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The Role of Curcumin in Obesity: Mechanisms and Metabolic Implications

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Abstract

Obesity is a complex, multifactorial chronic disease associated with metabolic, inflammatory, cardiovascular, renal, and gastrointestinal complications. Increasing interest has been directed toward bioactive dietary compounds with potential anti-obesity properties. Curcumin, the principal polyphenolic compound derived from Curcuma longa, has been extensively investigated for its metabolic, anti-inflammatory, antioxidant, and regulatory effects on adipose tissue, liver metabolism, insulin sensitivity, and gut microbiota. This review summarizes and critically analyzes available evidence regarding the role of curcumin in obesity, drawing on in vitro studies, animal models, clinical trials, and mechanistic investigations. The findings indicate that curcumin supplementation is associated with attenuation of weight gain, adipogenesis, inflammation, insulin resistance, lipid accumulation, and obesity-related organ dysfunction through multiple molecular pathways. However, most available evidence originates from preclinical models, while clinical data remain limited and heterogeneous, highlighting the need for cautious interpretation of translational relevance. Further well-designed, large-scale clinical studies are required to clarify curcumin's therapeutic potential in obesity management.

Background: The global prevalence of obesity has risen dramatically over recent decades, representing a major public health challenge. Obesity is associated with chronic low-grade inflammation, insulin resistance, dyslipidemia, non-alcoholic fatty liver disease, cardiovascular disease, renal complications, and gastrointestinal disturbances. Conventional obesity treatments, including lifestyle modification, pharmacotherapy, and bariatric surgery, are often limited by poor adherence, adverse effects, or invasiveness. Consequently, interest has grown in natural bioactive compounds with potential preventive or adjunctive therapeutic roles. Curcumin has attracted considerable scientific attention due to its broad spectrum of biological activities and long history of dietary and medicinal use.

Aim: The aim of this review is to synthesize and evaluate current evidence on the role of curcumin in obesity, focusing on its effects on body weight regulation, adipose tissue biology, metabolic pathways, inflammation, insulin resistance, gut microbiota modulation, and obesity-related complications.

Material and Methods: This narrative review was based on a qualitative synthesis of peer-reviewed articles selected by the author, encompassing experimental, clinical, and review studies relevant to the role of curcumin in obesity. The analyzed literature included in vitro experiments, animal models of diet-induced obesity, randomized controlled clinical trials, observational studies, and narrative and systematic reviews. No additional databases or external sources beyond the provided materials were used. Data were extracted and synthesized to evaluate the biological effects, mechanisms of action, and clinical relevance of curcumin in the context of obesity and its related metabolic complications.

Results: Across experimental models and human studies, curcumin supplementation was associated with reductions in body weight gain, adiposity, lipid accumulation, inflammatory markers, and metabolic dysfunction. Mechanistic studies demonstrated that curcumin modulates key signaling pathways involved in adipogenesis, lipogenesis, inflammation, oxidative stress, insulin signaling, and gut microbiota composition. Clinical trials reported modest but significant improvements in anthropometric parameters, metabolic markers, and gastrointestinal symptoms in individuals with obesity.

Conclusions: Available evidence suggests that curcumin exerts multi-targeted effects that may contribute to the prevention and attenuation of obesity and its related complications. Despite promising findings, heterogeneity among studies and limitations related to bioavailability and study design warrant further large-scale, well-controlled clinical investigations.

Key words: Curcumin; obesity; adipogenesis; inflammation; insulin resistance; gut microbiota; metabolic disorders

1. Introduction

Obesity is a chronic, multifactorial disease characterized by excessive accumulation of adipose tissue resulting from a sustained imbalance between energy intake and energy expenditure. It represents a major global health concern due to its rapidly increasing prevalence and its strong association with metabolic, cardiovascular, renal, and gastrointestinal complications. Obesity is no longer regarded solely as a disorder of excess body weight but rather as a complex metabolic condition involving profound alterations in endocrine, inflammatory, and signaling pathways that affect multiple organ systems.

Adipose tissue plays a central role in the pathophysiology of obesity, functioning as an active endocrine organ rather than a passive energy reservoir. Hypertrophic and dysfunctional adipocytes secrete a wide range of adipokines, cytokines, and chemokines that contribute to chronic low-grade inflammation, insulin resistance, and metabolic dysregulation. These processes are further amplified by immune cell infiltration into adipose tissue, oxidative stress, and ectopic lipid accumulation in organs such as the liver, skeletal muscle, and kidneys. Together, these mechanisms underlie the development of obesity-related complications, including type 2 diabetes, non-alcoholic fatty liver disease, cardiovascular disease, and obesity-associated nephropathy.

Current strategies for obesity management include lifestyle modification, pharmacological interventions, and bariatric surgery. While lifestyle changes remain the cornerstone of treatment, long-term adherence is often limited. Pharmacotherapy may be associated with adverse effects and variable efficacy, whereas surgical interventions are invasive and reserved for selected patient populations. These limitations have stimulated growing interest in complementary and preventive approaches that target metabolic health through dietary and nutritional strategies.

In this context, bioactive dietary compounds, particularly polyphenols, have attracted considerable scientific attention due to their potential to modulate key pathways involved in

obesity pathogenesis. Curcumin, a naturally occurring polyphenolic compound derived from the rhizome of Curcuma longa, has been extensively studied for its anti-inflammatory, antioxidant, and metabolic regulatory properties. Traditionally used as a culinary spice and medicinal agent, curcumin has gained prominence in biomedical research owing to its broad spectrum of biological activities and favorable safety profile.

Experimental evidence suggests that curcumin may influence multiple processes relevant to obesity, including adipocyte differentiation, lipid metabolism, inflammatory signaling, insulin sensitivity, oxidative stress, and gut microbiota composition. Through modulation of transcription factors, enzymes, and intracellular signaling pathways, curcumin appears to exert pleiotropic effects that extend beyond body weight regulation alone. In addition, emerging clinical data indicate that curcumin supplementation may improve selected metabolic and gastrointestinal parameters in individuals with obesity, although reported effects are generally modest and heterogeneous.

Despite the growing body of literature, the overall role of curcumin in obesity remains incompletely defined. Variability in experimental models, study design, dosage, formulation, and bioavailability complicates direct comparison of results and limits the translation of preclinical findings into clinical practice. A comprehensive synthesis of available evidence is therefore necessary to clarify the potential mechanisms, benefits, and limitations of curcumin in the context of obesity and its related metabolic disturbances.

2. Research materials and methods

The research materials analyzed in this review include cellular studies using adipocytes, hepatocytes, podocytes, and intestinal models; animal studies employing high-fat or very-high-fat diet-induced obesity models; and clinical trials involving overweight and obese individuals. Methodological approaches across studies included biochemical assays, gene and protein expression analyses, histological assessments, metabolic profiling, gut microbiota analysis, and anthropometric measurements.

3. Research results

3.1. Effects of Curcumin on Body Weight and Adiposity

Across experimental models of diet-induced obesity, curcumin supplementation was consistently associated with attenuation of body weight gain and reductions in adipose tissue

mass. Studies employing high-fat and very-high-fat diet models reported decreases in total body weight, visceral fat accumulation, and abdominal fat index following curcumin administration, even when animals remained exposed to obesogenic diets. These effects were accompanied by reductions in adipocyte size and improvements in adipose tissue morphology, suggesting an influence of curcumin on adipose tissue remodeling rather than solely on caloric intake.

In human studies, curcumin supplementation was associated with modest but statistically significant improvements in anthropometric parameters, including body mass index, waist circumference, and neck circumference. Although the magnitude of these changes was generally limited, they were observed across different study populations and intervention durations, indicating a reproducible, albeit moderate, effect of curcumin on body weight regulation in individuals with obesity.

3.2. Regulation of Adipogenesis and Lipogenesis

In vitro studies using preadipocytes and hepatocyte-derived cell lines demonstrated that curcumin treatment was associated with inhibition of adipocyte differentiation and suppression of lipid droplet formation. These effects coincided with reduced expression of key adipogenic transcription factors, including peroxisome proliferator-activated receptor gamma (PPARγ) and members of the CCAAT/enhancer-binding protein family. Additionally, curcumin exposure was linked to inhibition of sterol regulatory element-binding protein 1c (SREBP-1c), a central regulator of de novo lipogenesis.

At the enzymatic level, curcumin supplementation was associated with reduced expression and activity of lipogenic enzymes such as acetyl-CoA carboxylase and fatty acid synthase, leading to decreased triglyceride and cholesterol synthesis. Comparative studies evaluating isolated curcumin and turmeric-derived extracts indicated that both forms exert anti-lipogenic effects, with some evidence suggesting enhanced efficacy of complex extracts due to synergistic interactions among curcuminoids.

3.3. Effects on Inflammation and Immune Signaling

Chronic low-grade inflammation represents a defining feature of obesity, and multiple studies included in this review demonstrated anti-inflammatory effects of curcumin across experimental and clinical settings. Curcumin supplementation was associated with reductions in circulating and tissue levels of pro-inflammatory cytokines, including tumor necrosis factor-α, interleukin-6, and monocyte chemoattractant protein-1. These changes were observed in

adipose tissue, liver, kidney, and vascular compartments, indicating systemic immunomodulatory activity.

Mechanistic investigations revealed that curcumin-mediated anti-inflammatory effects were accompanied by inhibition of nuclear factor kappa B (NF-κB) signaling pathways and reduced macrophage infiltration into adipose tissue. In animal models, curcumin supplementation resulted in downregulation of inflammatory gene expression and attenuation of immune cell activation within metabolically active tissues.

3.4. Insulin Sensitivity and Glucose Homeostasis

Experimental studies consistently demonstrated improvements in insulin sensitivity and glucose metabolism following curcumin administration. In high-fat diet-fed animals, curcumin supplementation was associated with enhanced insulin signaling, reduced fasting glucose levels, and improved glucose tolerance. These metabolic improvements were frequently accompanied by reductions in lipid accumulation and inflammatory signaling, suggesting interconnected regulatory effects.

Clinical trials conducted in overweight and obese individuals reported improvements in insulin resistance indices and selected glycemic parameters following curcumin supplementation. While the magnitude of these effects varied across studies, the overall findings support a beneficial role of curcumin in modulating glucose homeostasis in the context of obesity.

3.5. Modulation of Gut Microbiota

An increasing number of studies have examined the influence of curcumin on gut microbiota composition and function. Curcumin supplementation was associated with increased microbial diversity and shifts in the relative abundance of bacterial taxa linked to improved metabolic health. These microbiota alterations were accompanied by reduced intestinal permeability and decreased markers of metabolic endotoxemia.

Animal and human studies further demonstrated that curcumin-induced modulation of gut microbiota was associated with attenuation of systemic inflammation and improvements in metabolic parameters. These findings suggest that the gut microbiota may represent an important intermediary through which curcumin exerts metabolic effects in obesity.

3.6. Effects on Obesity-Related Organ Complications

Beyond its effects on adipose tissue and systemic metabolism, curcumin supplementation demonstrated protective actions against multiple obesity-related organ complications. In hepatic tissue, curcumin administration was associated with reduced lipid accumulation and improvements in markers of non-alcoholic fatty liver disease. In renal models of obesity-related glomerulopathy, curcumin supplementation was linked to reductions in proteinuria, glomerular hypertrophy, and podocyte injury, partly through inhibition of inflammatory and profibrotic signaling pathways.

Additional studies reported beneficial effects of curcumin on vascular risk factors and gastrointestinal function. Improvements in gastrointestinal symptoms such as bloating, reflux, and constipation were observed in individuals with severe obesity, highlighting potential benefits of curcumin beyond classical metabolic endpoints.

4. Discussion

This review integrates experimental and clinical evidence indicating that curcumin exerts pleiotropic effects relevant to obesity pathogenesis and its associated complications. Rather than acting on a single molecular target, curcumin influences a network of interconnected pathways involved in adipogenesis, lipid metabolism, inflammation, insulin resistance, oxidative stress, and gut microbiota regulation.

A consistent observation across preclinical studies is the inhibitory effect of curcumin on adipocyte differentiation and lipid accumulation. Suppression of key transcriptional regulators of adipogenesis and lipogenesis appears to limit fat storage in both adipose tissue and the liver, processes that are central to metabolic dysfunction in obesity. These findings are supported by reductions in ectopic lipid accumulation observed in animal models.

Chronic low-grade inflammation represents a central mechanism linking obesity to metabolic and organ-specific complications. Curcumin-mediated reductions in pro-inflammatory cytokine production and NF-κB signaling activity suggest that its metabolic effects are closely intertwined with immunomodulatory actions. The attenuation of macrophage infiltration into adipose tissue and reduced inflammatory gene expression across multiple organs further supports this notion.

The modulation of gut microbiota composition has emerged as an additional mechanism through which curcumin may influence metabolic homeostasis. Alterations in microbial diversity, intestinal permeability, and metabolic endotoxemia may act synergistically with anti-inflammatory and metabolic effects, contributing to improved insulin sensitivity and lipid metabolism.

Limitations Related to Curcumin Bioavailability

A major limitation in translating the beneficial effects of curcumin observed in experimental studies into clinical practice is its low bioavailability. Curcumin exhibits poor intestinal absorption, rapid metabolism, and extensive systemic elimination, which markedly limit its bioactive concentrations following oral administration. These pharmacokinetic constraints may partly explain the discrepancy between robust preclinical findings and the modest effects reported in clinical trials.

To address these limitations, various strategies have been explored, including the development of curcumin derivatives, nanoformulations, and delivery systems designed to enhance stability, absorption, and tissue distribution. Experimental and computational studies suggest that such approaches may improve the pharmacokinetic profile and biological efficacy of curcumin. However, evidence supporting their long-term safety and clinical effectiveness in obesity remains limited, underscoring the need for further well-designed human studies.

5. Conclusions

The accumulated evidence indicates that curcumin exerts pleiotropic effects that target key mechanisms underlying obesity and its associated metabolic disturbances. Through regulation of adipogenesis, lipid metabolism, inflammation, insulin sensitivity, gut microbiota, and organ-specific complications, curcumin demonstrates potential as a complementary intervention in obesity management. Future large-scale, well-designed clinical trials are required to establish optimal formulations, dosing strategies, and long-term efficacy.

Disclosure

Author's contribution

Conceptualization: [WW], [JB]
Methodology: [EC], [AB], [KWoj]
Check: [JM], [TS], [JN]
Investigation: [JB], [KWor], [JM]
Data curation: [JM], [PZ], [EC], [WW]
Writing - rough preparation: [TS], [AB], [PZ]
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Conflict Of Interest

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