

Article

Childhood Obesity and Chronic Low-Grade Inflammation: A Review of Metabolic and Immunological Mechanisms

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Abstract: Childhood obesity has emerged from a nutritional and anthropometric issue into a metabolic and immunological disorder that is defined by chronic changes in adipose tissue biology, immune-cell function, endocrine function and systemic metabolism. Recent studies have suggested that there is a state of chronic low-grade inflammation associated with excessive adiposity in children, which may start early in childhood and lead to the development of insulin resistance, dyslipidemia, metabolic dysfunction associated steatotic liver disease (MASLD), endothelial dysfunction and other cardiometabolic conditions. It is now known that adipose tissue is an active immunometabolic organ that communicates with macrophages, T lymphocytes, neutrophils, and other immune cells through hypertrophic adipocytes. This interaction alters the secretion of adipokines and inflammatory mediators such as leptin, adiponectin, tumor necrosis factor alpha (TNF- α), interleukin-6 (IL-6) and interleukin-1 beta (IL-1 β). This process is further exacerbated by oxidative stress, mitochondrial dysfunction, endoplasmic reticulum stress and activation of inflammatory signaling pathways. Meanwhile, changes in gut microbiota and intestinal barrier function could lead to systemic inflammation via gut-derived metabolites and metabolic endotoxemia. Childhood is an important developmental time window in which inflammatory and metabolic abnormalities can become biologically programmed via epigenetic changes is a key point. This review aims to highlight key mechanisms involved in childhood obesity that contribute to the development of chronic low-grade inflammation, to describe the effect on clinically relevant biomarkers and organ-specific consequences, and to explore emerging strategies for the prevention and treatment of childhood obesity. An immunometabolic perspective of obesity could help to identify and prevent or treat obesity earlier and more individually.

Keywords: Childhood obesity; chronic low-grade inflammation; adipose tissue; insulin resistance; cytokines; adipokines; immunometabolism; oxidative stress

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1. Introduction

Childhood obesity is a complex disorder resulting from interactions between genetic susceptibility, dietary patterns, physical inactivity, environmental, socio-economic, developmental and biological factors which impact on energy balance in children. It's not only about the body weight – obesity in childhood may trigger the metabolism changes that are manifesting themselves in adolescence and adulthood [1]. Chronic low-grade inflammation is an important mechanism linking excess adiposity and cardiometabolic disease and increasing evidence suggests that it is a key mechanism underlying the biological consequences of pediatric obesity [2]. Obesity-associated inflammation is generally mild, chronic and characterized by small, sustained increases in inflammatory mediators, whereas acute inflammation is more rapid, often protective and is characterized by greater increases in inflammatory mediators [3].

Adipose tissue is an important factor in this. When energy stored increases the adipocytes become hypertrophied and stressed, particularly in the visceral fat depots.

Along with these changes are changes in the secretion of adipokines and chemokines, and recruitment and activation of immune cells [4]. Consequently, the function of adipose tissue in the interaction of metabolic and immune pathways comes into play. Some research has indicated a correlation between higher concentrations of inflammatory markers such as C-reactive protein (CRP) as well as higher levels of adiponectin and leptin with greater adiposity in obese children [5].

The inflammatory environment can disrupt the insulin pathway, lipid metabolism, vascular function and hepatic metabolism. Concurrently, oxidative stress, mitochondrial dysfunction, gut microbiota changes, and activation of inflammatory pathways like nuclear factor-kappa B (NF- κ B) and the NLRP3 inflammasome may be interconnected [6].

Important is that children have the opportunity for early detection and intervention since inflammatory and metabolic abnormalities can be in part modifiable in childhood, before irreversible organ damage occurs. This review reviews the key pathways linking childhood obesity to chronic low-grade inflammation, and explores the metabolic, immunological and clinical implications of these pathways.

2. Materials and Methods

This study employed a narrative review approach to synthesize current evidence regarding the metabolic and immunological mechanisms linking childhood obesity with chronic low-grade inflammation. Relevant peer-reviewed literature was identified and critically examined with emphasis on studies addressing adipose tissue expansion and dysfunction, immune-cell remodeling, adipokine and cytokine signaling, insulin resistance, oxidative stress and mitochondrial dysfunction, gut microbiota and intestinal barrier alterations, and obesity-related systemic complications. Particular attention was given to evidence concerning inflammatory mediators and biomarkers, including C-reactive protein (CRP), interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF- α), interleukin-1 beta (IL-1 β), leptin, adiponectin, insulin-related indices, and markers of oxidative stress. The selected literature included original research articles, systematic and narrative reviews, meta-analyses, and clinically relevant studies concerning pediatric obesity and related metabolic disorders. Evidence was synthesized thematically according to the major biological pathways discussed in the review, including adipose tissue inflammation, immunometabolic interactions, inflammatory signaling, oxidative and mitochondrial stress, gut-adipose-liver interactions, and organ-specific metabolic consequences. The findings were subsequently integrated to provide a mechanistic framework describing the progression from excessive adiposity to chronic inflammation and cardiometabolic dysfunction during childhood. Because this study was based exclusively on previously published literature and did not involve direct participation of human subjects or collection of identifiable patient data, ethical approval and informed consent were not required.

3. Results

3.1 Adipose Tissue Expansion and the Initiation of Chronic Inflammation

Adipose tissue is not only a storage of surplus energy, but also a metabolically active endocrine and immune organ [7]. In normal development, the adipose tissue is involved in energy storage, thermogenesis, endocrinology and immune surveillance. Persistent positive energy balance leads to adipocyte enlargement and, in some cases, to adipocyte number increases, in childhood obesity [8]. Adipocytes that become hypertrophic undergo metabolic and cellular stress, and acquire distinct lipid handling, metabolic, mitochondrial and cytokine secretion patterns. The changes can lead to the presence of a chronic low-grade inflammation (Figure 1) [9].

Visceral adipose tissue seems to play a special role and is more closely linked with metabolic problems than subcutaneous adipose tissue. The ability of the adipocytes to store lipids safely may be reduced as they enlarge [10]. Ectopic accumulation of lipid in the liver and skeletal muscle and delivery of free fatty acids to the circulation can further disrupt metabolic homeostasis. In parallel, under stress conditions adipocytes produce chemotactic signals to recruit immune cells into the adipose tissue [11]. Macrophages are

a central component of the immune cells involved in obesity-associated inflammation, albeit the immune cell infiltrate is much more complex than the simple M1/M2 paradigm implies [12].

Stressed adipocytes also are linked with greater secretion of chemokines like monocyte chemoattractant protein-1 and inflammatory mediators like tumor necrosis factor α and interleukin 6. Both of these can have a local or systemic effect [13]. This inflammatory environment may impact adipocyte insulin sensitivity, facilitate lipolysis and release free fatty acids, setting up a vicious cycle of inflammation and metabolic dysfunction.

The magnitude and clinical expression of inflammation in adipose tissue may differ among children based on age, sex, pubertal status, fat distribution and duration of obesity. Thus BMI is not an adequate measure of the biological diversity of children with obesity. By developing an understanding of adipose tissue dysfunction, the process by which some children with obesity have more severe metabolic dysfunction and others have less at a given stage of development can be explained.

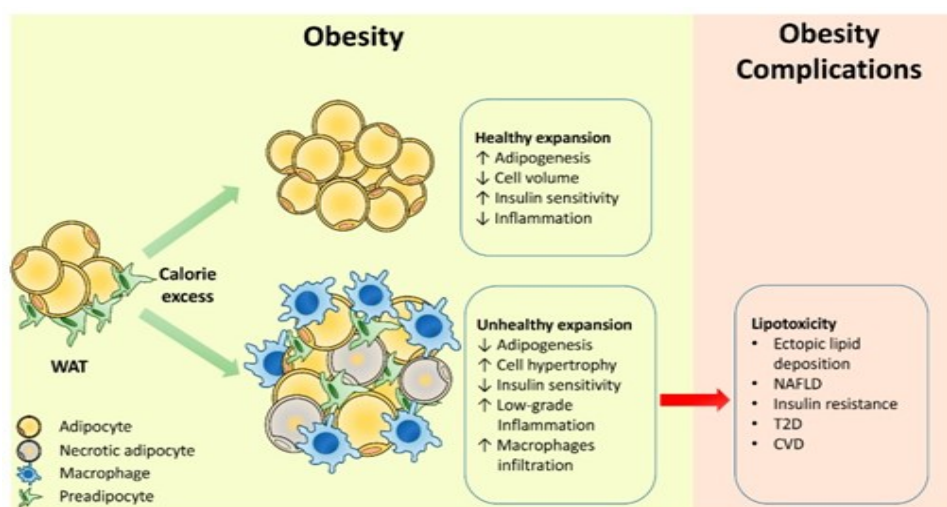


Figure 1. Proposed Mechanistic Transition from Excess Energy Storage to Chronic Low-Grade Inflammation in Childhood Obesity

3.2 Immunological Remodeling of Adipose Tissue in Childhood Obesity

In obesity, there is a significant remodeling of inflammatory environment in adipose tissue that accompanies the development of chronic inflammation. Innate and adaptive immune cells are involved [14]. In addition to the many macrophages, adipose tissue contains T lymphocytes, B lymphocytes, neutrophils, natural killer cells, dendritic cells and regulatory immune cells. These cells are altered in number and normal function, so that adipose tissue becomes a more pro-inflammatory tissue [15].

Macrophages are recruited by hypertrophied and stressed adipocytes. The recruitment by chemokines causes the accumulation of macrophages around the adipocytes, which can secrete TNF- α , IL-6, IL-1 β and other mediators that antagonize normal metabolic signals [16]. While macrophages have been traditionally classified as either pro-inflammatory M1-like or anti-inflammatory M2-like, existing evidence shows there's a great deal of heterogeneity and plasticity in adipose tissue macrophages [17,18]. This more complex understanding is significant as it can be dynamic during the course of obesity or obesity treatment, and is especially relevant for immune-cell phenotypes.

In addition, adaptive immunity is also a source of obesity-associated inflammation. Alterations in T cell numbers have been linked to changes in the activation of macrophages and the production of cytokines, and B cells could play a role in inflammatory responses by producing antibodies and by regulating immune response (Figure 2) [19]. However, anti-inflammatory mediators like IL-10, and regulatory T cells, can counteract excessive inflammation, but this regulatory effect can be lost as adipose dysfunction progresses [20]. More recently, pediatric obesity has been linked to

widespread immune-regulatory abnormalities, such as cytokine profiles and activation of immune cells.

One of the main aspects of this process is the relationship between metabolism and immunity, known as immunometabolism [21]. Immuno-cell behavior can be directly affected by nutrient excess, lipid intermediates, oxidative stress and mitochondrial abnormalities. In contrast, in inflammatory conditions, cytokines can affect the metabolism of glucose and lipids in adipocytes, skeletal muscle and liver [22]. Therefore, metabolic dysfunction and inflammation should not be considered separate outcomes of obesity, but they can act as interconnected processes, potentially moving in a positive feedback loop.

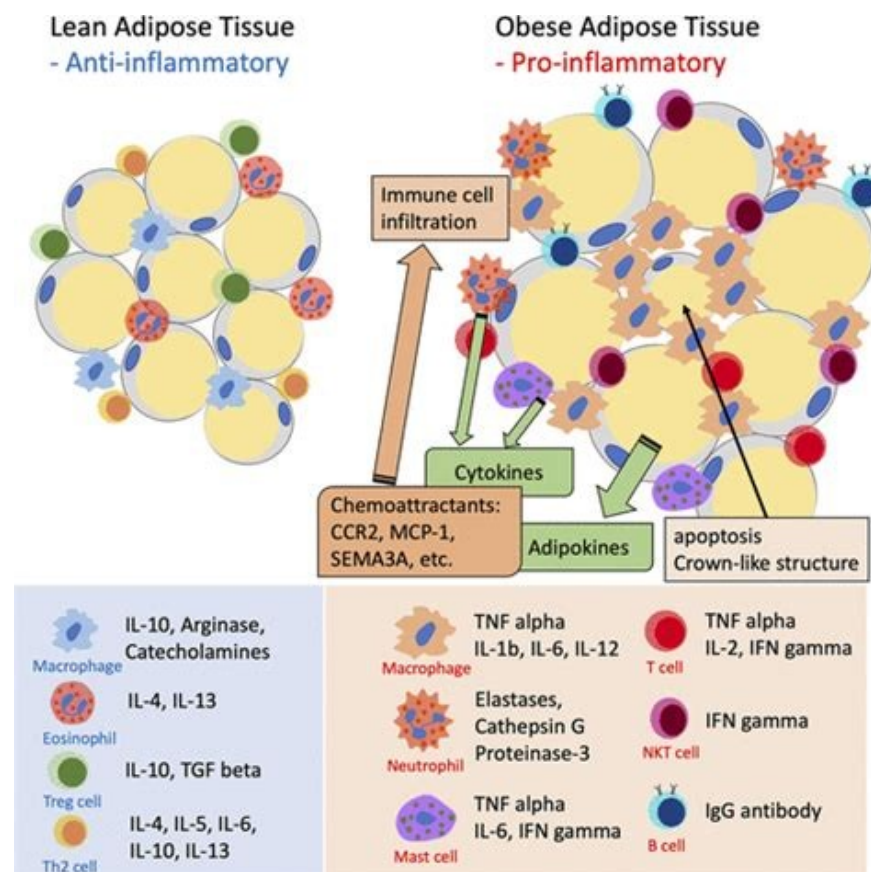


Figure 2. Immunological Remodeling of Adipose Tissue in Childhood Obesity: Interactions among Adipocytes, Macrophages, T Cells, and Cytokines

3.3. Adipokines, Cytokines, and Inflammatory Signaling Pathways

Increased adiposity is associated with systemic metabolic dysfunctions and is accompanied by the release of molecular mediators, the adipokines and cytokines. There are two main adipokines that have opposing biological profiles: leptin and adiponectin. Leptin is normally involved in energy homeostasis and appetite regulation, but levels of circulating leptin tend to rise with adiposity [23,24]. Long duration of elevated may include leptin resistance, and elevated may also help to drive inflammatory signaling [25]. The levels of adiponectin, however, are inversely related to adiposity, and it has insulin sensitizing and anti-inflammatory effects.

Obesity associated metabolic dysfunction is associated with several pro-inflammatory cytokines. TNF- α can influence insulin signaling processes, and can induce expression of inflammatory genes; IL-6 is associated with systemic inflammation and metabolic alterations (Figure 3) [26]. IL-1 β is particularly relevant in the context of being one of the pathways that can be activated by the inflammasome [27]. The metabolic danger signal, lipid disturbance, mitochondrial dysfunction and mitochondrial stress, in obesity, might trigger the activation of the NLRP3 inflammasome, leading to activation of Caspase-1 and

maturation of IL-1 β . This introduces a mechanism for a link between excess nutrients and inflammatory signaling [28,29].

Intracellular effects through inflammatory signaling pathways: NF- κ B, mitogen activated protein kinase pathways, stress related kinases. The pathways influence the transcription of inflammatory genes and could intervene with insulin receptor pathways [30]. Importantly, inflammatory signals might lead to the phosphorylation of insulin receptor substrate proteins in a negative manner, thus reducing insulin receptor activation within the insulin receptor pathway leading to phosphatidylinositol 3-kinase and Akt. This leads to less glucose being taken up by insulin, and a progressive rise in insulin resistance [31].

It is the ratios of pro-inflammatory and anti-inflammatory signals that are more important than individual cytokine levels. Pediatric literature has recently focused on the relationship between IL-1, IL-6, IL-17, IL-18, TNF- α , TGF-related pathways, IL-10, adipokines and immune cells with regard to the metabolic diseases associated with obesity [32].

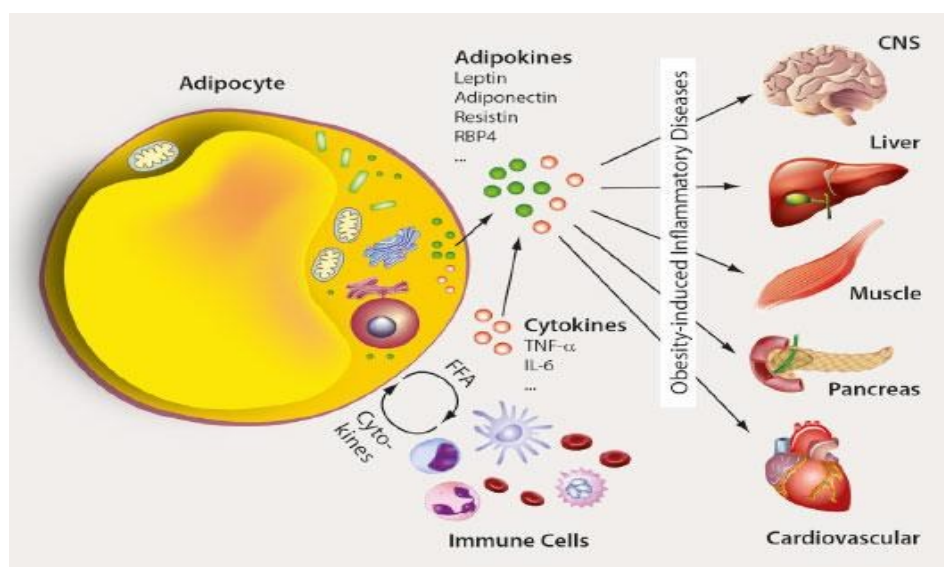


Figure 3. The Adipokine–Cytokine Network Linking Adipose Dysfunction to Systemic Inflammation and Metabolic Disease

3.4. Insulin Resistance, Oxidative Stress, and Mitochondrial Dysfunction

Insulin resistance is one of the most significant metabolic consequences of childhood obesity, and is a key link between inflammation and cardiometabolic disease. Insulin resistance can occur in skeletal muscle, liver and fat in obese children [33]. Initially the pancreatic β -cells can compensate by secreting more insulin, and the concentration of glucose is maintained at a relatively normal level [34]. But if the situation is chronic, it is possible compensatory mechanisms can become exhausted, leading to high risk of glucose intolerance or type 2 diabetes.

Insulin resistance is caused directly by inflammation in a number of ways. TNF- α , IL-6 and other inflammatory mediators may disrupt insulin receptor signaling, and increased free fatty acids and lipid intermediates may stimulate pathways of stress (Figure 4) [35]. The greater rates of adipose lipolysis also enhance the incorporation of lipids into liver and skeletal muscle, which results in greater fatty acid levels in the circulation. The changes that occur create a metabolic imbalance, which in time can become worse due to the insulin-signaling [36].

The other important factor is oxidative stress. When nutrients are available in excess, the workload on the mitochondria can be increased and this can lead to an increase in production of reactive oxygen species [37]. Oxidative stress can be further exacerbated by mitochondrial dysfunction, endoplasmic reticulum stress and inflammatory macrophage activity [38]. ROS and RNS may damage proteins, lipids and nucleic acids, and initiate

additional inflammatory signaling [39]. What is important, however, is that oxidative stress and inflammation are interrelated; that is, oxidative stress can lead to inflammation and vice versa.

The NLRP3 inflammasome is an additional interface, as well as the mechanistic connection between cell metabolism and inflammation. The metabolic stress, mitochondrial disturbances could lead to inflammasome activation, which in turn leads to production of IL-1 β and may exacerbate insulin resistance [40].

Pediatric obesity thus can be viewed as a metabolic stress-inflammation-oxidative stress triangle, each component contributing to the other. This model offers a rationale for the presence of inflammatory abnormalities in nonclinical diabetes and may even offer the potential for early intervention to have effects beyond weight loss.

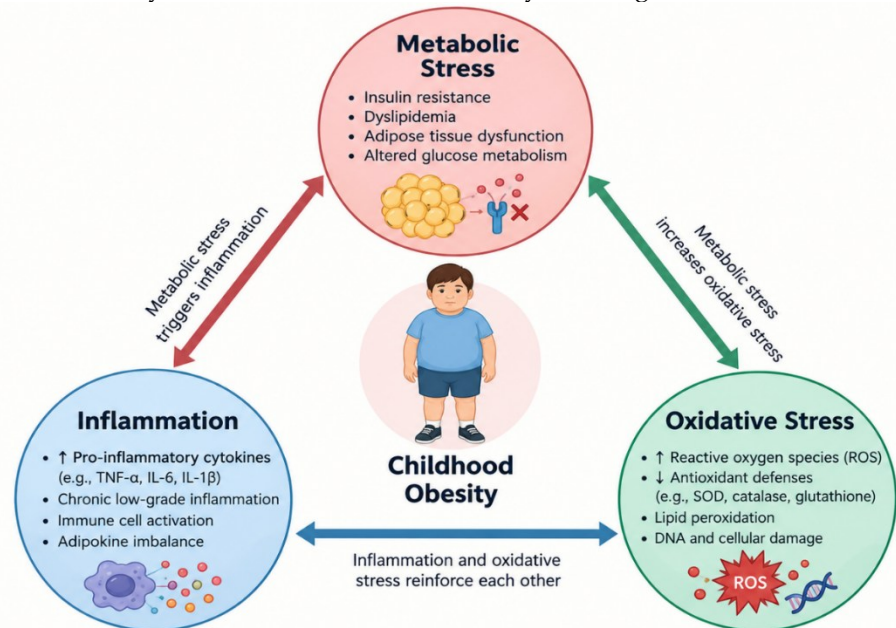


Figure 4. The Metabolic Stress–Inflammation–Oxidative Stress Triangle in Childhood Obesity

3.5. Gut Microbiota, Intestinal Barrier Dysfunction, and Systemic Inflammation

The gut microbiota is a key player in the immunometabolic network of childhood obesity (Figure 5). The intestinal microbial ecosystem affects nutrient metabolism, energy harvest, the generation of microbial metabolites, the integrity of the intestinal barrier, maturation of the immune system and inflammatory signaling [41]. In recent years, pediatric studies have found links between microbial diversities and composition with obesity, but they have varied between populations and studies [42,43].

Disruption of the intestinal barrier is one of the suggested mechanisms. Alterations in diet, microbial flora, bile acid metabolism, and intestinal physiology can cause intestinal permeability to rise, and lead to the presence of bacterial constituents in the blood, like lipopolysaccharide [44]. This is known as metabolic endotoxemia and can trigger activation of innate immune receptors and lead to inflammatory signaling throughout the body [45]. This inflammatory environment may have an impact on insulin sensitivity, liver metabolism and adipose tissue.

The metabolites from the microbes can also affect host metabolism. Short chain fatty acids, such as acetate, propionate and butyrate, can act through receptors in the host and are involved in regulation of immune function, intestinal integrity, energy metabolism and appetite [46]. But the association of specific microbial taxa with obesity is intricate [47]. The most recent evidence indicates that no single "obesity-associated microorganism" is likely to exist, but that rather the risk of disease may be due to the shift in the microbial community, dietary substrates, microbial metabolites, and host responses [48,49].

Notably, diet can have an impact on obesity and microbiota-mediated inflammation. Fiber-rich dietary patterns can create a beneficial environment for the production of

beneficial microbial metabolites, whereas high energy density and low fiber diets may create an unfavorable environment for microbial metabolites [50]. There has recently been renewed interest in dietary interventions and microbiota-modifying strategies that have the potential to affect inflammatory and metabolic outcomes in children, but with limited long-term clinical evidence [51]. Based on this, the gut can be considered as yet another important interface between nutrition, immunity and metabolism in obesity during childhood.

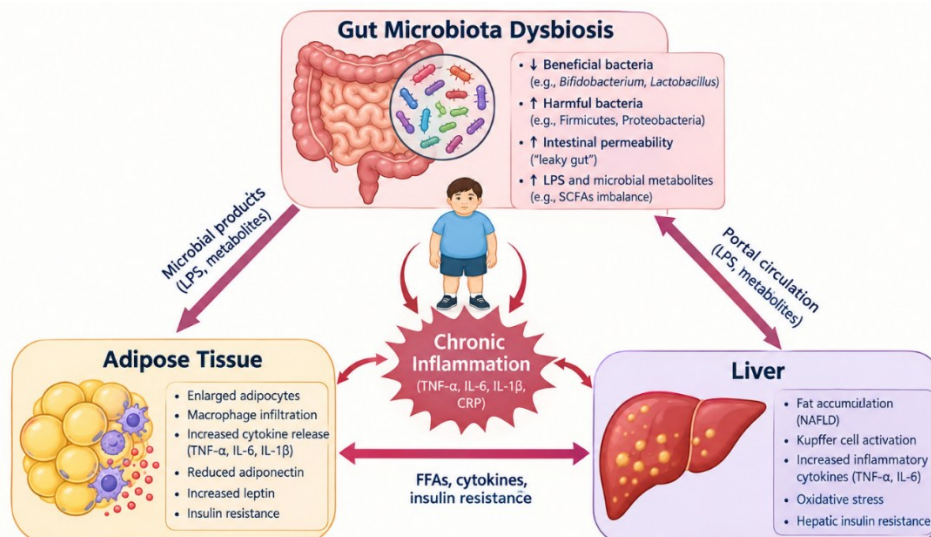


Figure 5. The Gut–Adipose–Liver Axis: How Microbiota Dysbiosis May Promote Chronic Inflammation in Childhood Obesity

3.6. Systemic Consequences: Liver, Cardiovascular System, and Metabolic Organs

Low-grade inflammation that accompanies childhood obesity may be widespread and involve several organs besides the fat. Increased delivery of free fatty acids from adipose tissue, insulin resistance, dyslipidemia, oxidative stress, and inflammatory mediators are all factors that can lead to hepatic lipid accumulation, particularly affecting the liver [52,53]. This is a factor in the emergence of metabolic dysfunction-associated steatotic liver disease (MASLD) as an important pediatric complication of obesity [54]. Paediatric MASLD is a continuum from hepatic steatosis to inflammatory/fibrotic disease, and obesity is a key risk factor [55].

Hepatic injury may be mediated by inflammatory cytokines through mechanisms of oxidative stress, activation of immune cells and stress to the hepatocytes. The relationship may be bi-directional as systemic metabolic signaling may also be influenced by hepatic inflammation [56]. In recent years, the literature has focused on the fact that obesity, insulin resistance, inflammation, oxidative stress, dyslipidemia, and MASLD are not separate diseases, but rather are interconnected [57,58].

The cardiovascular system is a target of early onset of pediatric obesity. Children with obesity have been found to have endothelial dysfunction and this may be a precursor for the development of atherosclerotic disease [59]. Impaired endothelial homeostasis may be due to inflammatory mediators, oxidative stress, insulin resistance, alteration of lipid metabolism, and decreased bioavailability of nitric oxide in the blood vessels [60].

In addition to the liver and the vascular system, chronic inflammation can affect skeletal muscle metabolism, function of pancreatic β -cells, regulation of blood pressure, and general cardiometabolic risk (Figure 6) [61]. These effects are important because they can last long-term. Childhood obesity is not just a predictor of obesity in adulthood; it can set the stage for developing pathways to future chronic diseases. This helps to reinforce the notion that inflammation is an early event in the process of obesity related risk, and not simply a late event in established metabolic disease.

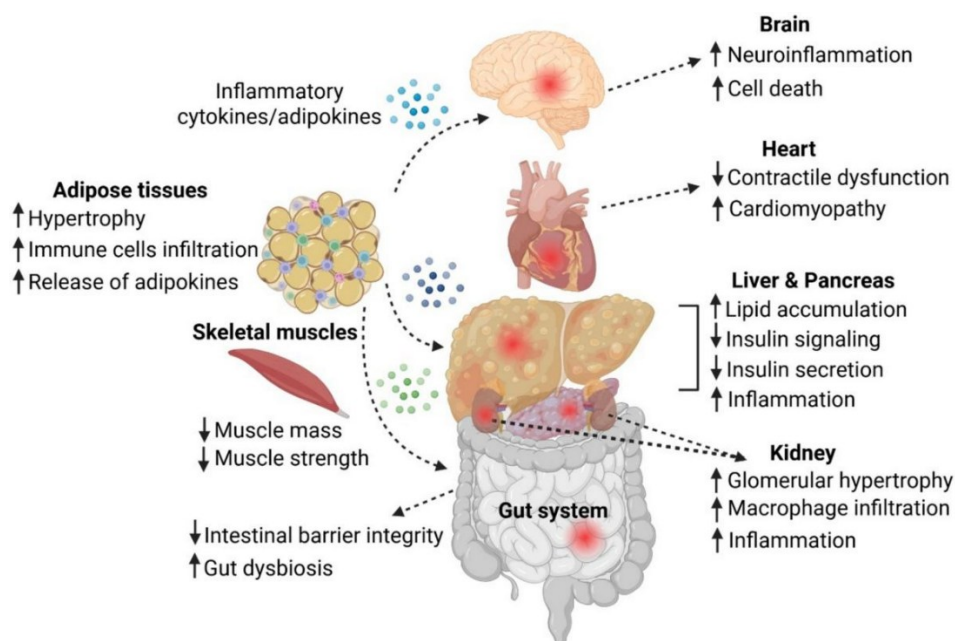


Figure 6. Systemic Organ Crosstalk in Childhood Obesity: From Adipose Inflammation to Liver, Pancreas, Skeletal Muscle, and Cardiovascular Dysfunction

3.7. Biomarkers, Early Intervention, and Future Directions

Identifying potentially more reliable biomarkers can increase the identification of children with obesity who are at higher risk for metabolic complications. In children, many markers have been studied, such as CRP, high sensitivity CRP, IL-6, TNF- α , leptin, adiponectin, insulin, HOMA-IR, lipid parameters and markers of oxidative stress [62]. Interpretation is tricky, though, since inflammation/metabolism markers are affected by age, sex, pubertal stage, body fat distribution, infection, and other biological factors [63]. Pediatric reviews stress that inflammatory markers are currently hampered by some limitations, and that consistent, age-specific cut-off values are not readily available.

The immunometabolic model has many implications, one of which is that BMI normalization is not a critical step for successful intervention [64]. Modifying lifestyle through alterations in physical activity, dietary quality, insulin sensitivity and body composition may resolve metabolic and inflammatory characteristics [65]. Overall, there is a meta-analytical evidence that exercise performed in children with overweight and/or obesity can lead to a decrease in inflammatory parameters like IL-6 and CRP, and to an increase in adiponectin [66], yet, the impact of exercise on individual biomarkers can differ.

Exercise also can affect antioxidant activity, endothelial function, insulin sensitivity and mitochondrial function [67]. There is recent evidence that the combination of HIIT can lower CRP in children and adolescents who are overweight or obese [67,68], but further research is needed to better understand how training should be structured and the long-term benefits.

Future studies should aim for a panel of biomarkers instead of single inflammatory markers. The integration of anthropometric data, metabolic indices, adipokines, inflammatory cytokines, metabolomics, and microbiome properties, along with perhaps epigenetic factors, could help identify the risk better. Childhood is a developmental stage in which environmental exposures can affect the regulation of genes, making epigenetic mechanisms particularly interesting. Existing evidence for associations of childhood obesity with DNA methylation, non-coding RNAs, and other epigenetic mechanisms is limited and inconclusive, and applying this knowledge is not yet ready.

4. Discussion

Childhood obesity should be understood not only as an excessive accumulation of body fat but also as a complex immunometabolic condition characterized by persistent

low-grade inflammation. The evidence synthesized in this review indicates that adipose tissue dysfunction represents a central initiating mechanism. As adipocytes enlarge in response to sustained positive energy balance, particularly within visceral adipose depots, their capacity to store lipids safely becomes impaired. This condition promotes free fatty acid release, ectopic lipid accumulation, cellular stress, and the secretion of chemotactic and inflammatory mediators, thereby creating a local environment that favors immune-cell recruitment and systemic metabolic disturbances.

An important finding of the reviewed evidence is that obesity-associated inflammation involves extensive remodeling of both innate and adaptive immune responses. Macrophages accumulate around hypertrophic and stressed adipocytes and release inflammatory mediators such as TNF- α , IL-6, and IL-1 β , while T lymphocytes, B lymphocytes, neutrophils, natural killer cells, and regulatory immune cells also contribute to the inflammatory profile of adipose tissue. This supports the concept of immunometabolism, in which metabolic dysfunction and immune activation are interdependent rather than separate processes. Nutrient excess, lipid intermediates, mitochondrial abnormalities, and oxidative stress can modify immune-cell behavior, whereas inflammatory cytokines can simultaneously disrupt glucose and lipid metabolism in adipose tissue, skeletal muscle, and the liver.

The imbalance between pro-inflammatory and anti-inflammatory mediators appears to be particularly important in determining the severity of metabolic dysfunction. Increased leptin concentrations, reduced adiponectin activity, and elevated inflammatory cytokines may contribute to insulin resistance through disruption of insulin-receptor signaling and activation of inflammatory pathways such as NF- κ B and the NLRP3 inflammasome. These mechanisms provide a biological explanation for the close relationship among childhood obesity, inflammation, and impaired glucose metabolism. In addition, mitochondrial dysfunction and excessive production of reactive oxygen species may further reinforce inflammatory signaling, creating a self-perpetuating interaction among metabolic stress, oxidative stress, and chronic inflammation.

Another relevant aspect is the contribution of the gut microbiota and intestinal barrier to systemic inflammation. Alterations in microbial composition, intestinal permeability, and microbial metabolites may facilitate the translocation of bacterial products such as lipopolysaccharide into the circulation, promoting metabolic endotoxemia and innate immune activation. At the same time, short-chain fatty acids and other microbiota-derived metabolites can influence immune regulation, energy metabolism, appetite, and intestinal integrity. These findings indicate that the gut–adipose–liver axis may act as an additional pathway through which dietary patterns and obesity interact with inflammatory and metabolic processes in children.

The systemic consequences of these mechanisms extend beyond adipose tissue. Persistent inflammation, insulin resistance, dyslipidemia, oxidative stress, and altered lipid metabolism may contribute to metabolic dysfunction-associated steatotic liver disease, endothelial dysfunction, pancreatic β -cell stress, impaired skeletal-muscle metabolism, and broader cardiometabolic risk. Importantly, these abnormalities may already be present during childhood, indicating that inflammation is not merely a late complication of obesity but may represent an early biological pathway linking pediatric adiposity with future chronic disease.

From a clinical perspective, these findings emphasize the importance of identifying metabolic risk beyond conventional anthropometric measures alone. Biomarkers such as CRP, IL-6, TNF- α , leptin, adiponectin, insulin-related indices, lipid parameters, and oxidative-stress markers may provide additional information regarding immunometabolic dysfunction; however, their interpretation remains challenging because they are influenced by age, sex, pubertal stage, fat distribution, infection, and other biological factors. Therefore, a combination of anthropometric, metabolic,

inflammatory, and potentially microbiome-related indicators may be more informative than reliance on a single biomarker.

Overall, the evidence reviewed suggests that effective management of childhood obesity should focus not only on body-weight reduction but also on improving metabolic and inflammatory health. Dietary improvement and regular physical activity may positively influence insulin sensitivity, endothelial function, mitochondrial activity, and inflammatory profiles even when changes in body mass are modest. Future research should further clarify age-specific biomarker patterns, longitudinal immunometabolic changes, microbiome–host interactions, and epigenetic mechanisms so that children at greatest metabolic risk can be identified earlier and managed through more individualized preventive and therapeutic strategies.

5. Conclusion

Obesity in childhood is more of an immunometabolic disease than a disease of excess weight. The transition to chronic low-grade inflammation occurs through a combination of adipocyte hypertrophy, immune-cell remodeling in adipose tissue, dysregulated adipokine and cytokine secretion, insulin resistance, oxidative stress/dysfunction of mitochondria, and inflammatory pathways. The gut microbiota and intestinal barrier can also contribute to this inflammatory environment and the systemic effects can be seen in the liver, cardiovascular system, skeletal muscle and pancreatic metabolism.

These mechanisms are important not only in childhood, as metabolic and inflammatory dysfunctions may create biological pathways that predispose to higher levels of cardiometabolic risk later in life. However, the inflammatory profile of childhood obesity is not uniform and should be assessed in the context of other factors such as age, pubescence, body fat distribution and clinical setting.

Early intervention is also very critical from a translation point of view. Lifestyle strategies that include healthy eating patterns and physical activity can have a beneficial effect on inflammatory and metabolic profiles even with relatively small changes in conventional anthropometric measures. Future studies should include the use of immunology, metabolomics, microbiome science, epigenetics and clinical biomarkers to create personalized strategies for identifying children at extreme metabolic risk. The precision-immunometabolic approach may help redefine pediatric obesity management from a body size measurement to understanding and altering biological processes that underlie long-term disease.

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