Chapter

Weight Management: Inflammation

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Abstract

Nowadays, obesity is considered as one of the fastest escalating nutritional disorders that reached pandemic throughout the world. Obesity is a condition in which overaccumulation of energy in the form of fat happens in an individual's subcutaneous and/or abdominal visceral tissue. It is described as an abnormal growth of adipose tissue due to the enlargement of fat cell size (hypertrophic obesity) or fat cell number (hyperplastic obesity) or a condition of both. Earlier, it was reported that the most common type of obesity that affects the general population is the polygenic form that results from a result of a positive energy balance between energy consumption and its expenditure – or a combination of both. The pandemic of obesity has enforced to analyze the link between the role of inflammation and complications of overweight and obesity. This led to crossroads of the field of nutrition, diet therapy, physiology, immunology, and epidemiology and makes the understanding that they are linked inexplicably. The remodeling of obesity as an inflammatory state has led a wide impression in our conceptualization of obesity-related diseases. In this chapter, we highlight the endocrine aspect of adipose tissue, the effect of dysregulated secretion of adipokines due to inflammation and dietary components that affect obesity related to inflammation.

Keywords: nutritional disorder, obesity, adipokines, inflammation, dietary components

1. Introduction

A famous ancient proverb states that "Eat breakfast like a king, lunch like a prince, and dinner like a pauper." In today's era, these words have long been discarded. The magnitude of obesity has reached in pandemic proportion due to new technology and modern life, which makes life easier and less active along with the intake of high energy dense food for better taste [1–3]. This is one of the biggest public health concerns of today's era, which affects the individual not only physically but also physiologically and psychologically.

The World Health Organization (WHO) has reported that obesity has been growing at an alarming rate worldwide and has nearly been tripled between 1975 and 2016. It was also reported by WHO in the year 2016 that more than 1.9 billion adults, 18 years and older, were overweight; of these over 650 million were obese (https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight) [4].

Nowadays, obesity is regarded as a complex dysfunctional neuroendocrine problem in which genetic makeup and environmental factors act in concert. The nongenetic risk factors encompass a wide range of social, physiological,

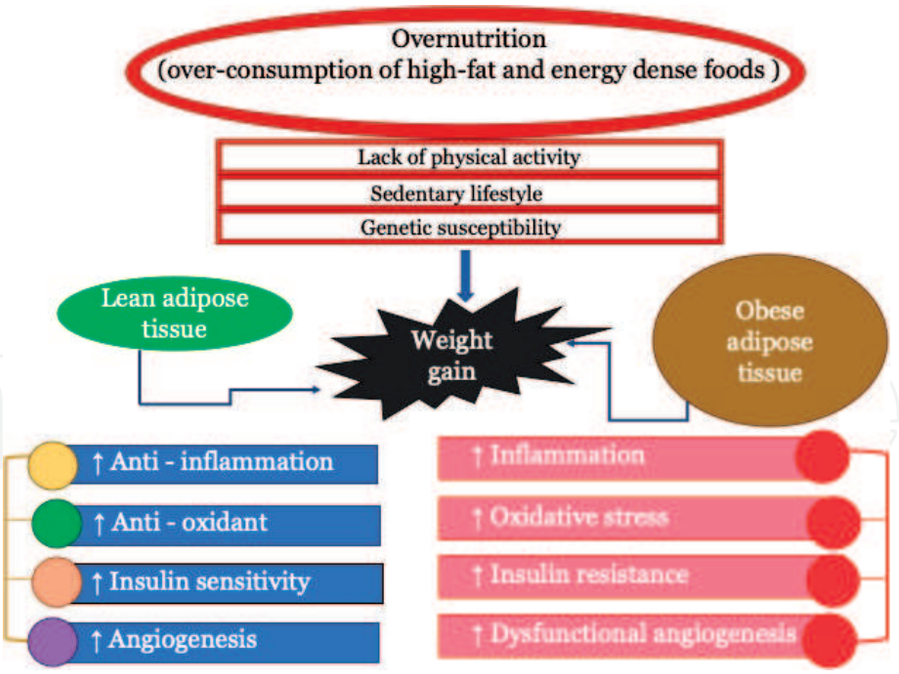

Figure 1.
Overnutrition (overconsumption of high-fat and energy dense foods), lack of physical activity, sedentary lifestyle, and genetic susceptibility are the leading factors associated with the development of obesity. In addition to dysfunctional angiogenesis, an obese state is characterized by an abnormal inflammatory response, low antioxidant capacity, and reduced insulin sensitivity that may eventually lead to the generation of inflammation, oxidative stress, and insulin resistance. The figure was modified from the following review paper by Dludla et al. [6].

environmental, and behavioral factors. Sedentary lifestyle and overconsumption of high-fat and energy dense foods are a major contributor to energy imbalance. The altered phenomenon of hunger and satiety, lack of physical activity, decreased thermogenesis, and resting metabolic rate over a long period of time may lead to the energy imbalance.

In addition, other external factors such as age, gender, food preference, breakfast skipping, medications, chemical toxicity, disorders of the endocrine system, socioeconomic status, and a psychological factor may give rise to weight gain problems. It is considered as a major contributor to the global burden of chronic diseases like hypertension, type 2 diabetes, hypercholesterolemia, heart diseases, insulin resistance, atherosclerosis, ischemic heart diseases, respiratory diseases, orthopedic disorders, several types of cancer, hormonal imbalance, disability, and many other diseases. Overweight and obesity also play a pivotal role in the development of low-grade inflammation, which contribute to the development of obesity-linked disorders, in particular to metabolic dysfunction [5]. However, a growing body of knowledge suggests that a possible convergence of an inflammatory state, which results in chronic inflammation and oxidative stress, is localized within adipose tissue [6] as shown in **Figure 1**. Adipose tissue inflammation plays a crucial role in promulgating obesity-related metabolic complications including the development of insulin resistance [6–8].

2. Adipose tissue: manager of inflammation

Over the past decades, it is well established that adipose tissue is not merely a fat storage depot but has been recognized as an endocrine organ capable of producing various bioactive substances. It then became evident that white adipose tissue (WAT) secretes ample of peptides. Few of them regulate the inflammatory

processes such as leptin and adiponectin, whereas others are well-known cytokines such as interleukin (IL)-6, IL-1 and its receptor antagonist (IL-1Ra), and tumor necrosis factor (TNF)-α [9]. As we know, obesity is one of the major causes of atherosclerosis, which is recognized as a chronic vascular inflammatory process in which cytokines and chemokines play a dramatic role [9–10]. White adipose tissue plays an important role in metabolism and inflammation as illustrated in **Figure 2**.

Cytokines are categorized as interleukins, interferons, chemokines, hematopoietic factors, and growth factors. They are knotted in many biological processes such as growth, differentiation, cell division, apoptosis, immunity, and inflammation [9]. Cytokines are produced by numerous cell types of the hematopoietic lineage including T cells, B cells, mast cells, macrophages, dendritic cells, and natural killer cells. In spite of these, cytokines are also produced by nonhematopoietic cells such as epithelial cells, hepatocytes, and fibroblasts [9, 12]. Evidence revealed that IL-1, IL-6, and TNF-α are characterized as a proinflammatory cytokine that activates both acute and chronic inflammatory responses [9]. Inhibitors that control inflammation can be categorized as anti-inflammatory cytokines, soluble receptors to cytokines, and naturally occurring proteins. Types of anti-inflammatory cytokines are IL-10, IL-4, and TGF-β; soluble receptors to cytokines are IL-1 and TNF-α; and naturally occurring proteins are IL-1Ra receptors. The classification of cytokines is depicted in **Figure 3**.

Chemokines are a type of cytokine that is a part of family molecules that are indulged in the chemotaxis of inflammatory cells via the generation of local concentration gradients. Chemokines play an important role in various physiological and pathological processes such as cell recruitment process and development of lymphoid organs or metastases. In spite of these, chemokines also participate in metabolic and inflammatory disorders such as rheumatoid arthritis, glomerulonephritis,

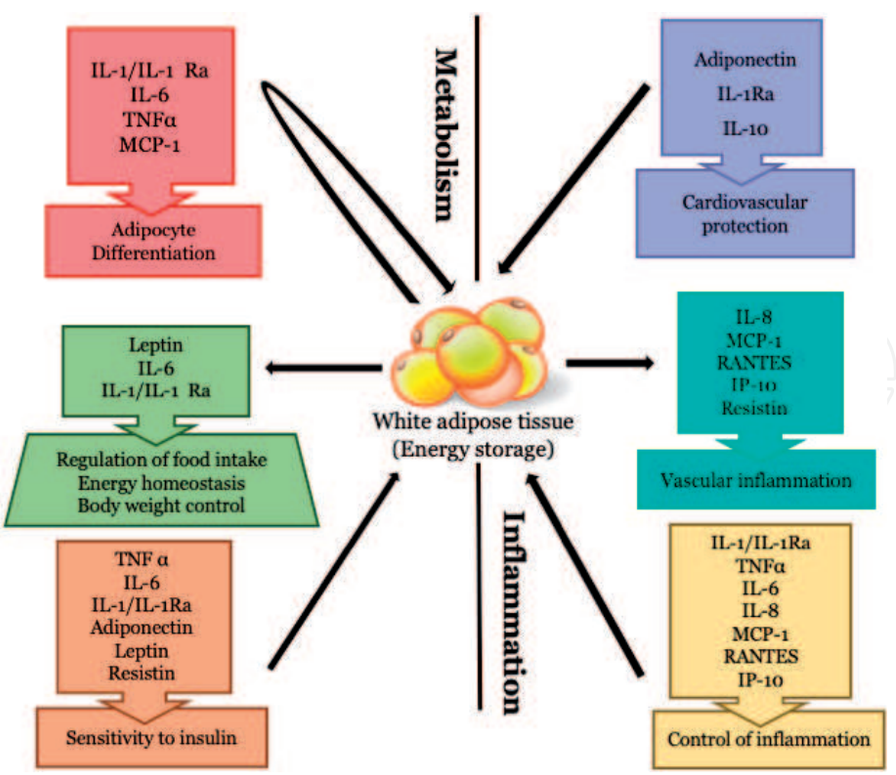

Figure 2.
Adipose tissue is a metabolically dynamic, highly active endocrine organ. White adipose tissue (WAT) produces a large variety of proteins regulating metabolism and inflammation, contributing to the maintenance of energy homeostasis and, probably, the pathogenesis of obesity-related metabolic and vascular complications. The figure was modified from the following research paper by Juge-Aubry et al. [9]. The following website was used for the extraction of image: https://scitechdaily.com/gc-1-turns-white-fat-brown-fat/ [11].

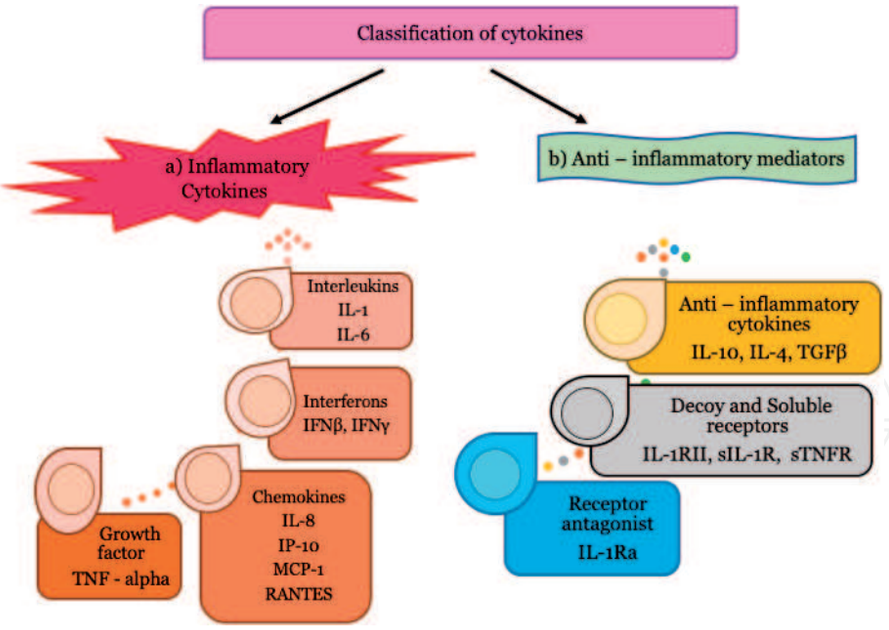

Figure 3.
Classification of cytokines. (a) Classes of inflammatory cytokines. (b) Anti-inflammatory mediators. The figure was modified from the following research paper by Juge-Aubry et al. [9].

and atherosclerosis via their innate ability to recruit and activate the inflammatory cells [9]. They are categorized into four subclasses according to the position of their cysteines (CXC, C, CX3C, and CC) [9, 13]. Chemokines that are produced from WAT are interferon-γ inducible protein 10 (IP-10 or CXCL10) and IL-8 (or CXCL8) belong to the CXC chemokines, while monocyte chemo-attractant protein-1 (MCP-1 or CCL2) and regulated upon activation normal T-cell express sequence (RANTES or CCL5) are CC chemokines [9, 13]. Previous studies showed that chemokines are paracrine rather than systemic factors, the significance of their secretion via adipose tissue may be seen in the context of fat depots found in close proximity to their target tissues, for example, subcutaneous fat in inflammatory skin diseases, perivascular adipose tissue in obesity-associated cardiovascular diseases, and perirenal fat in glomerulonephritis [9, 14].

In addition, several other metabolically important proteins with immunomodulatory actions are secreted by adipose tissue, including leptin, adiponectin, and resistin. The dysregulated expression of these factors, caused by excess adiposity and adipocyte dysfunction, has been linked to the pathogenesis of various disease processes through altered immune responses. As such, much attention has been paid to develop a better understanding of the immunoregulatory functions of adipose tissue. New factors secreted by adipose tissue have been identified that either promote inflammatory responses and metabolic dysfunction or contribute to the resolution of inflammation and have beneficial effects on obesity-linked metabolic disorders. These findings lend additional support to the notion that an imbalance of pro- and anti-inflammatory adipokines secreted by adipose tissue contributes to metabolic dysfunction [5].

3. Obesity: state of low-grade inflammation

Obesity is associated with alterations in immunity, a chronic low-grade inflammation, which is characterized by abnormal secretion of adipokines, that is, there is an increment in circulating proinflammatory cytokines and a decrement in anti-inflammatory cytokines. It is also linked with alteration in immunity. However,

with the reduction in body weight, these parameters may reverse or come to the normal level. Although, it is still debatable how obesity triggers inflammation. Earlier, several hypotheses were proposed regarding the inflammation of obesity. The first one stated that overburden of nutrients in the adipocytes leads to intracellular stress that results in the stimulation of inflammatory cytokines [15–17].

The excessive nutrients may lead to aggregation of unfolded proteins in the endoplasmic reticulum (ER) via activation of the unfolded protein response (UPR) pathway [15, 17]. The pathway of UPR depends on basically three main sensors of ER, that is, PKR-like eukaryotic initiation factor 2α kinase (PERK), inositol-requiring enzyme 1 (IRE-1), and activating transcription factor 6 (ATF-6) [15, 18]. The activity of the C-Jun amino-terminal kinase (JNK) and inhibitor of IκB (IKK-β), serine-phosphorylation of insulin-receptor substrate protein 1 (IRS-1), and the nuclear factor-κB (NF-κB) pathway may increase by the activated sensors of ER that results in increased expression of proinflammatory cytokines [15–16, 19–21].

The second hypothesis enumerates that overburdened adipocytes with fat cells intensely increase the infiltration of macrophages, which may lead to subsequent differentiation and activation of cytotoxic T cells. As a result, initiation and propagation of inflammatory cytokines cascades occur [15, 22]. Third hypothesis proposes that as during obesity, enlargement of adipose tissue happens as a result tissue becomes relatively hypoxic. Hypoxia within the adipose tissues results in the activation of inflammatory pathways [15, 23–24]. Above all, the last hypothesis suggests that overburdened adipocytes themselves may directly activate immune pathogen sensors that result in chronic inflammation [15, 25].

4. Dietary components that affect obesity related to inflammation

The analysis of dietary intake is an approach to investigate a link between diet and overweight and obesity-related inflammation. Various studies reported that bioactive nutrients and dietary non-nutrients strongly influence health, metabolism, and progression of pathologic states that ultimately result in chronic degenerative diseases [26]. Many studies indicate that diet may affect body weight by controlling satiety and metabolic efficiency or by harmonizing insulin secretion and action [3, 27]. It is an essential key factor for immune response. Earlier, evidence revealed that undernutrition brings about immunosuppression due to susceptibility to infection. Whereas, overnutrition brings about immunoactivation due to susceptibility to inflammatory diseases. As a result, optimum nutrition is mandatory for a healthy immune balance of an individual [15] as shown in **Figure 4**.

Dietary components play an important role in obesity-related inflammation as enumerated below:

4.1 Carbohydrates

Carbohydrates are the main food source of a living organism and a major source of energy. Carbohydrates are also known as energy giving foods. The source of energy was estimated based on their glycemic index (GI) or glycemic load (GL) values. GI is the value given to the foods on how quickly they increase the glucose level postprandially and measures the quality of carbohydrate. GL calculates both the quality and quantity of carbohydrates [15, 28]. Earlier studies reported that, positive correlation exists between dietary GI and GL and biomarkers of inflammation because a low GI diet decreases the rate of glucose absorption in the body that subsequently reduces hyperglycemia and hyperinsulinemia that results in the reduction of systemic inflammation. Earlier, it was also reported that weight loss

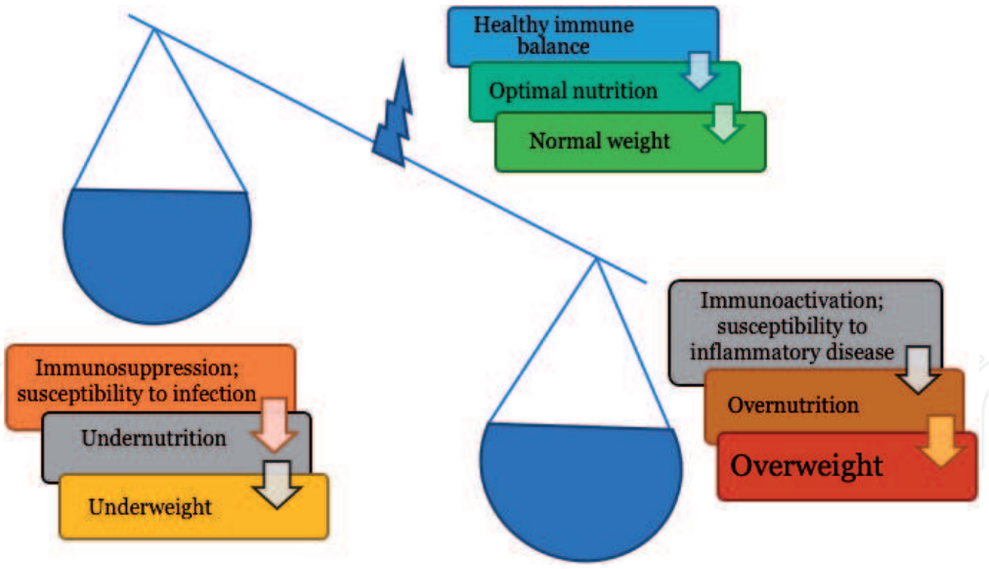

Figure 4.
Healthy immune balance between undernutrition and overnutrition. The figure was modified from the following research paper by Lee et al. [15].

leads to improvement in insulin sensitivity and a reduction in the level of proinflammatory cytokines. Various health organization also reported that low GI diets help in managing diabetes and coronary heart diseases and considered as a weapon against obesity [29–30].

Neuhouser et al. [31] revealed from randomized, crossover feeding study that respondents with high-fat mass (>32.0% for male and >25.0% for female) showed reduced CRP (P = 0.02) and marginally increased adiponectin (P = 0.06). Therefore, it was concluded that the quality of carbohydrates independent of energy was very important as low-GL foods improve the inflammatory and adipokine profiles of overweight and obese individuals [31]. Another study done by Levitan et al., among women (n = 18,137, >45 years of age), reported that diets characterized by lower GI and GL were associated with somewhat more favorable lipid profiles and lower CRP [32]. Interestingly, one of the epidemiological studies done by Vrolix and Mensick found that consumption of a diet with decreased GL does not decrease the metabolic risk parameters in overweight subjects [33]. Another study done by Kelly et al. also supports the above findings, that is, it does not found any additional benefit of including a low glycemic diet with exercise on insulin sensitivity and adipokine concentrations [34]. Above all, it may be stated that observational studies showed a positive association between intake of GI/GL diet and markers of inflammation. However, interventional studies do not found such an association.

4.2 Dietary fat

Fat is also one of the important sources of energy that serves both structural and metabolic functions of living organisms. The excessive accumulation of fat in the body leads to impairment of the immune system. A number of fatty acids have been studied including saturated, trans-fatty acids, and polyunsaturated fatty acids (PUFA) for their effect on inflammatory status [15].

4.2.1 Polyunsaturated fatty acids

The omega-3 (n-3) and omega-6 (n-6) PUFA families are precursors of eicosanoids, which play a vital role in the immune response [15]. Simpoulos [35]

stated that high omega-6 fatty acids increase leptin and insulin resistance, whereas omega-3 fatty acids lead to homeostasis and weight loss. This is so because the high omega-6/omega-3 ratio is associated with overweight/obesity, whereas a balanced ratio decreases obesity and weight gain [35]. Another study showed that an increase in the intake of n-6:n-3 PUFA potentiates the inflammatory processes that ultimately lead to many inflammatory diseases such as nonalcoholic fatty liver disease (NAFLD), cardiovascular disease, diabetes, obesity, inflammatory bowel disease (IBD), rheumatoid arthritis, and Alzheimer's disease. This change in the ratio of consumption of n-3/n-6 fatty acids changes the production of important mediators and regulators of inflammation and immune response that leads toward the pro-inflammatory state. Hence, it was concluded in the study that increasing the ratio of (n-3)/(n-6) PUFA in the diet may lead to a reduction in the incidence of chronic inflammatory diseases [36].

A clinical trial and in-vitro experiment study reported that supplementation of fish oil delineates the expression of adipose inflammatory genes including inflammasome-associated IL-18 and IL-1b and circulating IL-18 levels. In spite of this, it was also stated that both eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) decrease the inflammasome gene expression in obese human adipose and human adipocyte and macrophages [37]. Above all, various studies concluded that omega-3 fatty acids, namely EPA and DHA, have an anti-inflammatory effect.

4.2.2 Trans and saturated fatty acids

A review study was done by Rogero and Calder stated that saturated fatty acids induce inflammation by activating the TLR4 signaling pathway (TLR4 signaling pathway is recognized as the main pathway that triggers in obesity-induced inflammation) [38]. Another study revealed that the ingestion of excessive amounts of trans-fatty acids and saturated fatty acids is considered to be a risk factor for metabolic and degenerative diseases. It was also emphasized that saturated and trans-fatty acids favor a proinflammatory state leading to insulin resistance. These fatty acids can be indulged in several inflammatory pathways, contributing to disease progression in chronic inflammation, autoimmunity, allergy, cancer, atherosclerosis, hypertension, and heart hypertrophy as well as other metabolic and degenerative diseases. As a consequence, intake of dietary saturated and trans-fatty acids leads to lipotoxicity in several target organs by direct effects, represented by various inflammatory pathways, and through indirect effects, including an important alteration in the gut microbiota associated with endotoxemia process [39].

4.3 Fruits and vegetables

Fruits and vegetables comprise a myriad of nutrients, that is, vitamins, minerals, and many food compounds that have been inversely correlated with metabolic risk factors such as oxidative stress and inflammation. In a randomized controlled trial study, it was found that fruits and vegetables reduce the risk of metabolic disease that may be via modulation of gut microbiota. The study also revealed that fruits and vegetables decrease the secretion of interleukin-6 (IL-6) and lipopolysaccharide-binding protein (LBP) [40]. Another study done by Navarro et al. through factor analysis found that dietary patterns loaded with fruits and vegetables strongly negatively correlated with the secretion of hs-CRP among prepubertal girls [41]. An almost similar result was observed by Julia et al. that dietary pattern characterized by intake rich in vegetable and vegetable oil leads to the supply of essential fatty acids and antioxidant micronutrients showed a negative correlation with the risk of elevation of CRP [42]. Another cross-sectional study done on a group of 7574

Koreans found that an inverse correlation exists between vegetable pattern and CRP and the association appeared to be more predominant in men having hypertensive blood pressure [43]. Surprisingly, the study done by Salas-Salvado et al. (n = 772, 55–80 years of age) and Freese et al. (n = 77, 19–52 years of age) did not found any association between a diet rich in vegetables and fruits with inflammatory markers [adiponectin, CRP, IL-6, intercellular adhesion molecule-1 (ICAM-1), and vascular cell adhesion molecule-1 (VCAM-1)] [15, 44–45]. Another study done by Morand et al. (n = 24, mean age of 56 years) also showed a similar pattern of above finding that a single fruit supplementation (500 mL of orange juice/d for 4 weeks) did not change the levels of CRP, IL-6, ICAM-1, and VCAM-1 [15, 46].

4.4 Other nutrients

Oxidative stress and imbalance in immune responses play a crucial role in the development of obesity and its associated comorbidities. Various epidemiological shown that several vitamins and minerals have a favorable response on the level of inflammatory markers, that is, CRP, IL-6, and TNF-α.

4.4.1 Vitamin A

Various cross-sectional and intervention studies reported regarding overweight and obese respondents that they have lower circulating carotenoids in the plasma because of a high proportion of carotenoids, as lipid-soluble compounds, being stored in adipose tissue [15, 47]. The Women's Health Study (n = 2895, aged ≥45 years of age) reported that higher plasma concentrations of α- and β-carotene were associated with low levels of plasma CRP. In spite of this, plasma carotenoids were associated with obesity, HDL-cholesterol, LDL-cholesterol, HbA1c, and smoking [15, 48]. Another study done by Julia et al. suggested that the β-carotene status was inversely associated with low-grade inflammation [49]. Another cross-sectional meta-analysis study focusing on Syndrome X respondents showed an inverse association between total plasma carotenoids and metabolic syndrome. Respondents with the highest total circulating carotenoids had a 24% reduced risk for developing metabolic syndrome. Interestingly, when, individual carotenoids were included, and significant associations were found for β-carotene, lycopene, α-carotene, and β-cryptoxanthin [50–51].

4.4.2 Vitamin C

Vitamin C is effective in strengthening the immune system, capillary blood vessels, and protecting the dental health, as well as in the convenient use of iron, calcium, thiamine, riboflavin, folic acid, and vitamins A and E in the body. Vitamin C also acts as a cofactor for 15 different enzymes and shows the antioxidant activity as an electron donor reducing agent. It acts as a powerful free radical scavenger by protecting tissues against oxidative stress and reduces inflammation [52]. Totan et al. reported that vitamin C reduces the systemic inflammation by inhibiting CRP and TNF-α pathways. In spite of this, vitamin C inhibits hypoxia in adipose tissue that has the potential for protection against free radicals and decreasing lipid peroxidation. On the other hand, the study also revealed that vitamin C inhibits mature adipocyte formation and cell growth, inhibits lipolysis, and can be considered as a treatment model for obesity to offer solutions for abnormal fat accumulation [52]. Another study reported that vitamin C may improve inflammation by reducing the pro-inflammatory and inflammatory markers such as CRP, IL-6, and TNF-α [53]. Additionally, Fumeron et al. reported in the prospective, randomized, open-label

trial study (n = 42, 18–80 years of age) that vitamin C supplementation (750 mg/d for 8 weeks) did not change blood levels of CRP [15, 54].

4.4.3 Magnesium

Magnesium is the second most abundant intracellular cation and is involved in about 300 biochemical reactions related to anabolic and catabolic actions in the body, such as glycolysis and protein and lipid metabolism [55–56]. The Women's Health Initiative Observational Study (n = 3713 postmenopausal women, aged 50–79 years) reported that intake of dietary magnesium was independently and inversely associated with plasma concentrations of hs-CRP, IL-6, and sVCAM-1 in postmenopausal women after an adjustment for multiple variables including dietary fiber, fruit, vegetables, folate, and saturated and trans-fatty intake [57]. Another study done by Guerrero-Romero and Rodriguez- Moran found that low serum Mg levels were independently related to elevated CRP concentration, in nondiabetic, nonhypertensive obese subjects (n = 371) [15, 58].

4.4.4 Flavonoids

Flavonoids, a group of natural substances with variable phenolic structures, are found in fruits, vegetables, grains, bark, roots, stems, flowers, tea, and wine. Nowadays, flavonoids are considered essential components in various applications such as nutraceutical, pharmaceutical, medicinal, and cosmetic. This is attributed to their anti-oxidative, anti-inflammatory, anti-mutagenic, and anti-carcinogenic properties coupled with their capacity to modulate key cellular enzyme function [59]. According to National Health and Nutrition Examination Survey (NHANES), a large, cross-sectional survey National Centre for Health Statistic (n = 9551 adults) showed that flavonoid consumption was inversely associated with obesity in both men and women in multivariate models. It was also observed that adults in the highest quartile of flavonoid intake had significantly lower body mass index and waist circumference than those in the lowest quartile of flavonoid intake ($P < 0.03$ and $P < 0.04$, respectively). The study also revealed that flavonoid intake was inversely related to C-reactive protein levels in women (p-trend, 0.01) [60]. The Nurses' Health Cohort Study (n = 2115 women, aged 43–70 years) reported that among flavonoid-rich foods, higher intake of grapefruit was significantly associated with lower concentrations of CRP and sTNF-R2. In spite of this, it was also reported in the study that flavonoids typically found in citrus fruits were modestly associated with lower plasma IL-18 concentrations [61]. Interestingly, a double-blind, placebo-controlled crossover study (n = 14, 35–53 years of age) reported that the supplementation of sea buckthorn flavonol extract for 4 weeks did not reduce CRP levels ($p < 0.05$) [15, 62].

4.4.5 Phytoestrogens

Phytoestrogens are plant-derived dietary compounds found in beans, seeds, and grains. The structure of phytoestrogens is similar to 17-β-oestradiol (E2), the primary female sex hormone. This structural similarity to E2 enables phytoestrogens to cause (anti) oestrogenic effects by binding to the oestrogen receptors [63]. Phytoestrogens had so many health benefits such as a lowered risk of menopausal symptoms such as hot flushes and osteoporosis, obesity, metabolic syndrome, and type 2 diabetes and lowered risks of cardiovascular disease, brain function disorders, breast cancer, prostate cancer, bowel cancer, and other cancers [63]. A randomized crossover clinical trial for 8 weeks (n = 42, postmenopausal women with

metabolic syndrome) reported that soy nut consumption reduces interleukin-18 [64]. On the other hand, in a randomized, double-blind, controlled trial study (n = 50, post-menopausal women age = 58 ± 5 years), it was found that supplementation of soy isoflavone for 6 months had no effects on plasma CRP level [65].

4.4.6 Probiotics, prebiotics and synbiotics

According to the Food and Agriculture Organization of the United Nations (FAO) and WHO, probiotics are defined as "live microorganisms which, when administered in adequate amounts, confer a health benefit on the host" [66–67]. Earlier studies reported that probiotic bacteria, when administered orally, are able to modulate the immune system; however, differences exist in the immunomodulatory effects of different probiotic strains [15]. A randomized, double-blind, and placebo-controlled parallel-group intervention study compared *Lactobacillus rhamnosus* with *Bifidobacterium animalis* ssp. Lactis Bb12 and *Propionibacterium freudenreichii* ssp. Shermanii JS for 3 weeks in healthy respondents (n = 81, 23–58 years of age). The study showed no effect on serum levels of TNF-α, IL-6, IL-10, or IFN-γ but a decreased level of CRP in the *L. rhamnosus* supplementation group [15, 68].

According to FAO/WHO, prebiotics is defined as "non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacterial species already established in the colon, and thus improve the host health" [67, 69]. Russo et al. reported in the study that intake of 11% enriched inulin-enriched pasta for 5 weeks improved lipidic and glicidic metabolism as well as insulin resistance in healthy young subjects [70]. Another study reported that intake of oligofructose (type of prebiotics) supplementation (8 g/day for 3 weeks) in the elderly (n = 19, mean age = 85 years) showed a decrease in the expression of IL-6 mRNA in peripheral blood monocytes [71]. In contrary to the above study, the intervention study showed that supplementation of oligofructose (1.95–3.9 g/day for 12 weeks) did not affect plasma levels of IL-6 or TNF-α in poorly nourished elderly subjects (mean age of 70 years) [15, 72].

Synbiotics are defined as a combination of suitable probiotics and prebiotics that enhances survival and activity of the organism, for example, a fructooligosaccharide (FOS) in conjunction with a Bifidobacterium strain or lactitol in conjunction with *Lactobacillus* strains [73–74]. Ferrarese et al. reported in the study that diet supplementation with Synbiotics prepared using selected strains (such as *Lactobacillus gasseri* strains) showed to exert weight reduction and anti-inflammatory activity. In spite of this, it was also concluded that their administration, together with galactomannan and/or inulin fibers, may increase weight management effects due to synergistic effect on short-chain fatty acid production and microbiota "re-configuration" [75].

5. Discussion

The pandemic of obesity and its associated comorbidities derives our attention to the mechanism associated with a pathological condition. Earlier investigations revealed how cells and tissues respond to the stress of overnutrition and about the interplay between adipose tissue and other cell types that are critically involved in energy homeostasis. These findings also suggest the inflammatory response of obesity that might be beneficial or harmful, depending on the stage and degree of obesity, as well as other factors [76]. Previously, it was also reported that obesity and its associated comorbidities are due to intermingled interactions between

genetic, metabolic, and environmental factors in which dietary pattern plays a central role [77].

The current review is a narrative review of the impact of inflammation on weight management. In this review, a model is outlined in which inflammation is closely associated with obesity. However, this is a simplified view. Earlier studies reveal that severely underweight people such as patients with anorexia nervosa (AN) also display an overproduction of inflammatory cytokines. Dalton et al. reported from an exploratory cross-sectional study that interleukin (IL)-6, IL-15, and vascular cell adhesion molecule (VCAM)-1 concentrations were significantly elevated, and concentrations of BDNF (brain-derived neurotrophic factor), tumor necrosis factor (TNF)-β, and vascular endothelial growth factor (VEGF)-A were significantly lower in anorexia nervosa (AN) participants [78]. An almost similar result was reported through meta-analysis by Solmi et al. that patients with anorexia nervosa (AN) have increased TNF-α, IL6, IL1-β, and TNF-R-II levels but decreased C-reactive protein and IL-6R [79]. Earlier studies also reported that immunosuppressive medications such as corticosteroids lead to visceral adiposity. Galitzky and Bouloumie reported that long-term exposure of glucocorticoids (GCs), either due to anti-inflammatory and immunosuppressive therapies or endocrine disturbances, accumulation of abdominal fat was observed in individuals with Cushing syndrome [80]. Lee et al. stated in the study that glucocorticoids (GCs) have profound effects on adipose tissue, adipogenesis, adipose tissue metabolic, and endocrine function. In the study, it was found that glucocorticoids (GCs) have multiple, depot-dependent effects on adipocyte gene expression and metabolism that enhances central fat deposition and lead to visceral obesity [81]. Further, contradicting study results are not included in the current study in order to provide a stringent model. Additionally, due to the limited space, important aspects of the topic such as physical activity and its influence on body weight regulation and cytokine production in detail are not included in the current study.

6. Conclusion

As we know that obesity is the condition of excessive accumulation of fat as a result of disequilibrium between energy intake and its expenditure. Several studies showed that adipose tissue acts as an endocrine organ that plays a critical role in maintaining the homeostasis of immunity. Studies also reported that obesity plays a pivotal role in the development of low-grade inflammation. As a result, optimal nutrition is required for maintaining a healthy immune balance. A healthy diet comprising of appropriate GI/GL, n-3 PUFAs, less amount of saturated and trans-fatty acids, vitamins, minerals, flavonoids, phytoestrogens, probiotics, prebiotics, and Synbiotics is beneficial in combating the obesity and its related complications.

Therefore, it is concluded that consuming different dietary components rather than a single component may prove beneficial in combating the burden of weight gain as its associated comorbidities.

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Conflict of interest

The author declares no conflict of interest.

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