and any consumption of SSBs (e.g., soda pop, sports drinks, non-100 percent fruit juices) in the previous week was a risk factor for obesity (147). These results were consistent with findings from Nigeria (99).

Energy intake. Total energy intake was associated with childhood obesity (77,84,95).

Early introduction to solid food. Early introduction to solid foods was associated with childhood obesity. Studies defined early introduction as occurring at age 2 months or younger (184), before age 3 months (143), and before age 4 months (67,84,144,205). A US study (175) found that inappropriate feeding was associated with obesity in children. Inappropriate feeding was defined by age: at age 3 months, any liquids except for breast milk or infant formula or solids; at age 6 months, cow's milk or soy milk instead of breast milk or infant formula, or juice, meat, eggs, cheese, junk food, fast food, or sweets; at age 9 months, cow's milk or soy milk, junk food, fast food, or sweets; and at age 12 or 18 months, flavored milks, junk food, fast food, or sweets. A study from Australia (142) found that children identified as obese were introduced to solid foods at an earlier age than normal-weight children.

Nutrients, serum biomarkers, and foods. Increased carbohydrate (79), protein (79,166), and sodium (90) intake were identified as risk factors for childhood obesity. Parent perceptions that their child was underweight in the first 2 years of life was associated with greater mean daily total fat and sugar intake in children (34). Studies have also identified higher levels of serum biomarkers as obesity risk factors: hypercholesterolemia (114), triglycerides (203), and high-density lipoprotein cholesterol (203). Low fruit and vegetable intake ($<$3 times/week) (51,147), a preference for fatty foods (99), and consumption of particular foods (e.g., meat, rice, potatoes) (124) were also risk factors for childhood obesity.

Meals and snacking. Eating fewer than three to four meals/day was identified as a risk factor for childhood obesity (54,63,70,118,120), as was iregular breakfast eating (63,70,80,116,123,132). A US study (61) found that eating lunch provided by the child's school was associated with obesity, compared to eating home-prepared lunches; a study from France found the opposite (116). Eating out $\geq$2 times/week was associated with childhood obesity (47,107,124). Studies identified the following features of snacking as risk factors: increased frequency (70), snacking between meals (193), irregular or non-scheduled snacking (116,201,202), and snacking on junk foods (37,83,95,198).

Mealtime behaviors. Eating fewer meals together as a family were associated with childhood obesity (63,89,110,111). Watching television while eating was also associated with increased risk (48,50,107,111), with a potential dose-dependent relationship (48). Families that were less engaged during family meals and families that did not consider mealtime to be important were at increased risk for having children identified as obese (64). In this study, family dinners were videotaped and coded using the ABC Mealtime Coding System (211).

Eating behaviors. Strong appetite (206), habitual overeating (123), and increased eating speed (54,194,206) among children were all associated with obesity. Another risk factor for childhood obesity was maternal daily consumption of SSBs or intake of sweets $\geq$2 times/week (182).

Physical activity

Low physical activity. Low activity level defined as lack of daily exercise (38,123,143,193), irregular vigorous physical activity (69), low activity during break times at school (115) or on weekdays (48) and weekends (48), limited outdoors playtime (35,202), and irregular or non-participation in organized sports (47,58,69,95,178) was consistently associated with childhood obesity.

Sedentary lifestyle. Children with a sedentary lifestyle were at increased risk for obesity (70). This included increased number of weekday study hours (63), access to electronic entertainment and communication devices (55,63,65), having any screen time (39,48,68,100,101,116,122,193,206), television watching (35,40,48,50,51,54,61,62,68,69,82,92,100,102,104,122,124,143,145,168,173,178,195), and computer use and video gaming (48,61,69,178).

Weight

Parent weight. Obesity in both parents was identified as a risk factor for childhood obesity in nine studies (58,80,93,97,144,145,168,192,195) whereas seven studies found that obesity in either parent was a risk factor (46,60,79,82,84,93,97,192). In terms of paternal weight, five studies (63,95,96,187,190) reported associations between

paternal BMI and childhood obesity, and 16 studies (48,77,80,87,92,104,107,123,144,169,193,194,201,202,206) found associations between paternal and childhood obesity. Regarding pre-partum maternal weight, three studies (187,190,196) found relationships between BMI and childhood obesity, and seven studies (59,109,135,144,156,186,199) reported associations between maternal obesity and childhood obesity. In terms of post-partum maternal weight, childhood obesity was associated with maternal BMI (57,63,65,95,96,191) and maternal obesity (43,44,48,56, 77,80,87,104,107,113,123,144,147,148,156,159,167,169,183, 184,185,193,198,201,202,32,194,206). There was also a linear relationship between gestational weight gain and childhood obesity (135,137,138,148,157,160), particularly when gestational weight gain was $\geq$15 kg (92,191).

Child's weight. Increased birth weight was associated with childhood obesity (38,44,54,58,103,109,113,145,195,196,200), particularly birthweights >85th and >90th percentiles (56,144) and birthweights $\geq$2.5 kg (104), $\geq$3 kg (77), $\geq$3.5 kg (107,143,201,202), $\geq$4 kg (73,92,183,194,206), and >4.5 kg (159). In addition, studies identified rapid weight gain in the first year of life (109,158,168,187,188,199) as well as high infant weight (147,151,155,156,179) as risk factors.

Parent perception of child's weight. Parents who underestimated their child's weight were more likely to have a child identified as obese than parents who accurately estimated their child's weight (34,42,52,63,75,86). Parent perceptions that their child was underweight in the first 2 years of life was associated with greater mean daily total fat and sugar intake in children (34).

Psychosocial factors

Maternal stress

Women with higher prenatal stress were more likely to have a child identified as obese, compared to women with lower prenatal stress (57). Postnatal maternal stress was also associated with childhood obesity (182).

Family functioning and social risk factors

Children in families with poor family functioning, or no patterns of behavior and rules, were at increased for obesity (56). Another study (172) found that exposure to $\geq$2 social risk factors (e.g., domestic violence, parent incarceration, maternal substance abuse, food insecurity, housing insecurity, maternal depression) increased risk for childhood obesity. Similarly, children who witnessed domestic violence and abuse were at greater risk for obesity than those who did not (186).

Parenting practices and childcare

Single parenting was a risk factor for childhood obesity (35,58,87,144,178,204). Children with authoritarian parents (not responsive but demanding) were more likely to be identified as obese compared to children with authoritative parents (responsive and demanding) (85). Restrictive parenting behaviors to reduce their child's food intake or for weight control were associated with childhood obesity (60,82,198). A study from Japan (201) found that children whose mother was not the primary caregiver were at increased risk for obesity compared to children whose mother was the primary caregiver. Two studies from China (37,206) found that children who were mainly cared for by their grandparents were at increased risk for obesity. One of the two studies (37) also found that children who lived with $\geq$2 grandparents were at increased risk for childhood obesity, compared to children who lived with no grandparents. A US study (170) found that within Hispanic families, children cared for by a nonrelative were more likely to be identified as obese than children cared for exclusively by relatives. Findings regarding child care are mixed. Entering childcare before age 1 and a greater number of child care placements were identified as risk factors for childhood obesity (91). Another study reported that never attending a center-based day care facility was a risk factor (147). Informal child care was also identified as a risk factor for obesity (42).

Child temperament. Children with low inhibitory control (i.e., less self-regulation) were at increased risk for obesity (130,150,151,208). Other risk factors were high emotionality (208), externalizing behavior problems (173), poor affective responsiveness (56,208), high-intensity pleasure expression (151), and soothability (208).

Medical factors

Family medical conditions

Having a parent, sibling, or grandparent with type II diabetes was a risk factor for childhood obesity (155). In addition, a systematic review (209) reported that moderate to severe maternal depression was a risk factor for childhood obesity. Permissive parenting among mothers with depression increased the risk for childhood obesity (117). A US study (147) found that mothers with a history of giving birth to a newborn whose birthweight was <4,000 g were at increased risk for having a child identified as obese.

Parental smoking

Parental smoking was a risk factor for childhood obesity, as were antenatal parental smoking (142) and child's exposure to secondhand smoke (108,143). Nine studies identified maternal smoking during pregnancy

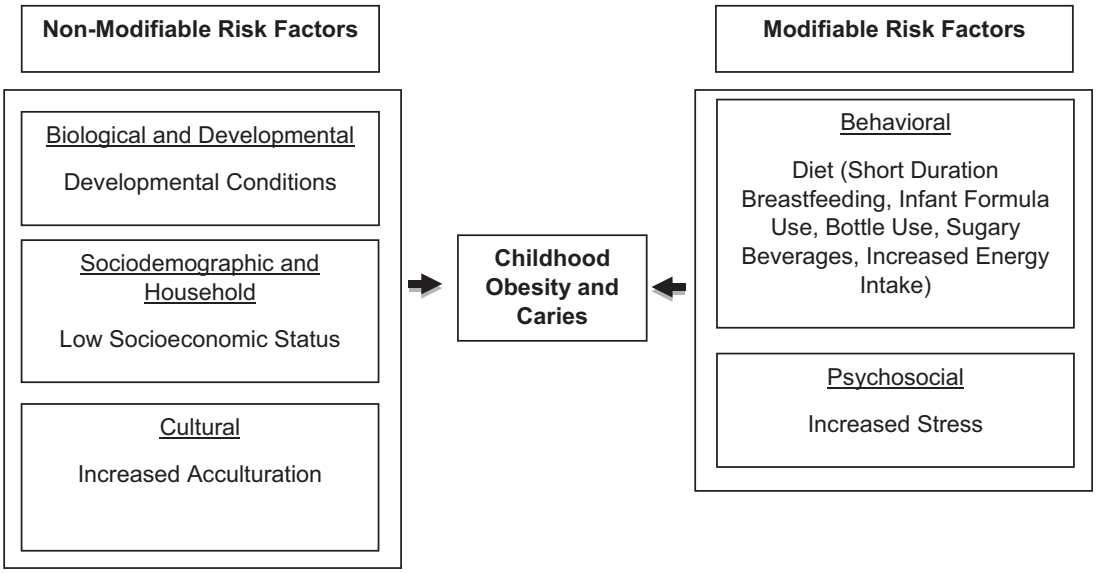

Figure 3 Conceptual model on common risk factors for childhood obesity and caries.

(28,35,38,77,105,135,144,145,178,191) and one study identified paternal smoking as risk factors.

Maternal health

Pregnant women with gestational hypertension or diabetes were more likely to have a child identified as obese (147,163,206). Another study (160) found that women with gestational diabetes and excessive gestational weight gain were at greater risk for having a child identified as obese than those with gestational diabetes and non-excessive gestational weight gain. One study (135) found that low maternal vitamin D (<64 nmol/L) was a risk factor for childhood obesity, and another study (45) found that elevated fasting glucose of 5.5mmol/L (95 mg/dL) was a risk factor.

Child's health

Children born by Caesarian section were at greater risk for obesity that children born vaginally 47,53,146,154, 161,162,165,167,181,205. Children that did not use health care services were at increased risk for childhood obesity (73). Children exposed to antibiotics in utero (162) and during the first year of life (136,177) were at increased risk for obesity. One study (131) found that not regularly taking multivitamins was a risk factor.

Poor sleep

Shorter sleep duration was identified as a risk factor for childhood obesity (38,60,77,81,104,105,127,145,168,169,173,195, 201), with the minimum number of hours of sleep ranging from 8 to 11 hours/night. Another study (176) found that children who were short persistent sleepers were at greater risk for obesity than children who slept for >11 hours/night.

Discussion

The scoping review of the literature identified risk factors for childhood obesity that were organized by risk factors into domains to develop a conceptual model (Figure 2). The seven domains were further classified as modifiable and non-modifiable. There are four main observations based on the conceptual model that provide guidance on future strategies to prevent both childhood obesity and dental caries.

The conceptual model on obesity indicates that there are number of risk factors potentially associated with both obesity and dental caries. We took each obesity risk factor and searched the dental literature to determine if there was evidence of it also being related to caries. The end product was a conceptual model on the common risk factors for childhood obesity and caries (Figure 3). These common risk factors include developmental conditions (212), socioeconomic status (213-215), acculturation (216), stress (217), and diet (218,219). Rather than adopting a traditional approach in which obesity and dental researchers work separately on disease-specific interventions, these findings support a holistic approach in which interventions and policies target common risk factors, such as SSB intake, as a way to prevent multiple diseases (28). While the common-risk-factors approach is consistent with public health principles, empirical data supporting such an approach are not yet available. However, at least one prospective cohort study is under way to define relevant pathways for future interventions (220).

Childhood obesity and dental caries are multifactorial diseases with common risk factors, but there are non-overlapping risk factors that may be equally important. For instance, if the goal of an obesity- and caries-prevention intervention is to reduce SSB intake, such an intervention would also likely need to improve physical activity and topical fluoride exposure. The intervention would involve modification of at least three health behaviors, which is a challenging proposition from the perspectives of study design, feasibility, pretesting, refinement, implementation, and dissemination. Most obesity- and caries-prevention interventions focus on modifying one health behavior (221,222). In addition, the evaluation process becomes complex because of the need to not only assess the primary disease outcomes but also identify potential mechanisms to explain how an intervention worked or why certain components were ineffective (223). Furthermore, there is an implicit assumption that common-risk-factor interventions cost less, but this assumption needs to be formally evaluated (224). These data may be of particular interest to policymakers interested in supporting evidence-based, cost-effective interventions (225).

Many of the risk factors from the conceptual model that are modifiable in the short-term are related to behaviors or lifestyle choices. For instance, dietary factors related to obesity and dental caries in younger children tend to revolve around breastfeeding and bottle use, in which caregivers have a key role. Older children start to show increasing independence related to diet, especially away from the home environment, which means that interventions will involve both children and caregivers. Interventions for older children could focus on empowering caregivers to present their children with viable alternatives to sugar sweetened beverages. These factors highlight the role that health behavior theories can have in helping researchers understand the barriers or facilitators to specific behaviors and providing guidance on ways to modify individual-level behaviors. Various theories and models are relevant in understanding obesity- and caries-related behaviors (226-229). Such work is optimized when conducted within interdisciplinary teams (230). Additional resources are available for researchers interested in developing and testing theory-driven behavioral interventions (231). Social and policy interventions can help to reinforce behavioral interventions focusing on individuals (232-234).

The remaining risk factors are either non-modifiable (e.g., race) or modifiable only in the long term through upstream approaches that go beyond behavior-change interventions (e.g., income). There are two ways to account for non-modifiable risk factors, both of which stem from a health equity and social justice framework (235). The first is for interventions to target specific high-risk population subgroups. One example is publicly insured children (236,237). Multiple states have special oral health programs for children enrolled in Medicaid (238), but states have only recently started to explore programs to address obesity (239,240). The second is to push for comprehensive policies aimed at eliminating poverty and income inequality (241). This upstream approach will require obesity and oral health researchers to become part of the broader advocacy landscape by working with individuals outside of health care to ensure that vulnerable families have the resources and support to make optimal health decisions for their children.

This is the first known study to identify risk factors for childhood obesity with the goal of developing a conceptual model to help guide future research on obesity and dental caries prevention. However, there were three limitations. First, most risk factors from our model are correlates rather than causal determinants of obesity. Observational study designs are the only way to identify many of these risk factors because of the inability to randomize. Second, our model focuses primarily on main-effect risk factors because only a few studies examined interactions. Third, the relationships among variables is not specified. For example, numerous studies found that television watching is associated with obesity. It is unlikely that television watching by itself would lead to obesity. A plausible mechanism is that children who watch television are more likely to be sedentary, snack on unhealthy foods, and consume excess calories. To address these limitations, future research needs to focus on strengthening analytic methods that allow for stronger causal inferences to be made from observational data. Examples include causal mediation analytic techniques and other statistical methods that address limitations associated with approaches such as instrumental variables (242).

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Appendix

Table 1 Selected Studies Included in Scoping Review of Childhood Obesity Risk Factors

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
Isganaitis E 2015 (190)	5.337	Associations of cord blood metabolites with early childhood obesity risk	Unites States	26 controls 26 cases	Just after delivery, infancy, early childhood, and mid-childhood	Case-control	2000 Centers for disease control and prevention (CDC) reference	t-test, bivariate logistic regression	Shorter breastfeeding duration Higher maternal age Higher maternal body mass index (BMI) Higher paternal BMI
Robinson SM 2015 (135)	6.77	Modifiable early-life risk factors for childhood adiposity and overweight: an analysis of their combined impact and potential for prevention	UK	991 children	Ages 4 and 6 years	Prospective cohort	International obesity task force definition	t-test, Mann–Whitney Rank Sum test and Chi-square test	Maternal obesity Excess gestational weight gain Smoking during pregnancy Low maternal vitamin D status (<64 nmol/L) Short duration of breastfeeding (<1 month)
Bailey LC 2014 (136)	9.528	Association of antibiotics in infancy with early childhood obesity	United States	65,480 children	Infancy: Ages 0–23 months Early childhood: Ages 24–59 months	Retrospective cohort	2000 CDC reference	Multivariate analysis with Cox proportional hazards models	Cumulative exposure to antibiotics Early exposure to broad-spectrum antibiotics
Bergmeier H 2014 (208)	7.51	Associations between child temperament, maternal feeding practices, and child BMI during the preschool years: a systematic review of the literature	Varies	18 studies	Birth-age 6 years	Systematic review	2000 CDC reference	N/A	Poor self-regulation High emotionality (e.g., anger, frustration) Low negative affectivity High and low soothability
Ensenauer R. 2013 (138)	5.337	Effects of suboptimal or excessive gestational weight gain on childhood overweight and abdominal adiposity: results from a retrospective cohort study	Germany	6,837 children	Mean age 5.8 years; no age range given	Retrospective cohort	International obesity task force definition	t-test, Chi-square test, multivariate linear and logistic regression models	Excessive gestational weight gain

Table 1. Continued

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
Lin SL 2011 (141)	7.522	Is informal child care associated with childhood obesity? Evidence from Hong Kong's "Children of 1997" birth cohort	Hong Kong, China	8,327 in cohort; 7,933 alive at age 11; 6,796 had 11-year-old BMI assessed	Ages 6 months, 3 years, 5 years, and 11 years	Prospective cohort	International obesity task force definition	Hosmer–Lemeshow–Cressie test	Informal care (current) Informal care (at age 5 years)
Seach KA 2010 (142)	5.337	Delayed introduction of solid feeding reduces child overweight and obesity at age 10 years	Australia	307 children	Mean age 10 years (SD 1.9); no age range given	Prospective cohort	International obesity task force definition	Independent group t-test, Mann–Whitney Rank Sum test, Chi-square test	Early introduction to solid foods Antenatal parental smoking
Hillier TA 2007 (45)	8.42	Childhood obesity and metabolic imprinting: the ongoing effects of maternal hyperglycemia	United States	9,439 mother-child pairs	Ages 5–7 years	Cross-sectional	2000 CDC reference	t-test, Pearson Chi-square test, Mantel–Haenszel Chi-square test	Abnormal oral glucose tolerance test Increasing maternal hyperglycemia Gestational diabetes
Danielzik S 2004 (58)	5.337	Parental overweight, socioeconomic status (SES), and high birthweight are the major determinants of overweight and obesity in 5 children ages 5–7 years: baseline data of the Kiel Obesity Prevention Study (KOPS)	Germany	2,631 children	Ages 5–7 years	Cross-sectional	Overweight: BMI 90–97th percentile Obesity: BMI ≥97th percentile	Mann–Whitney Rank Sum test, Kruskal–Wallis test, Chi-square test	Low SES High birthweight Parental smoking (boys) Single households (boys) Low activity (girls)
Flores G 2013 (147)	5.337	Factors predicting childhood obesity in kindergarteners	United States	6,800 children	Age 5 years	Prospective cohort	Obesity: BMI ≥99th percentile	Pearson's Chi-square test, t-test	Crossing the 85th percentile of BMI at age 2 years Crossing the 85th percentile of BMI at preschool age Crossing the 85th percentile of BMI at age 9 months Maternal obesity (pregestational)

Table 1. Continued

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
									Gestational diabetes Drinking tea or coffee between meals/ before bedtime at 2 years Latino Male Lower parental educational attainment Poverty Non-English primary language spoken at home Higher number of adults in the household Multiracial Drinking SSBs at kindergarten age at least weekly Never attending center-based daycare Eating fruit less than weekly at kindergarten age
Govindan M 2013 (69)	5.80	Gender differences in physiologic markers and health behaviors associated with childhood obesity	United States	1,714 children	Ages 10–12 years	Cross-sectional	2000 CDC reference	Chi-square test, t-test, multivariate logistic regression models	Less physical activity (boys) Less participation in school sports (boys) TV >2 hours/day Computer time <2 hours/day (girls)
Graziano PA 2010 (150)	5.337	Toddler self-regulation skills predict risk for childhood obesity	United States	57 children	Ages 2–5.5 years	Prospective cohort	2000 CDC reference	None described	Poorer emotional regulation Poorer inhibitory control skills
Graziano PA 2013 (151)	5.337	Predicting weight outcomes in preadolescence: the role of toddlers' self-regulation	United States	195 children	Ages 2–10 years	Prospective cohort	2000 CDC reference	Chi-square test, t-test	Poor self-regulation Higher intensity in pleasure expression

Table 1. Continued

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
		skills and the temperament dimension of pleasure							
Hawkins SS 2008 (74)	5.337	Maternal employment and early childhood overweight: findings from the UK Millennium Cohort Study	UK	13,113 children	Ages 9 months and 3 years	Cross-sectional	International obesity task force definition	Univariate logistic regression analyses, odds ratios, Wald test	Any maternal employment after child's birth Increased risk for every 10 hours a mother worked/week Income <GBP 33,000 ($57,750)
He Q 2000 (194)	5.337	Risk factors of obesity in preschool children in China: a population-based case-control study	China	Cases: 661 children Controls: 661 children	Ages 0.1–6.9 years	Case-control	1990 CDC anthropometric reference weight for height obesity: weight that exceeded the standard weight for height, age, and sex by more than 20%	Chi-square test	Birthweight > 4.0 kg High eating speed Mother's BMI > 25 kg/m^2 Father's BMI >25 kg/m^2
Hui LL *et al.*, 2003 (77)	5.337	Risk factors for childhood overweight in Hong Kong children ages 6–7 years	Hong Kong, China	343 children	Ages 6–7 years	Cross-sectional	Overweight: BMI ≥92nd percentile	ANOVA, Chi-square test	Parental obesity Decreased sleeping duration <9 hours Father current smoker
Layte R 2014 (159)	5.337	Social class variation in the predictors of rapid growth in infancy and obesity at age 3 years	Ireland	11,134 children	Ages 9 months–3 years	Prospective cohort	International obesity task force definition	Logistic regression models	Higher birthweight, less breastfeeding, prenatal smoking, and Maternal BMI
Locard E 1992 (195)	5.337	Risk factors of obesity in a five-year-old population; parental versus environmental factors	France	9,261 children	Age 5 years	Case-control	Obesity: weight for height and sex z-score > +2	Chi-square test, Student's t-test, Mantel–Haenszel test, logistic regression model	Overweight parents Birth overweight Southern European origin of mother TV viewing >4 times/day Snacks between meals Sleep duration <11 hours

Table 1. Continued

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
Maffeis C 1994 (96)	5.337	Parental and perinatal factors associated with childhood obesity in northeast Italy	Italy	1,363 children	Ages 4–12 years	Cross-sectional	2000 CDC reference	Chi-square test, t-test, logistic regression analysis	Parental BMI
Mueller NT 2015 (162)	5.337	Prenatal exposure to antibiotics, cesarean section, and risk of childhood obesity	United States	436 mother-child pairs	Birth-age 7 years	Prospective cohort	2000 CDC reference	Binomial regression models, general linear regression models, linear regression analysis	Antibiotic exposure during second or third trimester
Pan L 2014 (164)	5.80	A longitudinal analysis of sugarsweetened beverage (SSB) consumption in infancy and obesity at age 6 years	United States	1,189 children	Age 6 years	Prospective cohort	2000 CDC reference	Logistic regression analyses	SSB consumption during infancy Any SSB consumption before age 6 months Consumption of SSBs >3 x/week during ages 10–12 months
Suglia SF 2012 (172)	5.80	Cumulative social risk and obesity in early childhood	United States	1,605 children	Age 5 years	Prospective cohort	2000 CDC reference	Logistic regression analyses	>2 social risk factors; maternal substance use, housing insecurity, food insecurity, intimate partner violence, maternal depression, paternal incarceration
Trasande L 2013 (177)	5.337	Infant antibiotic exposures and early-life body mass	UK	11,532 children	Birth-age 7 years	Prospective cohort	Under age 2 years: World Health Organization (WHO) reference weight-for-length z-score over age 2 years: 1990 UK. BMI z-score (no definition for obesity)	Multivariable models, linear models, logistic models, regression models	Antibiotic exposure <age 6 months
Tremblay MS and Willms JD, 2003 (178)	5.337	Is the Canadian childhood obesity epidemic related to physical inactivity?	Canada	7,216 children	Ages 7–11 years	Prospective cohort	International obesity task force definition	ANOVA, three logistic regression models	Less organized/unorganized sport and physical activity TV >2 hours

Table 1. Continued

Citation and reference number	Journal impact factor	Title	Country	*N*	Age	Study design	Definition of obesity	Statistical methods	Risk factors for childhood obesity and/or overweight
von Kries R 2002 (127)	5.337	Reduced risk for overweight and obesity in children ages 5 and 6 years by duration of sleep – a cross-sectional study	Germany	6,862 children	Ages 5–6 years	Cross-sectional	Overweight: BMI >90th percentile obesity: BMI >97th percentile	Crude and adjusted odds ratios, Mantel–Haenszel statistics, logistic regression analysis	Less sleeping (<10 hours)
Whitaker RC 2004 (185)	5.80	Predicting preschooler obesity at birth: the role of maternal obesity in early pregnancy	United States	8,494 children	Ages 2–4 years	Retrospective cohort	2000 CDC Reference	Chi-square test	Maternal obesity
Wilkinson PW 1977 (204)	8.04	Obesity in childhood: A community study in Newcastle upon Tyne	Wales, England	161 children	Age 10 years	Case-control	Obesity: BMI ≥97th percentile	No test described	1 parent missing One or no siblings
Zilanawala A 2015 (189)	5.337	Racial/ethnic disparities in early childhood BMI, obesity, and overweight in the UK and United States	UK and United States	UK: 19,244 children United States: 10,700 children	UK: Ages 9 months, 3 years, 5 years, 7 years, and 11 years United States: Ages 9 months, 2 years, 4 years, and upon entry to kindergarten	Prospective cohort	International obesity task force definition	Multinomial logistic regression models	Black Caribbean Black African Whites in UK (versus Pakistani)