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Review Article

Metabolic Syndrome: Pathophysiology, Clinical Implications, and Management Strategies

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Keywords

Metabolic syndrome, lung diseases, cardiovascular disease, insulin resistance, obesity, dyslipidemia, hypertension, cardiovascular disease, systemic inflammation, oxidative stress, management strategies.

Abstract

Metabolic syndrome is a complex disorder characterized by a cluster of conditions, including insulin resistance, obesity, dyslipidaemia, and hypertension, which collectively elevate the risk of cardiovascular disease and type 2 diabetes mellitus and its significant impact on patients with lung diseases such as chronic obstructive pulmonary disease (COPD), asthma, and interstitial lung disease (ILD). This review explores the pathophysiology of Metbolic Syndrome, emphasizing the roles of insulin resistance, chronic inflammation, the complex interplay between MetS and lung diseases, focusing on systemic inflammation, oxidative stress, and immune system activation in its development. These factors exacerbate pulmonary symptoms and contribute to multi-organ complications, including cardiovascular disease, non-alcoholic fatty liver disease (NAFLD), chronic kidney disease (CKD), and cognitive decline. Clinical implications are discussed, highlighting the increased risks of cardiovascular disease, cognitive impairment, and frailty, particularly in older adults and specific gender groups. Management strategies, such as lifestyle interventions, pharmacological treatments, and novel therapeutic approaches like sacubitril/valsartan and telmisartan, are reviewed to underscore the importance of early intervention. This review also highlights the importance of a multidisciplinary approach to management, integrating lifestyle modifications, pharmacological interventions (e.g., statins, GLP-1 agonists), and emerging therapies (e.g., senolytics, gut-lung axis modulation). The paper concludes with a call for targeted therapies to address the underlying mechanisms of Metabolic Syndrome in high-risk populations and by addressing pulmonary components, such strategies aim to improve patient outcomes and reduce morbidity and mortality.

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1. Introduction

Metabolic syndrome (MetS) is a systemic metabolic disorder characterized by a cluster of interrelated abnormalities, including insulin resistance, central obesity, dyslipidaemia, and hypertension, which together increase the risk of cardiovascular disease and type 2 diabetes mellitus [1]. The concept of MetS was introduced to facilitate early identification of individuals at increased cardiometabolic risk and to enable timely preventive and therapeutic interventions. The hallmark features of MetS include abdominal obesity, elevated blood pressure, reduced high density lipoprotein cholesterol, hypertriglyceridaemia, and impaired glucose metabolism [2].

Primary hypertension, the most common form of hypertension in adolescents, is frequently associated with metabolic disturbances indicative of MetS. A substantial proportion of adolescents with primary hypertension exhibit features such as increased visceral fat accumulation, accelerated biological maturation, and heightened sympathetic nervous system activity. These interrelated mechanisms emphasize the importance of early recognition and management of MetS to prevent progression to more severe cardiovascular and metabolic disorders later in

life [3].

Recent evidence highlights the significant role of MetS in pulmonary diseases, particularly chronic obstructive pulmonary disease, asthma, and interstitial lung disease, where it contributes to increased symptom burden, morbidity, and mortality [4]. The interaction between MetS and lung diseases is complex and involves systemic inflammation, oxidative stress, endothelial dysfunction, and insulin resistance, which collectively drive both pulmonary and extrapulmonary complications. This review focuses on the pathophysiological mechanisms linking MetS with lung disease, its impact on other organ systems, and the clinical implications for management [5].

2. Pathophysiology of Metabolic Syndrome

2.1. Insulin Resistance and Obesity

Insulin resistance represents a central pathogenic feature of MetS and is closely linked to obesity, particularly excess abdominal and visceral fat. Insulin resistance impairs glucose uptake in peripheral tissues, leading to hyperglycaemia and compensatory hyperinsulinaemia. Visceral adipose tissue is metabolically active and releases increased amounts of free fatty acids and proinflammatory mediators, which further worsen insulin resistance and contribute to dyslipidaemia and hypertension.

2.2. Dyslipidaemia and Hypertension

Dyslipidaemia in MetS is characterized by elevated triglyceride levels, reduced high density lipoprotein cholesterol, and an increased proportion of small dense low density lipoprotein particles, as illustrated in Figure 1 [6]. These lipid abnormalities promote endothelial dysfunction and accelerate atherosclerotic cardiovascular disease. Hypertension in MetS results from multiple interacting mechanisms, including increased sympathetic nervous system activity, impaired endothelial nitric oxide bioavailability, activation of the renin–angiotensin–aldosterone system, and altered renal sodium handling, as depicted. The kidneys play a critical role in long term blood pressure regulation, and disruption of pressure natriuresis is a key feature of MetS associated hypertension [7].

Figure 1 illustrates the stepwise pathophysiology of heart disease, beginning with major risk factors such as smoking, hypertension, and unhealthy diet. These factors initiate endothelial damage, which promotes plaque formation within the blood vessels and leads to reduced coronary blood flow. Persistent impairment of blood supply results in myocardial ischemia and may ultimately progress to myocardial infarction, highlighting the progressive nature of cardiovascular disease [8], [9].

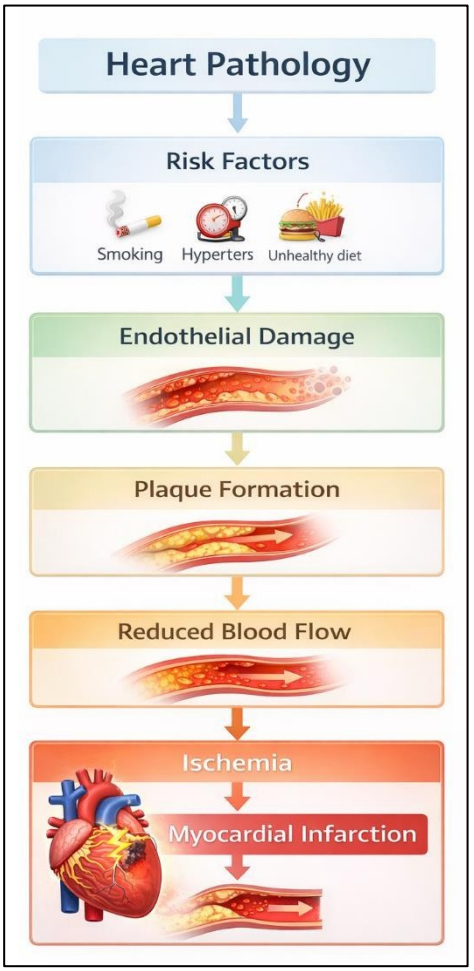

Figure1: Flow diagram showing the sequential pathophysiological events in heart disease leading from risk factors to myocardial infarction.

2.3. Role of Inflammation and the Immune System

Growing evidence indicates that chronic low grade inflammation and activation of the immune system play a crucial role in the pathophysiology of both hypertension and metabolic syndrome. Proinflammatory cytokines such as interleukin six and interleukin seventeen contribute to endothelial dysfunction, vascular inflammation, and structural remodeling of blood vessels, which are key features in the development of hypertension [10], [11]. Immune cell activation promotes oxidative stress and sustains inflammatory signaling within the vascular wall, thereby exacerbating vascular stiffness and impairing normal vasoregulatory mechanisms. The increasing recognition of immune mediated pathways highlights the importance of inflammation as a unifying mechanism linking metabolic disturbances with cardiovascular dysfunction [12], [13].

2.4. Pathophysiology of Metabolic Syndrome in Lung Disease

2.4.1. Systemic Inflammation and Oxidative Stress

Metabolic syndrome is characterized by persistent low grade systemic inflammation and increased oxidative stress, both of which play a significant role in the progression of chronic lung diseases such as chronic obstructive pulmonary disease and asthma [14]. In chronic obstructive pulmonary disease, systemic inflammation driven by adipokines and proinflammatory cytokines, including interleukin six and tumor necrosis factor alpha, exacerbates airway obstruction and accelerates the decline in lung function, as illustrated in Figure 2 [15]. Similarly, in asthma, obesity associated inflammation contributes to increased airway hyperresponsiveness, reduced responsiveness to standard therapies, and poorer disease control [16].

Oxidative stress represents a hallmark feature of metabolic syndrome and further contributes to pulmonary injury through excessive generation of reactive oxygen species. These reactive species impair endothelial function, disrupt alveolar integrity, and promote fibrotic remodeling of lung tissue [17], [18]. In patients with interstitial lung disease, oxidative stress plays a particularly detrimental role by accelerating fibrotic progression and worsening clinical outcomes. Together, systemic inflammation and oxidative stress form a pathogenic link between metabolic syndrome and chronic lung diseases, contributing to increased disease severity and adverse prognosis [19], [20].

Figure 2 illustrates the key molecular and cellular pathways through which components of metabolic syndrome contribute to the development and progression of chronic respiratory diseases. Adipose tissue dysfunction leads to increased secretion of pro-inflammatory cytokines such as IL-6 and TNF-α, resulting in systemic inflammation and endothelial damage. These processes promote airway obstruction in chronic obstructive pulmonary disease (COPD), enhance TH2-mediated immune responses in asthma, and contribute to fibrotic remodeling in interstitial lung diseases (ILD) [21].

In parallel, insulin resistance induces mitochondrial dysfunction and excessive generation of reactive oxygen species (ROS), leading to oxidative stress, endothelial injury, and cellular senescence mediated by p16 and p53 signaling pathways [22]. The convergence of inflammatory and oxidative mechanisms ultimately accelerates tissue fibrosis in COPD and ILD, highlighting metabolic syndrome as a critical driver of chronic lung pathology [23].

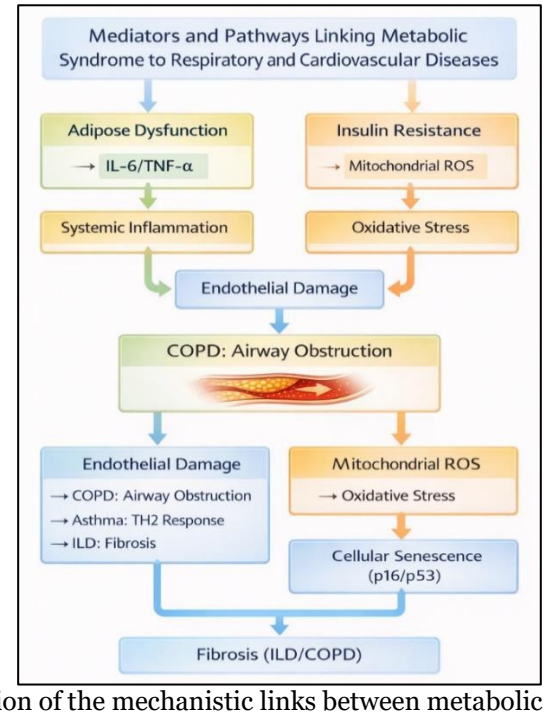

Figure 2: Schematic representation of the mechanistic links between metabolic syndrome and chronic respiratory diseases through inflammatory and oxidative stress pathways.

2.4.2. Insulin Resistance and Obesity

Insulin resistance is a defining feature of metabolic syndrome and is closely associated with obesity, particularly excess abdominal adiposity. Impaired insulin signaling leads to altered glucose metabolism and compensatory hyperinsulinaemia, which contribute to endothelial dysfunction and vascular remodeling within the pulmonary circulation. In patients with chronic obstructive pulmonary disease, insulin resistance is associated with heightened systemic inflammation and an increased risk of disease exacerbations [24].

Obesity, a major component of metabolic syndrome, also exerts mechanical effects on respiratory physiology. Increased body mass reduces chest wall compliance, elevates airway resistance, and impairs diaphragmatic movement, leading to compromised lung function [25]. These effects are particularly evident in obese individuals with asthma, who often experience more severe symptoms, reduced responsiveness to therapy, and a poorer quality of life compared with non obese patients [26].

3. Clinical Implications of Metabolic Syndrome

3.1. Cardiovascular Disease and Diabetes

Metabolic syndrome represents a major risk factor for the development of cardiovascular disease, including ischemic heart disease, stroke, and chronic kidney disease. The clustering of metabolic abnormalities accelerates atherosclerotic processes and significantly increases the likelihood of adverse cardiovascular events [27], [28]. Metabolic syndrome is also widely regarded as a preclinical stage of type two diabetes mellitus, with insulin resistance and chronic hyperglycaemia serving as central drivers of disease progression. In patients with chronic lung diseases, particularly chronic obstructive pulmonary disease, the coexistence of metabolic syndrome is associated with a substantially higher incidence of cardiovascular complications [29], [30].

3.2. Gender and Age Differences

Gender and age significantly influence the manifestation and progression of metabolic syndrome. Women with conditions such as polycystic ovary syndrome frequently exhibit a more severe cardiometabolic profile, particularly when hyperandrogenism and insulin resistance are present [31]. In contrast, men tend to develop hypertension and dyslipidaemia at a younger age, contributing to an increased burden of cardiovascular disease. Advancing age is also a major determinant, with the prevalence of metabolic syndrome, diabetes, and frailty increasing markedly among older adults [32].

3.3. Cognitive Impairment and Frailty

Cognitive impairment and frailty are increasingly recognized complications of metabolic syndrome, especially in older individuals with diabetes [33]. Frailty is characterized by reduced physical strength, impaired mobility, and increased vulnerability to adverse health outcomes, and is closely linked to insulin resistance and chronic systemic inflammation. Targeted interventions focusing on nutritional optimization and physical activity have demonstrated potential to partially reverse frailty and improve functional capacity in elderly populations [34].

3.4. Liver

Non alcoholic fatty liver disease is a common comorbidity in patients with metabolic syndrome and chronic lung diseases. Persistent systemic inflammation and insulin resistance promote hepatic lipid accumulation, inflammation, and progressive fibrosis, thereby increasing the risk of liver related morbidity. In individuals with chronic obstructive pulmonary disease, the presence of fatty liver disease further amplifies systemic inflammation and contributes to the progression of both hepatic and pulmonary pathology [35].

3.5. Kidneys

Chronic kidney disease is another frequent complication of metabolic syndrome, particularly among patients with chronic obstructive pulmonary disease and interstitial lung disease. Metabolic syndrome promotes renal inflammation and fibrosis through neurohormonal activation and metabolic stress, leading to progressive decline in kidney function. Renal impairment further exacerbates systemic inflammation and may indirectly worsen pulmonary disease outcomes [36].

3.6. Brain

Metabolic syndrome is associated with an increased risk of neurodegenerative disorders, including Alzheimer's disease and Parkinson's disease. Chronic inflammation, oxidative stress, and vascular dysfunction contribute to neuronal injury and cognitive decline. In patients with chronic lung diseases, the coexistence of metabolic syndrome may accelerate neurocognitive impairment and increase the risk of dementia [37].

4. Pathophysiological Mechanisms

4.1. Inflammation and Immune Dysregulation

Inflammation and immune dysregulation play central roles in linking metabolic syndrome with chronic lung diseases [38]. In chronic obstructive pulmonary disease, macrophage polarization toward a proinflammatory phenotype predominates, leading to the release of cytokines such as interleukin one beta and interleukin eight, as illustrated in Figure 3. In asthma, metabolic disturbances such as hyperglycaemia activate inflammasome pathways, resulting in increased production of inflammatory mediators that sustain airway inflammation and disease severity [39], [40].

4.2. Insulin Resistance

Insulin resistance contributes directly to pulmonary vascular dysfunction by impairing intracellular signaling pathways involved in glucose uptake and endothelial homeostasis. Disruption of these pathways in lung endothelial cells promotes hypoxia, oxidative stress, and vascular remodeling, thereby worsening pulmonary dysfunction [41].

4.3. Obesity and Adipokines

Adipose tissue derived mediators play a critical role in metabolic syndrome associated lung pathology. Elevated leptin levels enhance type two immune responses and contribute to airway inflammation in asthma, while reduced adiponectin levels promote fibrotic processes in interstitial lung disease. These adipokine imbalances further strengthen the link between obesity, metabolic syndrome, and progressive lung injury [42].

4.4. Oxidative Stress

Oxidative stress represents a key pathogenic mechanism in metabolic syndrome related lung disease [43]. Excessive generation of mitochondrial reactive oxygen species induces cellular senescence and tissue damage through activation of stress responsive signaling pathways. In chronic obstructive pulmonary disease, oxidative stress accelerates airway remodeling, inflammation, and loss of pulmonary function [44].

Figure 3 illustrates the molecular regulation of hypoxia-inducible factor-1 alpha (HIF-1α) under normoxic and hypoxic conditions and its downstream transcriptional effects. Under normoxia, HIF-1α undergoes proline hydroxylation by prolyl hydroxylase domain (PHD) enzymes, leading to ubiquitination and subsequent proteasomal degradation [45]. In contrast, inhibition of PHD activity during hypoxia prevents HIF-1α hydroxylation, allowing its stabilization and accumulation. Stabilized HIF-1α translocates to the nucleus, where it dimerizes with HIF-1β (ARNT) and binds to hypoxia response elements (HREs) in target gene promoters [46]. This activation induces the transcription of hypoxia-responsive genes involved in angiogenesis, erythropoiesis, metabolic adaptation, and inflammation, including VEGF, EPO, and PPARA. Collectively, the figure highlights the central role of HIF-1α signaling in coordinating cellular responses to hypoxic stress, inflammation, and oxidative imbalance [47].

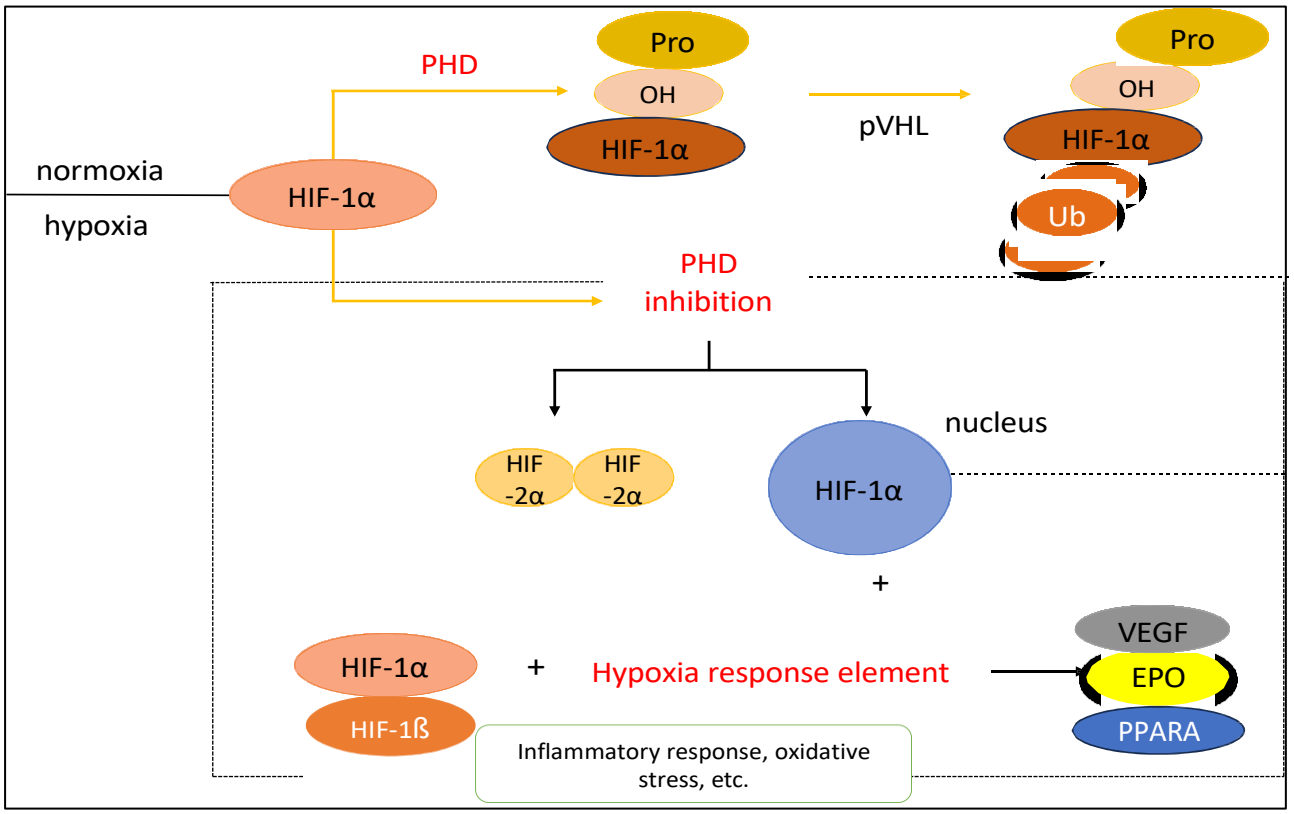

Figure 3: Pathophysiological Mechanisms of Inflammatory response and oxidative stress.

5. Management Strategies for Metabolic Syndrome

5.1. Integrated Treatment Approach

The management of metabolic syndrome in patients with lung disease requires a comprehensive and multidisciplinary approach that simultaneously addresses metabolic abnormalities and pulmonary dysfunction. Lifestyle modification remains the foundation of management and should be complemented by appropriate pharmacological therapy when indicated [48]. Interventions such as weight reduction, dietary optimization, and regular physical activity play a central role in improving insulin sensitivity, reducing systemic inflammation, and lowering cardiovascular risk [49]. In patients with chronic lung diseases, pulmonary rehabilitation programs that integrate nutritional counseling and structured exercise have demonstrated benefits in improving functional capacity, enhancing lung function, and reducing the frequency of disease exacerbations [50].

5.1.1. Lifestyle Interventions

Lifestyle modification is the cornerstone of metabolic syndrome management. Dietary interventions focused on calorie control, balanced macronutrient intake, and reduction of refined carbohydrates and saturated fats are essential for achieving sustainable weight loss and improving metabolic parameters [51], [52]. Regular physical activity, particularly moderate intensity

aerobic exercise combined with resistance training, improves insulin sensitivity, lowers blood pressure, enhances lipid profiles, and promotes overall cardiometabolic health. In patients with lung disease, tailored exercise programs should account for respiratory limitations while encouraging gradual increases in activity levels to maximize both metabolic and pulmonary benefits [53].

5.2. Pharmacological Treatments

Pharmacological therapy is often required to control individual components of metabolic syndrome when lifestyle interventions alone are insufficient. Antihypertensive agents such as angiotensin converting enzyme inhibitors and angiotensin receptor blockers are commonly preferred in patients with metabolic syndrome due to their favorable effects on renal function and cardiovascular protection [54]. Insulin sensitizing agents, including metformin and thiazolidinediones, are widely used to manage insulin resistance and type two diabetes mellitus, with metformin being favored for its cost effectiveness and weight neutral profile. In many patients, combination pharmacotherapy is necessary to address multiple metabolic abnormalities, such as the concurrent use of lipid lowering agents with antihypertensive medications to achieve comprehensive risk reduction [55].

5.2.1. Pharmacological Interventions in Lung Disease

Several pharmacological agents used in the treatment of metabolic syndrome may also provide additional benefits in patients with chronic lung diseases. Statins have demonstrated anti inflammatory properties beyond lipid lowering and may contribute to improved lung function and reduced cardiovascular risk in patients with chronic obstructive pulmonary disease [56]. Similarly, angiotensin converting enzyme inhibitors and angiotensin receptor blockers may exert protective effects on the pulmonary vasculature by reducing inflammation and oxidative stress [57]. Thiazolidinediones have also shown potential in improving metabolic control and modulating inflammatory pathways, although their use requires careful consideration due to potential adverse effects. Overall, an individualized treatment strategy that balances metabolic control with pulmonary safety is essential for optimizing outcomes in patients with coexisting metabolic syndrome and lung disease [58].

Table 1: Drug therapy for metabolic syndrome in lung disease patients.

S. No.	Drug class	Examples	Mechanism of action	Indication in lung disease	Reported efficacy	References
1.	Statins	Atorvastatin	HMG CoA reductase inhibition	Cardiovascular risk reduction in COPD	Reduced CRP levels and fewer exacerbations	[59], [60]
2.	Statins	Rosuvastatin	Lipid lowering and anti inflammatory effects	Dyslipidaemia in COPD	Improved endothelial function	[61]
3.	GLP 1 receptor agonists	Liraglutide	Appetite suppression and insulin sensitization	Obesity related asthma	Significant weight loss and improved FEV1	[62], [63]
4.	GLP 1 receptor agonists	Semaglutide	Delayed gastric emptying and glycaemic control	MetS with asthma	Improved metabolic profile and symptom control	[64]
5.	PPAR gamma agonists	Pioglitazone	Anti inflammatory and insulin sensitizing	Insulin resistance in ILD	Improved gas diffusion and reduced fibrosis	[65], [66]
6.	ACE inhibitors	Ramipril	Renin angiotensin system inhibition	Hypertension in COPD	Reduced cardiovascular mortality	[67], [68]
7.	ACE inhibitors	Enalapril	Vasodilatation and antifibrotic effects	MetS with pulmonary hypertension	Improved vascular outcomes	[69], [70]
8.	ARBs	Losartan	Angiotensin II receptor blockade	Hypertension in COPD	Reduced inflammation and blood	[71]

					pressure	
9.	ARBs	Valsartan	Vascular protection	MetS with lung disease	Improved cardiovascular outcomes	[72], [73]
10.	SGLT2 inhibitors	Empagliflozin	Glycosuria and weight reduction	Heart failure in obesity related asthma	Reduced hospitalizations	[74]
11.	SGLT2 inhibitors	Dapagliflozin	Improved insulin sensitivity	MetS with COPD	Improved cardiometabolic status	[75], [76]
12.	Metformin	Metformin	Reduced hepatic glucose output	Insulin resistance in asthma	Improved glycaemic control	[77]
13.	Beta blockers	Nebivolol	Beta one selective blockade	Hypertension in COPD	Improved endothelial function	[78], [79]
14.	Calcium channel blockers	Amlodipine	Smooth muscle relaxation	Hypertension with lung disease	Reduced blood pressure variability	[80]
15.	Thiazide diuretics	Indapamide	Sodium excretion	Hypertension in MetS	Improved blood pressure control	[81], [82]
16.	Anti inflammatory agents	Colchicine	Inhibition of inflammasome activity	Systemic inflammation in COPD	Reduced inflammatory markers	[83]
17.	Antioxidants	N acetylcysteine	Reduction of oxidative stress	COPD with MetS	Improved lung function	[84], [85]
18.	Fibrates	Fenofibrate	Triglyceride reduction	Dyslipidaemia in MetS	Improved lipid profile	[86], [87]
19.	Mineralocorticoid receptor antagonists	Spironolactone	Aldosterone blockade	MetS related hypertension	Reduced fibrosis and inflammation	[88]
20.	PCSK9 inhibitors	Evolocumab	LDL receptor upregulation	Severe dyslipidaemia in MetS	Marked LDL cholesterol reduction	[89], [90]

5.3. Novel Therapeutic Approaches

Recent advances in the understanding of metabolic syndrome pathophysiology have facilitated the development of novel therapeutic strategies targeting both metabolic and cardiovascular complications [91]. Sacubitril and valsartan, a dual angiotensin receptor and neprilysin inhibitor combination, has demonstrated beneficial effects on glycaemic regulation and a reduction in heart failure risk in patients with metabolic dysfunction, as illustrated in Figure 2. Similarly, telmisartan, an angiotensin receptor blocker with partial peroxisome proliferator activated receptor gamma agonist activity, has shown favorable effects on insulin sensitivity, adipokine modulation, and metabolic regulation, as depicted in Figure 2 [92].

5.3.1. Novel Therapies

Emerging pharmacological agents such as glucagon like peptide one receptor agonists and sodium glucose cotransporter two inhibitors have demonstrated considerable potential in the integrated management of metabolic syndrome and chronic lung disease [93]. These agents improve glycaemic control, promote weight reduction, and exert anti inflammatory and cardioprotective effects, which may translate into improved pulmonary outcomes and reduced systemic inflammation in lung disease patients [94].

5.3.2. Lifestyle Modifications

Lifestyle modification remains a cornerstone of metabolic syndrome management. Dietary interventions, particularly adherence to a Mediterranean style diet, have been associated with reductions in systemic inflammatory markers and improvement in cardiometabolic health [95]. Structured physical activity programs, including pulmonary rehabilitation combined with metabolic conditioning, have demonstrated improvements in exercise tolerance, functional capacity, and overall quality of life in obese patients with asthma and chronic obstructive pulmonary disease [96].

6. Clinical Advancement of Metabolic Syndrome and Its Role in Lung Disease

Metabolic dysfunction has emerged as a critical determinant of lung health and disease progression

[97]. A growing body of evidence supports a strong association between metabolic abnormalities and chronic lung diseases through multiple interconnected mechanisms. Elevated triglyceride levels reflect underlying hyperglycaemia and dyslipidaemia, both of which adversely affect lung structure and function in experimental and translational studies [98].

Adipose tissue plays a central role as an active metabolic and endocrine organ involved in extensive cross talk between cardiovascular, metabolic, and pulmonary systems. In susceptible individuals, excessive adiposity leads to pathological responses to positive energy balance, contributing directly and indirectly to cardiometabolic disease. Genetic and mechanistic studies increasingly support the role of central obesity in driving adverse cardiovascular outcomes [99].

Metabolic syndrome is increasingly recognized as a prevalent and often underdiagnosed comorbidity in patients with chronic obstructive pulmonary disease [100]. A substantial proportion of individuals with chronic obstructive pulmonary disease exhibit metabolic syndrome, which is associated with increased systemic inflammation, particularly in patients with chronic bronchitis phenotypes and elevated inflammatory markers. The coexistence of metabolic syndrome significantly increases the risk of cardiovascular events, stroke, and mortality in this population [101].

Abnormal glucose metabolism is frequently observed in patients with acute coronary syndromes, with a large proportion exhibiting either diabetes or prediabetes [102]. These individuals are particularly vulnerable to recurrent ischemic events but also derive substantial benefit from intensive lipid lowering strategies. The shared pathological mechanisms linking metabolic syndrome, cardiovascular disease, and lung disease include endothelial dysfunction, oxidative stress, chronic inflammation, and adipokine imbalance [103].

Despite increasing recognition, the precise mechanisms underlying the development of metabolic syndrome in chronic obstructive pulmonary disease remain incompletely understood. Proposed contributors include aging, physical inactivity, adipose tissue inflammation, systemic inflammatory burden, and progressive decline in pulmonary function [104].

7. Discussion and Future Directions

The available evidence highlights a strong bidirectional relationship between metabolic syndrome and chronic lung diseases, particularly chronic obstructive pulmonary disease. Metabolic syndrome, characterized by central obesity, dyslipidaemia, and impaired glucose metabolism, exacerbates pulmonary dysfunction through systemic inflammation, adipose tissue dysregulation, and endothelial injury [105]. The high prevalence of metabolic syndrome in chronic obstructive pulmonary disease underscores its role as a silent but clinically significant comorbidity that contributes to worse cardiovascular outcomes, increased inflammatory burden, and accelerated disease progression [106].

Adipose tissue dysfunction appears to be a central mediator in this interaction by promoting chronic low grade inflammation, lipotoxicity, insulin resistance, and immune dysregulation, all of which may adversely affect lung structure and function [107]. The association between chronic bronchitis phenotypes and metabolic syndrome suggests that specific subgroups of chronic obstructive pulmonary disease patients may be particularly susceptible to metabolic derangements [108].

Future research should prioritize mechanistic studies to elucidate the molecular pathways linking metabolic syndrome and lung disease, with particular emphasis on adipokines, macrophage polarization, oxidative stress, and systemic inflammation. Phenotype specific therapeutic strategies should be explored to determine whether targeted metabolic or anti inflammatory interventions benefit select patient populations. Advances in personalized medicine, including genetic and biomarker driven approaches, may facilitate early identification of high risk individuals [109].

Routine metabolic screening should be integrated into pulmonary care, particularly for patients with chronic obstructive pulmonary disease, to enable early intervention. Multidisciplinary care models involving pulmonologists, endocrinologists, cardiologists, and rehabilitation specialists are likely to optimize clinical outcomes. Longitudinal studies are required to determine whether metabolic syndrome precedes lung disease progression or accelerates its course and whether effective metabolic control can mitigate pulmonary decline [110], [111].

Conclusion

Metabolic syndrome is a complex and multifactorial disorder that significantly increases the risk of cardiovascular disease and diabetes and represents an important comorbidity in patients with chronic lung diseases. Through interconnected mechanisms involving insulin resistance, dyslipidaemia, hypertension, oxidative stress, and chronic inflammation, metabolic syndrome contributes to both pulmonary and extrapulmonary complications. Early identification and comprehensive management of metabolic syndrome through lifestyle modification and pharmacological intervention are essential to prevent disease progression and reduce cardiopulmonary morbidity. Addressing metabolic dysfunction in patients with chronic obstructive pulmonary disease offers a promising opportunity to improve lung function, reduce cardiovascular risk, and enhance overall clinical outcomes. The intersection of metabolic and pulmonary diseases therefore represents a critical area for translational research and clinical innovation.

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Author Contribution
FK; Conceptualization of the review, **TS**; Literature survey, **NS**; Manuscript drafting, **SH**; Critical analysis, **U**; Data compilation, **RBY**; Reference management, **KK**; Supervision and final approval.

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Declarations
The authors declare that they used AI language tools (ChatGPT and Grammarly Premium) to enhance this manuscript's linguistic clarity and readability. They carefully reviewed and edited all generated text to ensure accuracy and alignment with the research's intended meaning.

References

1. M. R. Bhise, V. Trivedi, S. Devi, A. Kumar, T. Jayendra, and K. Sunand, "Graphene Quantum Dots in Cancer Diagnostics and Therapeutics : Advances in Biosensing , Imaging , and Treatment Applications," *Curr. Med. Sci.*, no. 0123456789, 2025, doi: 10.1007/s11596-025-00155-8.
2. Y. S. Shim, H. S. Lee, and J. S. Hwang, "Metabolic syndrome in children and adolescents," *J. Korean Med.*
3. S. K. Masenga, L. S. Kabwe, M. Chakulya, and A. Kirabo, "Mechanisms of Oxidative Stress in Metabolic Syndrome," 2023. doi: 10.3390/ijms24097898.
4. P. Vishvakarma *et al.*, "Nanocarrier Mediated Delivery of Gepotidacin : A Novel Triazaacenaph- thylene Antibiotic Targeting Drug-Resistant Bacterial Infections," *Anti-Infective Agents*, pp. 1–18, 2026, doi: 10.2174/0122113525430497251211145738.
5. G. Fahed *et al.*, "Metabolic Syndrome: Updates on Pathophysiology and Management in 2021," 2022. doi: 10.3390/ijms23020786.
6. H. Lou *et al.*, "Effects of a combination of dyslipidemia and hypertension on the glycemic control of patients with type 2 diabetes mellitus: a cross-sectional study," *SAGE Open Med.*, 2024, doi:
7. S. Mishra, B. Murry, N. K. Devi, S. Tripathi, and S. Suokhrie, "Obesity in dyslipidemia and hypertension: A study among young adults of Delhi/NCR," *Clin. Epidemiol. Glob. Heal.*, 2023, doi: 10.1016/j.cegh.2023.101335.
8. P. Mohseni *et al.*, "The synergistic effect of obesity and dyslipidemia on hypertension: results from the STEPS survey," *Diabetol. Metab. Syndr.*, 2024, doi: 10.1186/s13098-024-01315-x.
9. Shukar Singh, Gursewak Singh, Tawqeer Shafi, and Shafkat Hussain Malik, "Overview of Peptic Ulcer Disease: Epidemiology, Causes, Pathophysiology, and Clinical Importance," *Curr. Pharm. Res.*, vol. 1, no. 2, pp. 68–79, 2025, doi: 10.63785/cpr.2025.1.2.184192.
10. J. E. Woodell-May and S. D. Sommerfeld, "Role of Inflammation and the Immune System in the Progression of Osteoarthritis," 2020. doi: 10.1002/jor.24457.
11. R. Ahmad *et al.*, "Mechanistic insights into the neuroprotective effects of Radix Astragali (Huang Qi): Bridging Traditional Chinese Medicine and modern pharmacology," *Pharmacol. Res. - Mod. Chinese Med.*, vol. 17, no. July, p. 100711, 2025, doi: 10.1016/j.prmcm.2025.100711.
12. L. Zhao, T. Zhang, and K. Zhang, "Pharmacological effects of ginseng and ginsenosides on intestinal inflammation and the immune system," 2024. doi: 10.3389/fimmu.2024.1353614.
13. Mukesh Kumar, Shadab Ali, and Smriti Gohri, "Microsponge Drug Delivery Systems: Advancing Methotrexate Delivery for Rheumatoid Arthritis Management," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 15–29, 2025, doi: 10.63785/cpr.2025.1.1.1529.
14. S. Ali, S. A. Ali, S. Shamim, and N. A. Farooqui, "Emerging Trends in the Pathogenesis, Diagnosis, and Management of Human Metapneumovirus-Associated Respiratory Infections," *Anti-Infective Agents*, vol. 24, 2025, doi: 10.2174/0122113525396349251011213223.
15. Shadab Ali, Sayad Ahad Ali, Mukesh Kumar, Iram Jahan, and Jiyaul Hak, "Emerging Strategies for Targeted Drug Delivery across the Blood–Brain Barrier in Neurological Disorder," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 1–14, 2025, doi: 10.63785/cpr.2025.1.1.114.
16. W. Wang, M. Tu, X. P. Qiu, Y. Tong, and X. L. Guo, "The Interplay of Systemic Inflammation and Oxidative Stress in Connecting Perirenal Adipose Tissue to Hyperuricemia in Type 2 Diabetes Mellitus: A Mediation Analysis," *J. Inflamm. Res.* , 2024, doi: 10.2147/JIR.S488964.
17. S. A. Ali, S. Ali, and S. Shamim, "Role of Artificial Intelligence in Transforming Diagnosis, Treatment, and Patient Care: A Review," *Curr. Pharmacogenomics Person. Med.*, vol. 23, 2025, doi: 10.2174/0118756921404728251019182202.
18. Shadab Ali, Smriti Gohri, Sayad Ahad Ali, and Mukesh Kumar, "Nanotechnology for Diabetes Management: Transforming Anti-diabetic Drug Delivery Systems," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 45–59, 2025, doi: 10.63785/cpr.2025.1.1.4559.
19. V. Austin, P. J. Crack, S. Bozinovski, A. A. Miller, and R. Vlahos, "COPD and stroke: Are systemic inflammation and oxidative stress the missing links?," 2016. doi: 10.1042/CS20160043.
20. Tarmeen Ali, "Nanomedicine Approaches to Overcome Barriers in Pulmonary Drug Delivery

for Respiratory Diseases," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 30–44, 2025, doi: 10.63785/cpr.2025.1.1.3044.
21. T. H. Petek, T. Petek, M. Močnik, and N. M. Varda, "Systemic Inflammation, Oxidative Stress and Cardiovascular Health in Children and Adolescents: A Systematic Review," 2022. doi: 10.3390/antiox11050894.
22. Shadab Ali and Sayad Ahad Ali, "Hydrogel Nanostructures for Targeted Drug Delivery in Inflammatory Diseases: A Comprehensive Review," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 116–130, 2025, doi: 10.63785/cpr.2025.1.1.116130.
23. W. Gong *et al.*, "Glymphatic function and choroid plexus volume is associated with systemic inflammation and oxidative stress in major depressive disorder," *Brain. Behav. Immun.*, 2025, doi: 10.1016/j.bbi.2025.04.008.
24. H. Wu and C. M. Ballantyne, "Metabolic Inflammation and Insulin Resistance in Obesity," 2020. doi: 10.1161/CIRCRESAHA.119.315896.
25. Rinki Vishwas, "Peptide-Based Therapeutics in Fungal Infections: Challenges and Innovations," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 98–115, 2025, doi: 10.63785/cpr.2025.1.1.98115.
26. B. Arneth, "Mechanisms of Insulin Resistance in Patients with Obesity," 2024. doi: 10.3390/endocrines5020011.
27. S. D. Schraier, "CARDIOVASCULAR DISEASE AND DIABETES," 2020. doi: 10.47196/diab.v54i2Sup.249.
28. I. Jahan, S. Ali, J. Hak, S. Shamim, M. Kumar, and T. Ali, "Emerging Trends in Magnetic Nanoparticle Delivery, Synthesis and Applications in Biomedicine," *Drug Deliv. Lett.*, vol. 16, pp. 1–17, 2025, doi: 10.2174/0122103031400035251014115919.
29. P. Balakumar, K. Maung-U, and G. Jagadeesh, "Prevalence and prevention of cardiovascular disease and diabetes mellitus," 2016. doi: 10.1016/j.phrs.2016.09.040.
30. Mohita Thakur, "Importance of In-Process Quality Control for Product Safety and Integrity in Pharmaceutical Packaging," *Curr. Pharm. Res.*, vol. 1, no. 2, pp. 116–124, 2025, doi: 10.63785/cpr.2025.1.2.225232.
31. K. Singh *et al.*, "Emerging Applications and Innovations in Emulgel Technology for Enhanced Topical Drug Delivery," *Drug Deliv. Lett.*, vol. 15, pp. 1–16, 2025, doi: 10.2174/0122103031384904250930153320.
32. [32] E. A. Nosova, B. A. Spasennikov, and O. Y. Aleksandrova, "The gender and age differences of persons with suicidal behavior," *Probl. sotsial'noi Gig. Zdr. i Istor. meditsiny*, 2022, doi: 10.32687/0869-866X-2022-30-4-548-553.
33. Navdeep Singh and Talit Masood, "Berberine in Breast Cancer Management: Molecular Mechanisms, Therapeutic Applications, and Future Directions," *Curr. Pharm. Res.*, vol. 1, no. 2, pp. 29–41, 2025, doi: 10.63785/cpr.2025.1.1.150160.
34. N. Mustafa Khalid, H. Haron, S. Shahar, and M. Fenech, "Current Evidence on the Association of Micronutrient Malnutrition with Mild Cognitive Impairment, Frailty, and Cognitive Frailty among Older Adults: A Scoping Review," 2022. doi: 10.3390/ijerph192315722.
35. J. Chen, X. Qin, M. Chen, T. Chen, Z. Chen, and B. He, "Biological activities, Molecular mechanisms, and Clinical application of Naringin in Metabolic syndrome," *Pharmacol. Res.*, 2024, doi: 10.1016/j.phrs.2024.107124.
36. Y. H. Lee *et al.*, "Clinical implications of changes in metabolic syndrome status after kidney transplantation: A nationwide prospective cohort study," *Nephrol. Dial. Transplant.*, 2023, doi: 10.1093/ndt/gfad115.
37. S. Kumar, R. Malviya, and S. Sundram, "Nutritional neurology: Unraveling cellular mechanisms of natural supplements in brain health," 2024. doi: 10.1016/j.hnm.2023.200232.
38. R. Singh, S. Shamim, S. Ali, R. Kumar, and T. Ali, "A Global Public Health Review of the Mumps Virus: Epidemiology, Pathogenesis, and Advances in Vaccination," *Anti-Infective Agents*, vol. 24, 2025, doi: 10.2174/0122113525412555250922164155.
39. V. Papa, F. Li Pomi, P. L. Minciullo, F. Borgia, and S. Gangemi, "Skin Disorders and Osteoporosis: Unraveling the Interplay Between Vitamin D, Microbiota, and Epigenetics Within the Skin–Bone Axis," 2025. doi: 10.3390/ijms26010179.
40. Abhinay Tiwari, Anshu, Chirag Kumar, and Moh. Zaid, "Unravelling the Herbal Formulation of Floating Microspheres for Gut Microbiome Modulation: Curren1Abhinay Challenges and Future Prospects," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 144–162, 2025, doi: 10.63785/cpr.2025.1.1.144162.
41. C. K. Ugwoke, E. Cvetko, and N. Umek, "Skeletal Muscle Microvascular Dysfunction in Obesity-Related Insulin Resistance: Pathophysiological Mechanisms and Therapeutic Perspectives," 2022. doi: 10.3390/ijms23020847.
42. M. Packer, "The Adipokine Hypothesis of Heart Failure With a Preserved Ejection Fraction: A Novel Framework to Explain Pathogenesis and Guide Treatment," 2025. doi: 10.1016/j.jacc.2025.06.055.
43. A. Shrivastava *et al.*, "Heart Failure Management in the Modern Era: A Comprehensive Review on Medical and Device-based Interventions," *Curr. Cardiol. Rev.*, vol. 21, no. 6, pp. 1–14, 2025, doi: 10.2174/011573403x338702250226075044.
44. B. Roy, "Pathophysiological Mechanisms of Diabetes-Induced Macrovascular and Microvascular Complications: The Role of Oxidative Stress," 2025. doi: 10.3390/medsci13030087.
45. M. Wang, Y. Liu, Y. Liang, K. Naruse, and K. Takahashi, "Systematic Understanding of Pathophysiological Mechanisms of Oxidative Stress-Related Conditions—Diabetes Mellitus,

Cardiovascular Diseases, and Ischemia–Reperfusion Injury," 2021. doi: 10.3389/fcvm.2021.649785.
46. Robin Singh, "Revolutionizing Antimicrobial Therapies Through Biofilm-Targeted Nanomedicine," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 78–97, 2025, doi: 10.63785/cpr.2025.1.1.7897.
47. S. Tang, Y. Zhang, B. O. A. Botchway, X. Wang, M. Huang, and X. Liu, "Epigallocatechin-3-Gallate Inhibits Oxidative Stress Through the Keap1/Nrf2 Signaling Pathway to Improve Alzheimer Disease," 2025. doi: 10.1007/s12035-024-04498-6.
48. N. Theodorakis and M. Nikolaou, "From Cardiovascular-Kidney-Metabolic Syndrome to Cardiovascular-Renal-Hepatic-Metabolic Syndrome: Proposing an Expanded Framework," *Biomolecules*, 2025, doi: 10.3390/biom15020213.
49. S. et al. Singh, K., Gupta, J. K., Chanchal, D. K., Khan, S., Varma, A., Shanno, K., Kumar, S., & Shamim, "Deciphering the Genetic Landscape: Exploring the Relationship Between HLA-DQA1, HLA-DQB1, and HLA-DRB1 Genes in Diabetes Mellitus," *Curr. Pharmacogenomics Person. Med.*, vol. 21, no. 3, pp. 1–11, 2024, doi: 10.2174/0118756921310081240821065036.
50. H. Almhmoud *et al.*, "Polycystic ovary syndrome and its multidimensional impacts on women's mental health A narrative review," *Med. (United States)*, 2024, doi: 10.1097/MD.0000000000038647.
51. A. Ghafari, M. Maftoohi, M. E. Samarin, S. Barani, M. Banimohammad, and R. Samie, "The last update on polycystic ovary syndrome(PCOS), diagnosis criteria, and novel treatment," 2025. doi: 10.1016/j.endmts.2025.100228.
52. A. Anand *et al.*, "Neuroprotective Efficacy and Complementary Treatment with Medicinal Herbs: A Comprehensive Review of Recent Therapeutic Approaches in Epilepsy Management," *CNS Neurol. Disord. - Drug Targets*, vol. 24, no. 1, pp. 60–73, 2024, doi: 10.2174/0118715273332140240724093837.
53. R. H. Dhondge, S. Agrawal, R. Patil, A. Kadu, and M. Kothari, "A Comprehensive Review of Metabolic Syndrome and Its Role in Cardiovascular Disease and Type 2 Diabetes Mellitus: Mechanisms, Risk Factors, and Management," *Cureus*, 2024, doi: 10.7759/cureus.67428.
54. R. Shumnalieva, G. Kotov, and S. Monov, "Obesity-Related Knee Osteoarthritis—Current Concepts," 2023. doi: 10.3390/life13081650.
55. D. Herouvi, G. Paltoglou, A. Soldatou, C. Kalpia, S. Karanasios, and K. Karavanaki, "Lifestyle and Pharmacological Interventions and Treatment Indications for the Management of Obesity in Children and Adolescents," 2023. doi: 10.3390/children10071230.
56. D. Radu *et al.*, "The Impact of Insulin Resistance on Lung Volume Through Right Ventricular Dysfunction in Diabetic Patients—Literature Review," 2025. doi: 10.3390/jpm15080336.
57. Bhanu Pratap and Pankaj Singh Jadaun, "Hydrogel Microneedles: A Breakthrough in Disease Treatment and Drug Delivery Systems," *Curr. Pharm. Res.*, vol. 1, no. 2, pp. 60–77, 2025, doi: 10.63785/cpr.2025.1.1.6077.
58. A. Iliesiu, A. Cempeanu, and D. Dusceac, "Serum uric acid and cardiovascular disease Adriana," *J. Am. Coll. Cardiol.*, 2015.
59. N. Khatiwada and Z. Hong, "Potential Benefits and Risks Associated with the Use of Statins," 2024. doi: 10.3390/pharmaceutics16020214.
60. P. Kumar *et al.*, "Fused Deposition Modeling 3D-Printed Scafolds for Bone Tissue.pdf," *Appl. Biochem. Biotechnol.*, vol. 12, no. 22, pp. 1–11, 2024, doi: 10.54085/ap.2023.12.2.19.
61. J. H. Han *et al.*, "Comparative Efficacy of Rosuvastatin Monotherapy and Rosuvastatin/Ezetimibe Combination Therapy on Insulin Sensitivity and Vascular Inflammatory Response in Patients with Type 2 Diabetes Mellitus," *Diabetes Metab. J.*, 2024, doi: 10.4093/dmj.2022.0402.
62. L. B. Knudsen and J. Lau, "The discovery and development of liraglutide and semaglutide," 2019. doi: 10.3389/fendo.2019.00155.
63. Shamim, S. Ali, T. Ali, H. Sharma, B. N. Kishor, and S. K. Jha, "Recent Advances in Monodisperse Gold Nanoparticle Delivery, Synthesis, and Emerging Applications in Cancer Therapy," *Plasmonics*, no. 0123456789, 2025, doi: 10.1007/s11468-024-02732-4.
64. X. D. Yang and Y. Y. Yang, "Clinical Pharmacokinetics of Semaglutide: A Systematic Review," 2024. doi: 10.2147/DDDT.S470826.
65. S. Lim *et al.*, "A multicentre, double-blind, placebo-controlled, randomized, parallel comparison, phase 3 trial to evaluate the efficacy and safety of pioglitazone add-on therapy in type 2 diabetic patients treated with metformin and dapagliflozin," *Diabetes, Obes. Metab.*, 2024, doi: 10.1111/dom.15526.
66. M. R. Khan, D. Kumar, S. Shamim, K. Sunand, S. Sharma, and G. Rawat, "Ethnopharmacological relevance of Citrus limon (L.) Burm. f. as adjuvant therapy," *Ann. Phytomedicine An Int. J.*, vol. 12, no. 2, pp. 169–179, 2023, doi: 10.54085/ap.2023.12.2.19.
67. K. Č. Trobec, I. Grabnar, J. Trontelj, M. Lainščak, and M. K. Kos, "Population pharmacokinetics of ramipril in patients with chronic heart failure: A real-world longitudinal study," *Acta Pharm.*, 2024, doi: 10.2478/acph-2024-0018.
68. Rani Khan *et al.*, "Formulation and Characterisation of Herbal Ethosomal Gel of Luliconazole and Clove Oil for Modified Drug Diffusion to the Skin," *World J. Adv. Res. Rev.*, vol. 18, no. 4, pp. 488–501, 2025, doi: 10.1016/j.jaim.2024.100947.
69. J. J. V. McMurray *et al.*, "Aliskiren, Enalapril, or Aliskiren and Enalapril in Heart Failure," *N. Engl. J. Med.*, 2016, doi: 10.1056/nejmoa1514859.
70. T. Ali, "Chromatography and Spectroscopic

Characterization of Nano-Carrier Pharmaceuticals," *Pharm. Nanotechnol.*, 2024, doi: 10.2174/0122117385319695240911115239.
71. S. Şahin, A. Ç. Aydın, A. Y. Göçmen, and E. Kaymak, "Evaluation of the protective effect of losartan in acetaminophen-induced liver and kidney damage in mice," *Naunyn. Schmiedebergs. Arch. Pharmacol.*, 2024, doi: 10.1007/s00210-023-02937-0.
72. D. A. Morrow *et al.*, "Sacubitril/Valsartan in Patients Hospitalized With Decompensated Heart Failure," *J. Am. Coll. Cardiol.*, 2024, doi: 10.1016/j.jacc.2024.01.027.
73. H. S. S. & A. B. Pawan Kumar, Shamim, Mohammad Muztaba, Tarmeen Ali, Jyoti Bala, "Fused Deposition Modeling 3D-Printed Scafolds for Bone Tissue.pdf," 2024, *Springer Nature*. doi: 10.1007/s10439-024-03479-z.
74. S. D. Anker *et al.*, "Empagliflozin in Heart Failure with a Preserved Ejection Fraction," *N. Engl. J. Med.*, 2021, doi: 10.1056/nejmoa2107038.
75. Z. L. Cox *et al.*, "Efficacy and Safety of Dapagliflozin in Patients With Acute Heart Failure," *J. Am. Coll. Cardiol.*, 2024, doi: 10.1016/j.jacc.2024.02.009.
76. K. Singh *et al.*, "Recent Advances in the Synthesis of Antioxidant Derivatives: Pharmacological Insights for Neurological Disorders," *Curr. Top. Med. Chem.*, vol. 24, no. 22, pp. 1940–1959, 2024, doi: 10.2174/0115680266305736240725052825.
77. G. Rena, D. G. Hardie, and E. R. Pearson, "The mechanisms of action of metformin," 2017. doi: 10.1007/s00125-017-4342-z.
78. W. AlHabeeb, S. Mrabeti, and A. A. I. Abdelsalam, "Therapeutic Properties of Highly Selective β-blockers With or Without Additional Vasodilator Properties: Focus on Bisoprolol and Nebivolol in Patients With Cardiovascular Disease," 2022. doi: 10.1007/s10557-021-07205-y.
79. K. Singh *et al.*, "Deciphering the Genetic Landscape: Exploring the Relationship Between HLA-DQA1, HLA-DQB1, and HLA-DRB1 Genes in Diabetes Mellitus," *Curr. Pharmacogenomics Person. Med.*, vol. 21, pp. 1–11, 2024, doi: 10.2174/0118756921310081240821065036.
80. J. G. Wang, B. F. Palmer, K. Vogel Anderson, and P. Sever, "Amlodipine in the current management of hypertension," 2023. doi: 10.1111/jch.14709.
81. N. F. Al-Tannak, "UHPLC-UV method for simultaneous determination of perindopril arginine and indapamide hemihydrate in combined dosage form: A stability-indicating assay method," *Sci. Pharm.*, 2018, doi: 10.3390/scipharm86010007.
82. H. Sharma, A. P. Singh, D. Pathak, D. Taumar, and V. Chaudhary, "The Role of approved Kinase Inhibitors in Cancer Treatment : Medicinal Chemistry and Pharmacological Insights," *Med. Chem. (Los. Angeles).*, pp. 1–18,
83. L. K. Stamp, C. Horsley, L. Te Karu, N. Dalbeth, and M. Barclay, "Colchicine: the good, the bad, the ugly and how to minimize the risks," 2024. doi: 10.1093/rheumatology/kead625.
84. N. Primas *et al.*, "Stability Study of Parenteral N-Acetylcysteine, and Chemical Inhibition of Its Dimerization," *Pharmaceuticals*, 2023, doi: 10.3390/ph16010072.
85. J. Kumar *et al.*, "CFTR mRNA-Based Gene Therapy for Cystic Fibrosis: A Mutation-Agnostic Strategy to Restore Ion Transport Function," *Curr. Gene Ther.*, no. January, pp. 1–18, 2025, doi: 10.2174/0115665232413980251103133741.
86. C. Deerochanawong, S. G. Kim, and Y. C. Chang, "Role of Fenofibrate Use in Dyslipidemia and Related
87. A. P. Singh *et al.*, "Revolutionizing Drug and Gene Delivery: Cutting-Edge Smart Polymers for Precision Release," *Curr. Gene Ther.*, no. January, pp. 1–19, 2025, doi: 10.2174/0115665232390238251121074917.
88. B. Dréno *et al.*, "Efficacy of Spironolactone Compared with Doxycycline in Moderate Acne in Adult Females: Results of the Multicentre, Controlled, Randomized, Double-blind Prospective and Parallel Female Acne Spironolactone vs doxyCycline Efficacy (FASCE) Study," *Acta Derm. Venereol.*, 2024, doi: 10.2340/actadv.v104.26002.
89. M. L. O'Donoghue *et al.*, "Long-Term Evolocumab in Patients with Established Atherosclerotic Cardiovascular Disease," *Circulation*, 2022, doi: 10.1161/CIRCULATIONAHA.122.061620.
90. P. Chandel, S. Shamim, and S. Ali, "A Comprehensive Review on Nanoemulsions for Improved Bioavailability and Therapeutic Efficacy in Gastrointestinal Disorders," *Drug Deliv. Lett.*, no. August, pp. 1–18, 2021, doi: 10.2174/0122103031410345251205075031.
91. P. Kumar *et al.*, "Trends of Nanobiosensors in Modern Agriculture Systems," *Appl. Biochem. Biotechnol.*, vol. 197, no. 1, pp. 667–690, 2024, doi: 10.1007/s12010-024-05039-6.
92. M. G. Abrignani *et al.*, "Risk Factors and Prevention of Cancer and CVDs: A Chicken and Egg Situation," 2025. doi: 10.3390/jcm14093083.
93. Manisha Dev and Pallavi Chandel, "Nanostructured Lipid Carriers in Pulmonary Drug Delivery: Progress and Prospects," *Curr. Pharm. Res.*, vol. 1, no. 1, pp. 131–143, 2025, doi: 10.63785/cpr.2025.1.1.131143.
94. K. M. Munir, S. Chandrasekaran, F. Gao, and M. J. Quon, "Mechanisms for food polyphenols to ameliorate insulin resistance and endothelial dysfunction: Therapeutic implications for diabetes and its cardiovascular complications," *Am. J. Physiol. - Endocrinol. Metab.*, 2013, doi: 10.1152/ajpendo.00377.2013.
95. S. A. Ali, S. Ali, S. Rastogi, B. Shivhare, and M. Muztaba, "A Comprehensive Review on Advancements in Nanocarriers-Based Peptide Delivery for Cancer Therapeutics," *Micro Nanosyst.*, vol. 17, no. 4, pp. 283–297, 2025, doi: 10.2174/0118764029358553250325040749.

96. A. Menon, "The Physiological Aspects of Diabetes: Mechanisms, Complications, and Therapeutic Approaches Corresponding Author*," *J Diabetes Metab*, 2025.
97. D. Kumar, Rohan Kumar, Harsh Raj Singh, Rajni Tanwar, and Vrinda Gupta, "Duvyzat (Givinostat) in Duchenne Muscular Dystrophy: Mechanisms, Clinical Impact, and Future Directions," *Curr. Pharm. Res.*, vol. 1, no. 3, pp. 308–322, 2025, doi: 10.63785/cpr.2025.1.3.308322.
98. B. A. Durrani *et al.*, "Implementation of E-Government in Welcoming the Contemporary Industrial Revolution 4.0 Era in Indonesia," *Int. J. Mark. Stud.*, 2014.
99. D. Aguilar and M. L. Fernandez, "Hypercholesterolemia induces adipose dysfunction in conditions of obesity and nonobesity," 2014. doi: 10.3945/an.114.005934.
100. P. Chandel, T. Singh, A. Sharma, F. Sahib, and M. Gobindgarh, "Emerging Biomarkers for Early Detection of Alzheimer ' s Disease : Progress and Challenges School of Pharmacy , Deshbhagat University , off to NH-44 , Amloh Road , Mandi Gobindgarh District," *Curr. Pharm. Des.*, vol. 1, no. 3, pp. 364–372, 2025.
101. I. Jääskeläinen *et al.*, "Collagens Regulating Adipose Tissue Formation and Functions," 2023. doi: 10.3390/biomedicines11051412.
102. S. K. Kushwaha, P. Chandel, T. Singh, M. Thakur, and U. Pradesh, "Formulation and Evaluation of a Multicomponent Herbal Shampoo for Enhanced Hair and Scalp Health Department of Pharmacy , IIMT College of Medical Sciences , IIMT University , Ganga Nagar , Meerut- School of Pharmacy , Deshbhagat University Amloh Road , Ma," *Curr. Pharm. Res.*, vol. 1, no. 3, pp. 373–383, 2025.
103. E. C. Y. Iu and C. B. Chan, "Is Brain-Derived Neurotrophic Factor a Metabolic Hormone in Peripheral Tissues?," 2022. doi: 10.3390/biology11071063.
104. İ. Dağoğlu Polat and Ö. Baran, "The Effects of Taurine on Energy Homeostasis and Health: A Nutritional Perspective," *Turkish J. Diabetes Obes.*, 2025, doi: 10.25048/tudod.1744454.
105. S. Chawla, R. Gupta, S. K. Jha, and K. T. Jha, "Stereoisomerism in Chemistry and Drug Development: Optical, Geometrical, and Conformational Isomers," *Med. Chem. (Los. Angeles).*, 2025, doi: 10.2174/0115734064366389250923044201.
106. A. Alito *et al.*, "Brown adipose tissue human biomarkers: Which one fits best? A narrative review," *Med. (United States)*, 2022, doi: 10.1097/MD.0000000000032181.
107. S. Rana, B. Pratap, P. S. Jadaun, and U. Pradesh, "Development and Evaluation of Liquorice Root Extract-Based Cream for the Management of Hyperpigmentation" *Curr. Pharm. Res.*, vol. 1, no. 3, pp. 384–392, 2025.
108. M. Quan and S. Kuang, "Exosomal Secretion of Adipose Tissue during Various Physiological States," *Pharm. Res.*, 2020, doi: 10.1007/s11095-020-02941-6.
109. C. Zou and J. Shao, "Role of adipocytokines in obesity-associated insulin resistance," 2008. doi: 10.1016/j.jnutbio.2007.06.006.
110. N. Thompson, K. Huber, M. Bedürftig, K. Hansen, J. Miles-Chan, and B. H. Breier, "Metabolic programming of adipose tissue structure and function in male rat offspring by prenatal undernutrition," *Nutr. Metab.*, 2014, doi: 10.1186/1743-7075-11-50.
111. A. et al. Kumar, J., M., T., Musayev, "Stimuli-responsive Hydrogels for Targeted Antibiotic Delivery in Bone Tissue Engineering," *AAPS PharmSciTech*, vol. 26, no. 217, pp. 1–23, 2025, doi: https://doi.org/10.1208/s12249-025-03218-0.