(Liu et al., 2025); Meanwhile, the release of free fatty acids from adipose tissue increased, the synthesis of new fat in the liver became stronger, and a large amount of lipids deposited in the liver (Chao et al., 2019).

Excessive lipids in the liver can activate kupffer cells, causing them to secrete pro-inflammatory factors, further inhibiting insulin signaling in liver cells and promoting the development of simple fatty liver into non-alcoholic steatohepatitis (NASH) and fibrosis (Bhat and Mani, 2023). Disorders of glycolipid metabolism promote each other and are key to the occurrence of non-alcoholic fatty liver disease (NAFLD) (Chao et al., 2019), and aggravated insulin resistance increases the risk of dyslipidemia and cardiovascular diseases (Liu et al., 2025).

6.3 Sympathetic nerve activation and vascular function impairment

Hypertension is an important manifestation of metabolic syndrome and is related to central and peripheral inflammation. Chronic mild inflammation of the brainstem and hypothalamus can enhance sympathetic nerve activity, leading to vascular tension and persistent elevated blood pressure. Both animal and human studies have confirmed this (Kalos et al., 2025; Venugopal et al., 2025).

Excessive activation of the sympathetic nerve can impair endothelial function, reduce vasodilation ability and promote the formation of hypertension (Ding et al., 2025). In metabolic syndrome, obesity, insulin resistance and chronic inflammation amplify this mechanism, creating a vicious cycle of elevated blood pressure and significantly increasing the risk of cardiovascular events.

7 Evidence and Impact

7.1 Evidence from animal experiments

Animal experiments provide important evidence for studying the role of inflammatory factors in metabolic syndrome. For instance, in experiments on high-fat diets in mice, long-term consumption of high-fat foods can lead to hypothalamic inflammation, manifested as elevated pro-inflammatory factors such as TNF-α and IL-1β. This activates microglia and astrocytes in the hypothalamus, thereby interfering with leptin and insulin signals, resulting in increased appetite, weight gain, and systemic insulin resistance. The hypothalamus is particularly sensitive to inflammatory stimuli due to its high permeability of the blood-brain barrier and its ability to sense peripheral metabolic signals (Robison et al., 2020).

Interventions targeting inflammatory pathways have shown significant effects in animal experiments. Inhibiting key inflammatory signals through genetic or drug means (such as blocking the JAK2/STAT3 pathway or neutralizing IL-1β) can significantly alleviate hypothalamic inflammation and improve metabolic balance (Robison et al., 2020; Wang et al., 2021). These intervention measures, accompanied by improvements in glucose tolerance, insulin sensitivity and weight regulation ability, confirmed the causal role of central inflammation in the occurrence of metabolic syndrome.

7.2 Evidence from human studies

Human studies have shown that elevated levels of inflammatory factors are closely related to the presence and severity of metabolic syndrome. The pro-inflammatory indicators such as IL-6, TNF-α and CRP in the blood of patients were significantly higher than those of healthy people (Ferreira et al., 2022), and were directly involved in insulin resistance and vascular injury (Ion et al., 2023). Meanwhile, the level of the anti-inflammatory factor IL-10 in the body was relatively low, aggravating the immune imbalance. The study also found that cytokine levels were significantly associated with metabolic syndrome characteristics such as abdominal obesity and insulin resistance (Ferreira et al., 2022). For instance, elevated MCP-1 and TNF-α levels are associated with visceral fat accumulation and insulin resistance, and people with low IL-10 levels have a higher metabolic risk (Sumerkina et al., 2022). This indicates that cytokine profiles can serve as potential biomarkers for assessing the risk of metabolic syndrome and monitoring disease progression.

7.3 Evidence of intervention measures

Intervention studies have shown that lifestyle adjustments and drug treatments can effectively reduce inflammation levels and improve metabolic indicators. Weight loss (calorie restriction or surgery) can significantly reduce pro-inflammatory factors such as IL-6 and TNF-α, and improve insulin sensitivity (Ion et al.,