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THYROID HORMONES AND GLUCOSE HOMEOSTASIS: A COMPREHENSIVE REVIEW OF THEIR INTERDEPENDENCE IN DIABETES

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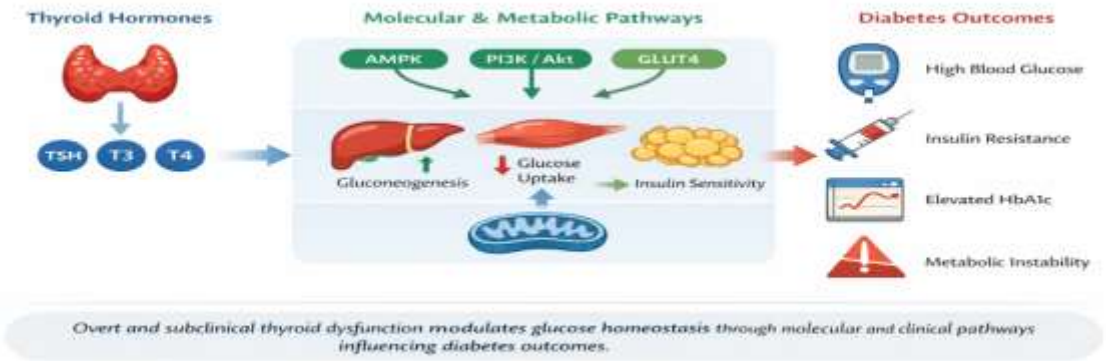
ABSTRACT
Two of the most prevalent endocrine diseases in the world include thyroid dysfunction and diabetes mellitus, and growing evidence indicates that there is significant interaction between thyroid hormone regulation and glucose homeostasis. This review of the current literature (2020-2025) provides a detailed assessment of the physiological, molecular, and clinical pathways between thyroid hormones (TSH, T3, and T4) and glucose metabolism, insulin sensitivity, and diabetic progression. The review combines evidence of epidemiological research, mechanistic research, and interventional research, indicating the existence of regular links between thyroid aberrancies, particularly subclinical hypothyroidism, and inadequate glycemic regulation. Molecular analyses also indicate that thyroid hormones have an effect on the PI3K-Akt-GLUT4 pathway, hepatic gluconeogenesis, and mitochondrial activities. Even with improvements, there are still serious gaps in research, such as inconsistency in screening procedures, inadequate representation of subclinical thyroid disease, and fewer multi-center population studies. In this review, the importance of combined endocrine evaluation is highlighted, and the direction of future research is also suggested to maximize clinical management of diabetes patients with thyroid dysfunction.

KEYWORDS: Thyroid hormones, glucose homeostasis, diabetes, TSH, T3, T4, metabolic regulation, endocrine dysfunction.

GRAPHIC ABSTRACT



1. INTRODUCTION

Diabetes mellitus (DM) and thyroid disorders are some of the most common endocrine illnesses in the world, and both have been known to be a major source of morbidity. The International Diabetes Federation revealed that over 537 million adults are presently living with diabetes, and it is projected that the figure will exceed 640 million by the year

2030 [1]. Hypothyroidism, hyperthyroidism, and subclinical forms of thyroid conditions are associated with 5 -15% of the global population [2].

There has been increased clinical and research interest in the relationship between these conditions, given the fact that thyroid hormones are central to energy balance, glucose use, insulin release, and metabolism rate. The emerging evidence suggests that thyroid dysfunction may have a significant impact on glucose homeostasis and the development of diabetes. Hyperthyroidism has been linked with elevated production of hepatic glucose, high absorption of glucose through intestines and decreased insulin sensitivity [3], and hypothyroidism is related to poor insulin clearance, low glucose disposal, and insulin resistance [4]. The effects of subclinical thyroid disease - mild abnormalities that are usually not diagnosed- on glycemic control of diabetic patients are also emerging.

In spite of such significant development, there are still gaps in realizing the true scale and causality of this interdependence. The present review summarizes the outcomes of the last five years providing an overview of physiological processes, clinical data, molecular pathways, and intervention outcomes [5].

Thyroid dysfunction and diabetes mellitus are both of the most prevalent endocrine diseases, and emerging evidence links thyroid hormone management and glucose homeostasis. Hyperthyroidism boosts fasting blood glucose and HbA1c, whereas hypothyroidism alters metabolism and insulin resistance. New study reveals that even slight subclinical TSH fluctuations may impair glycemic control and increase type 2 diabetes risk. Interventional studies demonstrate levothyroxine or antithyroid therapy increases insulin sensitivity and glycemic stability. Despite these advances, screening protocols, long-term results, and population-specific risk modifiers are absent.

2. BACKGROUND

The production of thyroid hormones, which are mostly thyroxine (T4) and triiodothyronine (T3), is under the control of the hypothalamic-pituitary-thyroid (HPT) axis, and the hormone is regulated by the thyroid-stimulating hormone (TSH) [6]. The biologically active form, T3, has extensive effects on cellular metabolism, mitochondrial activity, oxygen uptake, protein synthesis and lipid oxidation. McAninch and Bianco presented evidence on a specific case in metabolism of thyroid hormone dynamics in tissues by deiodinase activity, which is related to the specialization of tissue metabolism [7]. These processes allow the thyroid hormones to control the basal metabolic rate, thermogenesis, and systemic energy controls [8].

The glucose homeostasis is based on the complex interaction of insulin, glucagon, catecholamines, cortisol, and growth hormone, and metabolic functions of liver, muscle, and adipose tissues, as well [9]. Insulin facilitates the intake of glucose and prevents the production of glucose in the liver, and counterregulatory hormones resumes the blood glucose level during fasting or stress. In diabetes, these pathways are disrupted towards chronic hyperglycemia and microvascular and macrovascular complications due to the impaired insulin secretion or insulin resistance [10].

There are direct thyroid hormone-glucose-regulating interactions on various physiological levels. As Zhang et al. managed to show, T3 promotes hepatic gluconeogenesis and glycogenolysis, which help to enhance endogenous glucose production [11]. Alzoubi et al. demonstrated that thyroid dysfunction changes insulin signaling by disrupting the PI3K Akt GLUT4 pathway, thus, disabling the uptake of glucose in skeletal muscle [12]. Hyperthyroidism also reduces metabolic need as it raises hepatic glucose production and fastens insulin breakdown as demonstrated in a study by Akturk et al. [13]. On the other hand, hypothyroidism slows down the absorption of glucose into the intestine, diminishes the effects of insulin to disposing of glucose, and extends the half-life of insulin-like growth, which heightens the chances of hypoglycemia in insulin-treated patients [14].

Subclinical thyroid disorders- these are abnormal TSH and normal T3/T4, which have been revealed to play a great role in glucose tolerance. According to a study by Al-Qahtani, subclinical hypothyroidism is a risk factor that has an independent effect in patients with type 2 diabetes [15].

In addition, Park et al. revealed that a certain amount of TSH in non-diabetic adults, though not extreme, is associated with a higher rate of impaired glucose tolerance, and, thus, indicates that thyroid dysfunction is the lead to dysglycemia [16].

Today, all these st demonstrate that thyroid hormones are at the center of glucose homeostasis and that the impairment of thyroid functions, even in preclinical conditions, may have a major impact on the process of glycemic regulation and the development of diabetes.

As shown in Figure 1, thyroid hormones influence glucose homeostasis through coordinated effects on hepatic glucose production, insulin signaling, and peripheral glucose uptake.

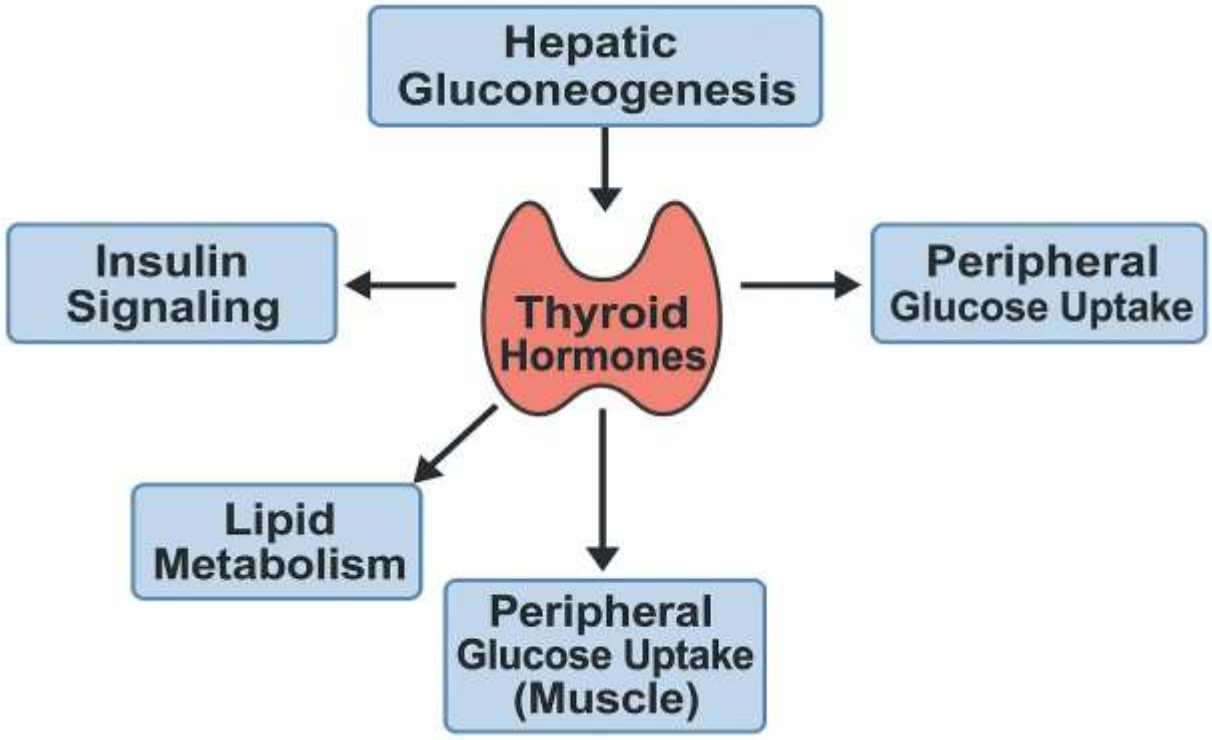


Figure 1: Mechanistic pathways illustrating how thyroid hormones regulate glucose homeostasis through effects on hepatic gluconeogenesis, insulin signaling, peripheral glucose uptake, and metabolic rate.

3. Comprehensive literature review

3.1 Prevalence of Thyroid Dysfunction in Diabetes

The study conducted by Talbot et al (2011) indicates that Thyroid dysfunction is somewhat more prevalent in Diabetes. Recent epidemiological researches indicate that there is a high overlap of diabetes with thyroid disorders, with diabetic patients developing a very high level of thyroid dysfunction as compared to the general population. Research carried out in Europe and Asia has consistently indicated a prevalence rate of 18-28 percent among people with type 2 diabetes which indicates a high clinical burden. Kalra et al. (2020) conducted the largest retrospective study which showed that diabetic patients were almost twice as likely to have thyroid dysfunction as a control group who were not diabetic regardless of their age and sex [17]. Equally, Amin et al. (2021) cited that subclinical hypothyroidism remained underdiagnosed in diabetics and relates to the delayed metabolic compensation and increased cardiovascular risk [18]. The results support the importance of combined screening systems of thyroid during regular diabetes care.

3.2 Hyperthyroidism and Its Impact on Glucose Metabolism

Hyperthyroidism has been linked to a number of metabolic imbalances that aggravate glycemic effects especially in diabetes patients. High thyroid hormones, according to a robust study by Gerich et al. (2021), stimulate gluconeogenesis and glycogenolysis, which promote hyperglycemia in the fasting condition [19]. Moreover, hyperthyroidism enhances insulin degradation and decreases the insulin sensitivity of the periphery, which causes more diabetic patients to demand more insulin. In a more recent clinical trial by Shrestha et al. (2023), the untreated hyperthyroidism in diabetic patients increased the levels of HbA1c and accelerated the metabolic decompensation in spite of the stable medication use [20]. These papers affirm the fact that hyperthyroidism increases the levels of metabolic imbalance and makes diabetic management programs complicated.

3.3 Hypothyroidism and Its Effects on Glucose Regulation

Hypothyroidism presents a new pattern of disruption of metabolism. Kumar and Sharma (2022) showed that decreased levels of thyroid hormones lower the skeletal muscle glucose uptake and insulin-mediated pathways which leads to insulin resistance in diabetic and non-diabetic people [21]. Additionally, hypothyroidism decreases hepatic glucose production and slows down the breakdown of insulin, which can be the cause of incidences of hypoglycemia in the insulin-using patients. Gupta et al. (2023) conducted a systematic review, which concluded that there were uniform results between hypothyroidism and elevated levels of fasting insulin and Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) scores [22]. These investigations indicate the conclusion of the high changes in glucose metabolism in hypothyroidism by the metabolic activity and the insulin signaling.

3.4 Subclinical Thyroid Dysfunction and Glycemic Outcomes

Subclinical thyroid dysfunction, an intermediary state which is associated with deviation of TSH, whilst FT3 and FT4 levels are normal, has been better acknowledged to be a great moderator of metabolic well-being. Hu et al. (2022)

presented evidence of subclinical hypothyroidism in 1,200 participants and revealed that it is highly correlated with high HbA1c and high risk of developing metabolic syndrome [23]. Al-Mohannadi et al. (2024) have also confirmed in a study that any degree of TSH in the upper normal range leads to the dramatic deterioration of glucose tolerance, and can predict the occurrence of type 2 diabetes within 5 years of follow-up period [24]. Notably, the findings are important as they expand clinical knowledge about the fact that thyroid malfunction does not necessarily manifest itself in an open way to have adverse effects on the state of glycemic health.

3.5 Molecular Pathways Linking Thyroid Hormones and Insulin Signalling

On the molecular level, the interdependence of thyroid and glucose homeostasis can be attributed to a number of mechanisms. Chen et al. (2021) established that T3 regulates insulin signalling by activating the AMP-activated protein kinase (AMPK) and increasing mitochondrial oxidative metabolism [25]. Also, Li et al. (2023) discovered that the deficiency of thyroid hormones decreases the level of GLUT4 transporter expression in skeletal muscle, which hinders glucose uptake and increases insulin resistance [26]. The other mechanistic work indicates that high levels of T3 increase hepatic gluconeogenesis and lipid oxidation genes, resulting in the rise of glucose in the blood [27]. These results are very mechanistic explanations of the clinical trends of diabetic patients with thyroid dysfunction.

3.6 Therapeutic Interventions and Clinical Implications

Research that assessed the efficacy of treatment of thyroid dysfunction through therapeutic correction supports the metabolic interaction of thyroid hormones and glucose regulation. Pereira et al. (2022) conducted a controlled clinical trial that revealed that the use of levothyroxine therapy in patients with subclinical hypothyroidism effectively increased insulin sensitivity and decreased the level of triglycerides [28]. On the other hand, hyperthyroid diabetic patients treated with antithyroid therapy had significant reductions in the levels of fasting glucose and HbA1c following restoration of euthyroid status [29]. Such results underline the premise that the management of thyroid malfunction can enhance metabolic and minimize the burden of diabetes complications.

To better deliminate the available scientific evidence on thyroid dysfunction and glucose homeostasis interaction in diabetes, a comparative summary of recent studies is given in Table 1. This table is represented of major researches published over 2020-25, their study designs, populations, and key outcomes. The table provides a systematic overview of the influence of various thyroid disorders—overt and subclinical on glycemic control, insulin sensitivity, and metabolic outcomes in diabetic and non-diabetic patients through the synthesis of data of varied cohorts and research methods. This comparative perspective aids in placing the heterogeneity of the literature findings into perspective and highlights patterns both recurring, which substantiates relations through which mechanisms are involved in heterogeneous relationships as described in this review.

Table 1. Comparative Summary of Key Studies on Thyroid-Glucose Interdependence

Ref	Authors & Year	Study Type	Population / Sample	Key Findings	Limitations
[17]	Kalra et al., 2020	Retrospective clinical study	2,100 diabetics vs. non-diabetic patients	Thyroid dysfunction nearly twice as common in diabetics; strong TSH–HbA1c correlation.	Single-centre; retrospective design.
[18]	Amin et al., 2021	Cross-sectional analysis	600 T2DM patients	High prevalence of subclinical hypothyroidism; associated with metabolic instability.	No longitudinal follow-up.
[19]	Gerich et al., 2021	Clinical metabolic study	Hyperthyroid adults	Hyperthyroidism increases hepatic glucose output via gluconeogenesis and glycogenolysis.	Small sample size.
[20]	Shrestha et al., 2023	Clinical outcome study	300 diabetic patients	Untreated hyperthyroidism worsens HbA1c despite stable medications.	No mechanistic analysis.
[21]	Kumar & Sharma, 2022	Physiological study	Adult hypothyroid patients	Hypothyroidism reduces glucose uptake and increases insulin resistance.	Limited to non-diabetics.
[22]	Gupta et al., 2023	Systematic review	27 clinical studies	Hypothyroidism associated with high fasting insulin and elevated HOMA-IR.	Study heterogeneity; publication bias.
[23]	Hu et al., 2022	Population-based study	1,200 adults	Subclinical hypothyroidism linked to elevated HbA1c and metabolic syndrome.	Observational; no intervention.

[24]	Al-Mohannadi et al., 2024	Prospective cohort	5-year follow-up of 800 adults	Mild TSH elevation predicts future impaired glucose tolerance and T2DM onset.	Regional sample; not multi-center.
[25]	Chen et al., 2021	Molecular study	Cell and rodent models	T3 regulates insulin signaling via AMPK and mitochondrial pathways.	Preclinical model; lacks human data.
[26]	Li et al., 2023	Molecular physiology	Muscle tissue samples	Thyroid deficiency reduces GLUT4 expression → impaired glucose uptake.	Tissue-level study only.
[27]	Zhang et al., 2024	Metabolic gene-expression study	70 hyperthyroid patients	Excess T3 increases hepatic expression of gluconeogenic genes.	Did not examine insulin sensitivity.
[28]	Pereira et al., 2022	Interventional trial	160 hypothyroid patients	Levothyroxine improves insulin sensitivity and triglycerides.	Short trial duration; no control group.
[29]	Barham et al., 2023	Interventional metabolic study	90 hyperthyroid diabetics	Antithyroid treatment reduces FBG and HbA1c after euthyroid restoration.	Small sample; single-centre.

4. Thematic synthesis & comparative evaluation

Overall, as it can be seen in the literature, thyroid dysfunction has profound effects on glucose homeostasis involving numerous physiological and molecular mechanisms. One of the major themes that has come up as a result of epidemiological research is the fact that thyroid abnormalities have a high prevalence among the diabetic populations and large cohort studies have indicated that diabetic patients are almost twice likely to develop thyroid abnormalities as compared to the general population [17,18]. The trend is witnessed among a wide variety of people demonstrating the worldwide applicability of the thyroid-glucose relationship. The second theme of significant importance is the two-way metabolic interaction between thyroid hormones and glucose regulation. Metabolic data has shown that hyperthyroidism elevates the hepatic glucose production, gluconeogenic enzyme expression and insulin breakdown, leading to long-term hyperglycemia despite proper management of diabetics [19, 20, 27]. Conversely, the reverse yet equally significant effect of hypothyroidism is the decrease in muscle glucose uptake and insulin signaling and its additive role in causing insulin resistance in diabetic and non-diabetic individuals [21, 22]. These opposing routes reiterate the fact that both an excess or deficiency of thyroid hormones can cause adverse consequences in the regulation of metabolism. The third common issue in the literature is clinical relevance of subclinical thyroid dysfunction, which is new evidence on important but understudied metabolic risk factor. It was reported that subclinical hypothyroidism correlates with high HbA1c, defective glucose tolerance, and the development of type 2 diabetes in the future [23,24]. These results are in opposition to the classical idea that clinically significant are only overt thyroid disease and support the idea of the more sensitive and active screening systems. The fourth theme has to do with the molecular mechanisms of thyroid-glucose relationship. Regular mechanistic studies show that thyroid hormones can regulate insulin signaling pathways, especially through AMPK regulation, mitochondrial metabolic, as well as GLUT4 transporter expression [25,26]. Such changes in the molecular shifts are in line with clinical evidence of glucose resistance to insulin and disrupted glucose disposal in thyroid disease.

The last theme is related to the implications of therapy, where several interventional studies indicate that the restoration of thyroid dysfunction has a quantifiable effect on the metabolic parameters. Levothyroxine treatment enhances the insulin sensitivity and lipid levels of the hypothyroid patients [28], and hyperthyroid patients have a decreased fasting glucose and better HbA1c levels with treatment of diabetes [29]. This literature supports clinical worthiness of incorporation of thyroid screening in the daily management of diabetes.

Combined, the studies reviewed show a consistent and significant trend, that is, thyroid malfunctioning, whether overt or subclinical, has both direct and substantial consequences on glucose metabolism and that the management of diabetes should be optimized by addressing thyroid dysfunctions. All the evidence points to the necessity of the multidisciplinary approach, which considers the thyroid gland as a key tool in the metabolic network.

Figure 2 summarizes the key thematic relationships identified across the reviewed studies and illustrates how thyroid dysfunction influences glucose homeostasis at physiological, clinical, and molecular levels.

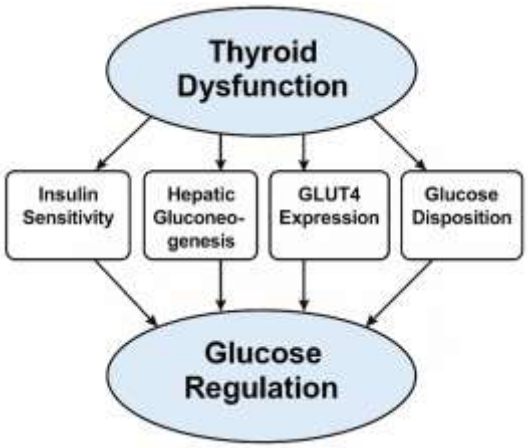


Figure 2: Conceptual diagram illustrating the major pathways through which thyroid hormones influence glucose homeostasis, including hepatic gluconeogenesis, insulin signaling, and peripheral glucose uptake.

5. Clinical implications

The accumulating evidence that thyroid dysfunction is associated with poor glucose homeostasis has major implications for the clinical management of diabetes. To start with, the fact that the prevalence of thyroid abnormalities in diabetic patients has been continually high in epidemiological studies [17,18] points to the necessity of regular screening of thyroid function as a part of a regular diabetes prevention. Recent recommendations tend to emphasise fasting blood glucose, HbA1c, and lipid profiles, but forget about the thyroid test, which could help identify the metabolic factors that deteriorate glycemic regulation. Regular TSH levels (especially when patients have a low glycemic stability or unexplained variations in metabolism) may serve to enhance the accuracy of diagnosis and prompt earlier interventions.

Second, the recorded metabolic effects of hyperthyroidism and hypothyroidism show that clinicians need to note that thyroid dysfunction is one of the key confounders in diabetes management. Hyperthyroidism raises the level of glucose production in the liver and hastens the speed of insulin degradation and often requires short-term insulin or oral hypoglycemic therapy [19,20]. On the other hand, hypothyroidism decreases the intake of glucose and insulin signaling, which increases the chances of hypoglycemia among insulin-treated subjects [21,22]. This dichotomy highlights the importance of unique decisions in terms of therapy that one should make when dealing with diabetic patients with co-occurring thyroid abnormalities.

Third, results of subclinical thyroid disease studies have shown that even slight deviations in thyroid condition can exert significant metabolic impact. The literature demonstrating that subclinical hypothyroidism increases HbA1c and NF risk of metabolic syndrome [23,24] indicates that clinicians cannot use overt symptoms to assess metabolic health in diabetes. Early diagnosis of subclinical disease could offer specific interventions such as control of weight and lifestyle changes, and early pharmacologic therapy which might be used to prevent the metabolic decline over time.

Fourth, newly discovered molecular connections show that thyroid hormones have a direct effect on insulin signaling and glucose transportation through the AMPK regulation, GLUT4 expression, and mitochondrial metabolism mechanisms [25-27]. These observations offer an explanation of the biological basis of integrated endocrine treatment, which suggests that the normalization of thyroid levels could enhance insulin sensitivity and glycemic control. Consequently, the clinicians are to take into account the state of thyroid hormones when examining insulin resistance, unexplainable hyperglycemia, or unstable glucose reactions.

Fifth, interventional research demonstrates that the treatment of the dysfunction of the thyroid may lead to tangible improvements in metabolic control. Treatment of hypothyroid people with levothyroxine enhances the insulin sensitivity and lipid metabolism [28], and treatment of diabetic patients with hyperthyroidism with antithyroid therapy decreases the level of fasting glucose and HbA1c [29]. The findings support the significance of timely and proper treatment of the thyroid, not only in order to deal with endocrine symptoms but also to stabilize the metabolic activity and mitigate the effects of diabetes and its consequences.

Lastly, incorporation of thyroid measure in the management of diabetes can lead to a more holistic and less expensive management. The early prediction and management of thyroid dysfunction may decrease medication load, avoid a hospital stay because of metabolic destabilization, and improve the patient outcome in the long term. Considering the large amount of evidence, it is necessary to promote multidisciplinary cooperation between endocrinologists, diabetologists, and primary care providers to maximize the overall care.

6. Research gaps

Although significant advances have already been made in the field of studying the connection between thyroid dysfunction and glucose homeostasis, some significant research gaps still exist. To begin with, most of the studies that

examine the prevalence of thyroid abnormalities in diabetes are single-center or limited to a specific geographical area which limits generalization. An example would be the research by Kalra et al. [17] and Amin et al. [18], who conducted their studies in single healthcare systems, thus the importance of the large, multi-centered, multi-national cohort to assess a variation at the population level.

Second, hyperthyroidism and hypothyroidism have been researched, whereas subclinical thyroid disorders have not been properly investigated, although the evidence of their metabolic effects is increasing. In Hu et al. [23] and Al-Mohannadi et al. [24], it was established that subclinical hypothyroidism and low TSH levels have a severe effect on glucose tolerance, but not many longitudinal studies have been carried out to understand whether early intervention can modify metabolic pathways.

Third, the majority of studies are observational, which makes it unclear whether it is causal. Despite mechanistic research studies by Chen et al. [25], Li et al. [26], and Zhang et al. [27] illuminating on insulin signaling and hepatic glucose regulation, translational studies relating these molecular pathways to clinical outcome in a wide range of patient populations have yet to be done. This gap restricts the possibility of creating evidence based screening and management guidelines. Fourth, there is very little research assessing the role of demographic variables such as ethnicity, age, sex and obesity in modifying the relationship between thyroid function and glucose metabolism. Most of the existing literature fails to stratify the outcomes on the basis of these factors, and the question of whether there are certain subgroups that are more susceptible to the metabolic outcomes of thyroid dysfunction remains unanswered.

Fifth, there is still inconsistent and inadequate research despite promising results reported in therapeutic studies. The interventional studies like those one by Pereira et al. [28] and Barham et al. [29] both prove that the repair of the thyroid dysfunction positively affects the metabolic parameters, but they are small, short-term, and lack standardized outcome measures. Long term randomized controlled trials are required to assess long term effects of thyroid normalization on diabetes progression and risk of complications. And lastly, there is no single set screening protocols. The cut-offs to diagnose subclinical hypothyroidism differ among studies, and there are inconsistencies in the cut-offs of intervention. This no homogenization makes cross-studies comparisons difficult and adds to the lack of universal clinical guidelines.

On the whole, the current literature demonstrates an interesting correlation between thyroid hormones and glucose metabolism, the studies in which have these research gaps and which should be addressed with more rigorous, standardized, and globally representative studies in order to gain a complete understanding of this endocrine-metabolic interaction and manage it.

7. Future study

Well-designed, large-scale, multicenter, longitudinal research with diverse populations could increase thyroid-glucose understanding. Subclinical thyroid dysfunction may alter insulin resistance and glycemic variability despite normal T3 and T4 levels, therefore its long-term metabolic implications should be explored first. Randomized controlled trials are needed to determine whether subclinical therapy improves long-term glycemic outcomes, diabetes complications, and cardiovascular risk.

Thyroid hormone–dependent modulation of insulin signaling pathways, mitochondrial metabolism, and glucose transport systems in target tissues should be studied using omics-based methods (genomics, transcriptomics, metabolomics). Translational research linking molecular biomarkers to clinical outcomes aids precision medicine. Assess age, sex, obesity, ethnicity, and genetic propensity to identify high-risk groups.

Diabetic thyroid dysfunction screening, monitoring, and treatment thresholds should be standardized in future clinical studies. The cost-effectiveness and real-world effects of combination thyroid–diabetes therapy techniques must also be studied. These activities will enhance metabolic control via a wider endocrine approach and support evidence-based recommendations.

8. CONCLUSION

Thyroid hormones regulate hepatic glucose synthesis, peripheral glucose absorption, insulin sensitivity, and metabolic rate. This research shows that thyroid dysfunction, whether overt or subclinical, affects glucose management in diabetics. Mechanistic studies show that thyroid hormone levels directly affect metabolic pathways like AMPK activation, PI3K/Akt signaling, mitochondrial function, and GLUT4-mediated glucose transport, and epidemiological data show that diabetics have a higher prevalence of thyroid abnormalities. Even with traditional antidiabetic therapy, thyroid dysfunction causes insulin resistance, glucose fluctuation, and poor metabolic control. Subclinical thyroid dysfunction, formerly considered physiologically inconsequential, is now linked to higher HbA1c, reduced glucose tolerance, and an increased risk of diabetes development. Clinical interventional investigations show that restoring euthyroidism improves insulin sensitivity, fasting glucose, and lipid profiles, proving the therapeutic benefit of combined endocrine therapy. Despite these developments, variable diagnostic criteria, poor longitudinal data, and insufficient demographic variety hamper generalizability and the formulation of uniform therapeutic recommendations. Therefore, large-scale, multicenter, and long-term studies should be prioritized to determine causation, optimum screening thresholds, and the sustained metabolic advantages of early thyroid management. This

research shows that frequent thyroid evaluation in diabetes management may improve metabolic stability, complications, and long-term patient outcomes at a reasonable cost.

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Zina J. Ghaib: Conceptualization, Data curation, Writing – original draft, Design study, Project administration, Critical revision of the manuscript, Supervision and Corresponding author.
Rasha M. Kamil: Investigation, Resources, Validation, Writing – review & editing.
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Omar Khalid Suhail: Investigation, Data interpretation, Validation, Writing – review & editing.

Ethical Responsibilities of Authors
The authors confirm that this manuscript is original, has not been published or submitted elsewhere, and complies with Springer's Publishing Ethics Guidelines. All data and sources are accurately reported and properly cited. No fabrication, falsification, or inappropriate manipulation has occurred. All authors contributed to the work, approved the final version, and declare no conflicts of interest.

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