abnormalities. Among them, the roles of TNF-α, IL-6, IL-1β and MCP-1 are particularly crucial. TNF-α mainly originates from adipose tissue macrophages and interferes with insulin signaling by promoting the phosphorylation of serine, a substrate of insulin receptors, thereby inducing insulin resistance.

IL-6 is derived from adipocytes and immune cells. Its content in the blood is directly related to the degree of obesity, visceral fat accumulation, and insulin resistance (Rossi et al., 2021; Tylutka et al., 2023). IL-1β is produced by activating inflammosomes, which can amplify inflammatory responses and interfere with blood glucose stability. As a chemokine, MCP-1 promotes the aggregation of monocytes to adipose tissue, triggering persistent inflammation and tissue changes (Cao et al., 2025).

These factors not only act locally but also cause endothelial dysfunction, arteriosclerosis and metabolic disorders through systemic effects. The levels of TNF-α, IL-6, and IL-1β in patients such as MetS continued to increase, and their contents were positively correlated with the severity of metabolic abnormalities (Rossi et al., 2021; Tylutka et al., 2023). It can also activate pathways such as NF-κB and JNK, enhance the expression of inflammatory genes, and form a persistent inflammatory environment to accelerate disease progression (Cao et al., 2025).

2.2 Key anti-inflammatory factors

Unlike pro-inflammatory factors, anti-inflammatory factors such as IL-10 and TGF-β can maintain immune balance and inhibit metabolic inflammation. IL-10 is derived from regulatory T cells and M2 macrophages, and can inhibit the release of pro-inflammatory factors and promote the resolution of inflammation. TGF-β has anti-inflammatory effects by regulating the function of immune cells and is also involved in tissue repair. In healthy individuals, these two factors remain balanced to maintain normal fat and metabolism (Tylutka et al., 2023).

Obesity and metabolic disorders can disrupt this balance. Fat dilation and pro-inflammatory immune cell infiltration can reduce IL-10 and alter TGF-β signaling (Tylutka et al, 2023), and decreased anti-inflammatory ability can aggravate insulin resistance. It is evident that the dynamic balance of these two factors is the key to determining metabolic status and disease progression.

2.3 Characteristics of cytokine changes

Unlike acute inflammation which experiences a significant increase in a short period of time, METS-related inflammation is characterized by low levels of cytokines, chronic and continuous changes, insipidous inflammation, and a long-term mild increase in cytokines. This is because metabolic stress such as overnutrition and adipocyte enlargement continuously stimulates adipose tissue and immune cells to release inflammatory substances (Rossi et al., 2021; Ren et al., 2022), this mild inflammation can also disrupt insulin signaling and cause cardiovascular problems (Van De Vyver, 2023).

Cytokine levels are not fixed and change with metabolic loads such as body weight, diet, and exercise (Koelman et al., 2019; Rossi et al., 2021). Measures to improve metabolism, such as weight loss and anti-inflammatory treatment, can reduce pro-inflammatory factors and enhance insulin sensitivity. When there is an excess of nutrition, inflammation and cytokine production will increase. This indicates that the environment and individual susceptibility jointly determine the inflammatory characteristics of MetS, and regulating cytokine balance may improve metabolism.

3 Sources of Peripheral Inflammation

3.1 Adipose tissue inflammation

Adipose tissue is the main source of chronic low-grade inflammation in metabolic syndrome. When there is overnutrition and obesity, the volume of fat cells increases, making them prone to metabolic stress, hypoxia and even death, which disrupts the homeostasis of adipose tissue. These changes prompt the massive aggregation and infiltration of immune cells, especially pro-inflammatory M1 macrophages, into adipose tissue. Infiltrating macrophages, T cells, etc. continuously release pro-inflammatory factors such as TNF-α, IL-6, and MCP-1, amplifying local inflammation and promoting systemic inflammation, which is closely related to insulin resistance and metabolic abnormalities (Reddy et al., 2019; Saito et al., 2021).