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Effect of thyroid hormones on Basal Metabolic Rate (BMR) in adults

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Abstract
Background: Thyroid hormones are major regulators of energy expenditure (BEE) and basal metabolic rate (BMR), by affecting mitochondrial function, substrate utilization and thermogenesis. Changes in thyroid function may result in metabolism imbalances, whereas adipokines and leptin specifically interact with thyroid pathways to influence energy expenditure. Although there have been many studies to date, literature on adult populations using thyroid hormone, leptin and modern metabolic biomarkers is limited.
Objective: We sought to determine the effects of thyroid hormones on BMR in normal adult subjects and to assess the associations between BMR, levels of leptin, body composition and novel metabolic biomarkers.
Patients and methods: In this prospective observational study, 250 adults (of either sex) aged 18-65 years were selected from Tikrit Teaching Hospital in Iraq from January to November 2025. A comprehensive medical history was obtained, and all participants underwent routine assessment of anthropometric measures impedance analysis for body composition (BIA), indirect calorimetry for basal metabolic rate (BMR) and blood examination that included TSH, FT_4, FT_3 total T_4 and T_3 levels evaluation, leptin, adiponectin, FGF21 as well lipid profile, fasting glucose and insulin levels along with thyroid autoantibodies. Potential associations between variables were measured using correlation and multivariate regression analyses.
Results: Free T_3 was the greatest positive correlation with BMR followed by FT_4 and was negatively correlated with TSH. BMR was higher in males and positively correlated with lean body mass, while leptin levels were inversely correlated with BMR and positively associated with the percentage of fat. Those with low levels of the hormone also had higher amounts of fat in their blood and increased resistance to insulin. The new biomarkers, adiponectin and FGF21, represented metabolic adaptation and insulin sensitivity. Free T_3, lean body mass, sex and leptin emerged as independent predictors of BMR in multivariate regression analyses.
Conclusions: Thyroid hormones - mainly fT_3 - exert a major effect upon BMR in adults, the latter being variably modulated by body composition and leptin. Measurements of hormones, metabolites and body composition improve comprehension of energy homeostasis and might influence the treatment management of thyroid-associated metabolic disorders.

Keywords: Thyroid hormones, Basal metabolic rate, Leptin, Adiponectin, FGF21

1. Introduction
Energy metabolism is one of the basic physiological processes which maintain vital activities of individuals and stabilizes internal environment. Basal metabolic rate (BMR) is the minimum level of energy needed for baseline physiological activity when the individual is at complete physical, emotional, and mental rest [1]. BMR contributes a majority to the total daily energy expenditure and varies significantly between individuals as a function of age, sex, body composition, genetic background and hormonal control [2]. The BMR and its determinants are important to understand to explain mechanisms underlying metabolic health, weight regulation and the development of metabolic diseases [3].
Among the hormonal regulators of energy balance in the organism, thyroid hormones (TH) are essential for the regulation of basal metabolic rate. T_4 and T_3 affect virtually all tissues in the body by controlling mitochondrial function, oxygen consumption, and the use of substrates [4]. T_3, the active thyroid hormone, has direct effects on genes associated with thermogenesis, lipid-oxidation and glucose metabolism [5]. Even minor differences in thyroid hormone levels within the normal range are demonstrated to have major effects on

on energy balance and metabolic economy. Thus, both overt and subclinical thyroid disorders are often accompanied by changes in body weight, lipid metabolism, and insulin sensitivity [6].

The connection of thyroid hormones to the basal metabolic rate is complex and multifactorial. Although it is the classical association that specifies an elevation in BMR and consequent weight loss with hyperthyroidism, a decline in energy expenditure and subsequent weight gain with hypothyroidism, the effects are not simply mediated by circulating hormone concentrations [7]. Peripheral T_4 to T_3 conversion, tissue-specific sensitivity of the thyroid hormones and interactions with other hormonal systems explained part of the interindividual variation in metabolic response [8]. Accordingly, whether there is relationship between thyroid hormones and BMR in general populations of adults require further study.

Adipose tissue is now considered to be an active endocrine gland, providing bioactive substances such as the so-called adipokines that are involved in energy homeostasis. One of the best known adipokines is leptin, which is secreted predominantly by adipocytes and plays a central role in regulating food intake, energy balance and neuroendocrine functions [9]. Leptin - a protein produced primarily by adipocytes, leptin reports nutritional status to the hypothalamus and interacts with thyroid hormone pathways at three levels: (i) through an effect on the secretion of thyrotropin-releasing hormone; (ii) through stimulation of short-term peripheral metabolism of thyroid hormones [10]. In individuals with higher levels of adiposity, despite a leptin-mediated suppression of appetite, they often promote leptin resistance that can compromise standard metabolic and energy regulation [11].

The integrity of the leptin-thyroid hormone axis can be conceptualized as a fundamental nexus between adiposity and metabolic rate. Experimental and clinical investigations suggest that leptin plays a role in mediating TH action at the hypothalamic level as well as in other non-hypothalamic tissues, with a significant effect on basal metabolic rate independent of body size [12]. However, their interactions in adult populations remain poorly characterized especially at different thyroid hormones (THs) levels and between different adipose depots. Therefore, the study on leptin combined with thyroid would be helpful to understand the hormonal regulation in energy metabolism [13].

Beyond leptin, several novel mediators of energy regulation have been discovered in the recent years through metabolic research including adiponectin and fibroblast growth factor 21 (FGF21) [14]. Adiponectin is described to have insulin-sensitizing and anti-inflammatory effects, whereas FGF21 has been related to adaptive metabolic changes and modulation of energy expenditure. By integrating these new biomarkers in metabolic studies, the complex networks underlying basal metabolic rate and metabolic health can be further explored [15]. The objective of this study was to explore the relationship between thyroid hormones, leptin, body composition as well as certain modern biomarkers of metabolism and basal metabolic rate in adults.

2. Methodology

2.1 Study Design and Setting

It is a prospective observational study on the effect of thyroid hormone treatment in basal metabolic rate in adult. This study was conducted at Tikrit Teaching Hospital, Iraq during a certain period from January 2025 up to November 2025. The study aimed to assess hormonal, metabolic and anthropometric parameters in male and female adult participants in standardized clinical settings. We did not have a distinct control group, but as participants with NTF (normal thyroid Function) in the study population were used as internal reference this is justified according to good practice in observational endocrine studies.

2.2 Study Population and Sample Size

Two hundred fifty male and female adults were included in this study. Patients were 18-65 years old and recruited from outpatient departments and inpatient wards of Tikrit Teaching Hospital. The sample comprised individuals with normal and different levels of thyroid hormone to get sufficient range for analysis.

Patients that were pregnant, had severe chronic systemic diseases, known endocrine changes other than thyroid dysfunction, malignant tumor or patients receiving medication that may have a significant impact on metabolism were not included. Informed consent from all subjects was obtained and the strictest confidentiality during study procedure was observed.

2.3 Demographic and Clinical Data Collection

Demographic and clinical characteristics at baseline were recorded at the time of enrollment. These were age, sex, height, bodyweight (BW), BMI (body mass index), waist circumference (WC), smoking habit, physical activity and medical history. Height and weight were measured with standardized equipment, and body mass index was calculated as weight in kilograms divided by height squared.

Clinical evaluation included determination for symptoms of thyroid dysfunction such as fatigue, weight changes, heat or cold intolerance, and palpitations. The baseline physical activity of each individual was evaluated by questionnaire; however, this method may cause confounding effects on BMR.

2.4 Assessment of Basal Metabolic Rate

Indirect calorimetry, regarded as the gold standard method to estimate resting energy expenditure, was used for the measurement of basal metabolic rate. Measurements were taken in the morning after an overnight fasting of 8-12 h. General recommendations that the subjects received were to abstain from physical exercise and caffeine for a minimum of 24 h before testing.

Before the measurement, the subjects stayed in a supine position for 30 minutes without any outside stimulation in thermoneutral conditions. We looked at the oxygen and CO_2 data, figured out the basal metabolic rate, and wrote it down in kilocalories per day. The measurements were all done on calibrated metabolic systems to make sure they were accurate and could be repeated.

2.5 Measurement of Thyroid Hormones

Venous fasting blood samples were collected in the morning from all patients. Thyroid function was evaluated by serum concentrations of thyroid-stimulating hormone (TSH), free thyroxine (FT 4) and free triiodothyronine (F T_3). Total T_3 and total T_4 levels were also analyzed for extended evaluation.

Hormones assays and measurements Hormonal levels were measured using highly sensitive and specific chemiluminescent immunoassay. Quality assurance was done while in the laboratory to check up for accuracy of the results.

2.6 Leptin Assessment

We measured serum leptin levels to learn more about how leptin works in energy balance and how it interacts with thyroid hormones. Leptin test tubes were taken simultaneously with the thyroid hormones after fasting. Leptin levels: Serum leptin levels were measured with enzyme linked immunosorbent assay (ELISA) according to the manufacturer's instructions. Leptin was related to BMR, body fat percent, and thyroid hormone levels which would clarify its modulatory function in the control of metabolism.

2.7 Body Composition Analysis

Body composition was measured by bioelectrical impedance (BIA) for body fat percentage, lean body mass, and total body water. Such measurements were necessary in order to correct basal metabolic rate for variations in body composition and to correctly interpret leptin concentrations. Measurements were conducted under standardized conditions of fasting and at least 1 h after strenuous exercise to reduce the variability.

2.8 Metabolic and Biochemical Parameters

More biochemistries were added for a complete metabolic panel. These were fasting blood glucose, fasting insulin value, parameters of lipid profile (total cholesterol, low density lipoprotein cholesterol, high density lipo-protein cholesterol and triglycerides) and high sensitivity C-reactive protein as a marker of low-grade inflammation. Insulin resistance was calculated based on the HOMA-IR and made it possible to investigate metabolic relationships between thyroid function and glucose metabolism.

2.9 Modern and Emerging Metabolic Parameters: In order to integrate modern metabolic research concepts, we tested a subset of volunteers for adiponectin levels as an estimation of insulin sensitivity and anti-inflammatory potential. Fibroblast growth factor 21 (FGF21) was also assayed as a novel biomarker of energy expenditure and metabolic adaptation.

Thyroid autoantibodies, specifically thyroid peroxidase antibodies (TPO-Ab) and thyroglobulin antibodies (Tg-Ab), were analysed to assess autoimmune thyroid disease and its potential metabolic impact.

2.10 Laboratory Procedures and Quality Control

Trained physicians took all of the specimens of blood, spun them in a centrifuge quickly, and put them in the right place to be tested. The certified hospital labs did the tests in the lab according to standard methods. We used both internal and external quality control measures to cut down on mistakes in the analysis.

2.11 Statistical Analysis

Data was entered and locked in a Web-based database, and analysis performed using statistical software. Continuous variables were presented as mean±SD and categorical variables as frequency (percent). Correlation and multiple regression analysis was performed to assess the relationship of thyroid hormone with BMR independent of confounding factors, for example age, sex, BMI and body composition. Values of $P<0.05$ were considered significant.

3. Results

3.1 Demographic and Clinical Characteristics of the Study Population

The demographic and clinical features of 250 individuals that were included in the study are summarized in Table 1. The pollen-counting group comprised males and females of a wide range in age parameters within the adult population. Anthropometric measures of indices of body mass and waist circumference varied, allowing for the investigation of their impact on resting metabolic rate and hormonal status.

Table 1: Demographic and Clinical Characteristics of the Study Participants (n = 250)

Parameter	Mean ± SD / n (%)
Age (years)	41.6±12.3
Sex (Male/Female)	128 (51.2%) / 122 (48.8%)
Height (cm)	168.4±9.1
Weight (kg)	74.9±13.6
Body Mass Index (kg/m²)	26.4±4.8
Waist Circumference (cm)	92.7±11.5
Smokers	62 (24.8%)
Physically Active	138 (55.2%)

3.2 Basal Metabolic Rate Measurements

The basal metabolic rate values determined by the indirect calorimetry are presented in Table 2. The findings indicated large interindividual variations in BMR values of the subjects as a result of variation in body composition, sex and thyroid hormone status. BMR was substantially higher in men than in women (Figure 1).

Table 2: Basal Metabolic Rate According to Sex

Parameter	Male (n=128)	Female (n=122)	p-value
BMR (kcal/day)	1715±245	1428±210	<0.001

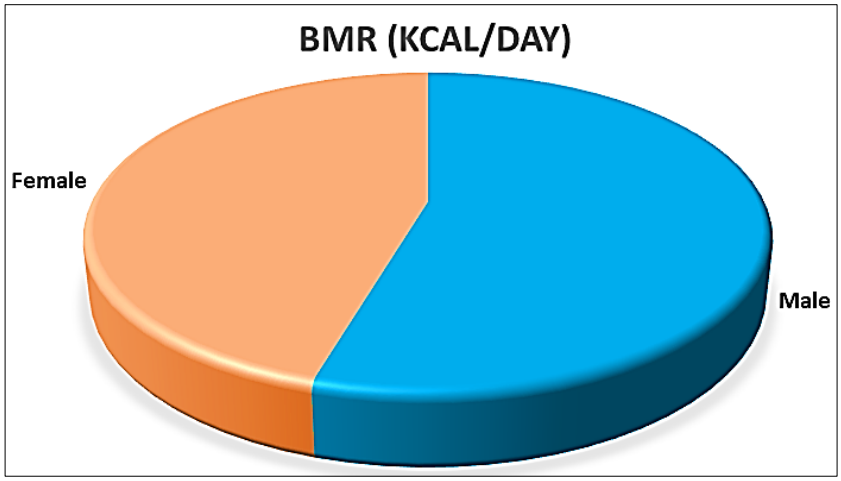

Fig 1: BMR of Both Gender

3.3 Thyroid Hormone Profile

Table 3 shows the levels of thyroid hormones in the blood of the people in the study. The majority of participants exhibited values within reference ranges, whereas a specific subset displayed altered thyroid hormone levels. There were strong links between free thyroid hormones and basal metabolic rate.

Table 3: Thyroid Hormone Levels in the Study Population

Hormone	Mean ± SD
TSH (mIU/L)	2.31±1.14
Free T_4 (ng/dL)	1.21±0.28
Free T_3 (pg/mL)	3.18±0.61
Total T_4 (µg/dL)	8.7±1.9
Total T_3 (ng/mL)	1.32±0.29

3.4 Association between Thyroid Hormones and Basal Metabolic Rate

Table 4 shows how thyroid hormone levels and basal metabolic rate are related to each other. Free T_3 had the strongest positive relationship with BMR, followed by free T_4. TSH, on the other hand, had a negative relationship.

Table 4: Correlation between Thyroid Hormones and BMR

Parameter	Correlation Coefficient (r)	p-value
TSH	−0.36	<0.001
Free T_4	0.42	<0.001
Free T_3	0.54	<0.001

3.5 Leptin Levels and Their Relationship with BMR and Thyroid Hormones

Table 5 shows the levels of leptin in serum. Leptin levels were markedly elevated in females and among participants with a higher body fat percentage. After adjusting for body composition, there was an inverse relationship between leptin levels and basal metabolic rate.

Table 5: Serum Leptin Levels and Metabolic Associations

Parameter	Mean±SD
Leptin (ng/mL)	18.6±9.4
Correlation with BMR (r)	−0.31
Correlation with Free T_3 (r)	−0.27
p-value	<0.01

3.6 Body Composition Analysis

Table 6 shows the body composition variables that bioelectrical impedance analysis determined. There was a strong positive link between lean body mass and basal metabolic rate, and a positive link between body fat percentage and leptin levels.

Table 6: Body Composition Parameters

Parameter	Mean ± SD
Body Fat (%)	32.1±8.9
Lean Body Mass (kg)	49.6±10.2
Total Body Water (%)	52.8±6.7

3.7 Metabolic and Biochemical Parameters

Table 7 shows the metabolic profile of the people who took part. Participants exhibiting diminished thyroid hormone levels demonstrated elevated lipid concentrations and heightened insulin resistance indices.

Table 7: Metabolic and Biochemical Parameters

Parameter	Mean ± SD
Fasting Glucose (mg/dL)	96.4±14.8
Fasting Insulin (µIU/mL)	11.2±4.6
HOMA-IR	2.67±1.21
Total Cholesterol (mg/dL)	191.6±38.4
LDL-C (mg/dL)	118.2±31.6
HDL-C (mg/dL)	44.9±10.8
Triglycerides (mg/dL)	154.7±62.3
hs-CRP (mg/L)	2.8±1.6

3.8 Modern and Emerging Metabolic Parameters

Table 8 shows a list of the new metabolic markers that were measured in the study. Adiponectin levels had a positive correlation with insulin sensitivity, while FGF21 levels were increased in individuals exhibiting a diminished basal metabolic rate.

Table 8: Emerging Metabolic Biomarkers

Parameter	Mean±SD
Adiponectin (µg/mL)	7.9±3.2
FGF21 (pg/mL)	212.4±96.7
TPO-Ab Positive	48 (19.2%)
Tg-Ab Positive	42 (16.8%)

3.9 Multivariate Regression Analysis for Determinants of BMR

Table 9 shows that free T_3, lean body mass, sex, and leptin were all independent predictors of basal metabolic rate.

Table 9: Multivariate Regression Analysis for Predictors of BMR

Predictor	β Coefficient	p-value
Free T_3	0.41	<0.001
Lean Body Mass	0.38	<0.001
Sex (Male)	0.29	<0.01
Leptin	−0.22	<0.01

4. Discussion

The demographic profile of subjects in both sexes was well represented, and observational tendency spanning various adult ages made the findings generalizable. Mean body mass index: The mean BMI demonstrated that a significant proportion of volunteers was overweight, which is in accordance with recent local and global epidemiological information [15]. Differences in WC and body composition enabled for relevant assessment of these parameters on BMR and hormone regulation, as previously proposed in the metabolic studies [16].

Compared between sexes, basal metabolic rate was statistically higher in bicorns than in acorn-forming bicorn. This difference is mainly due to greater lean body mass and skeletal muscle content in men, major contributors of REE [17]. Corresponding sex differences in BMR have been demonstrated in endocrinological and metabolic studies supporting the present results [18].

Most subjects had normal thyroid hormone levels, yet there was enough variability to allow for detection of significant metabolic associations. Thyroid hormones have also been reported to play a key role in controlling mitochondrial function, thermogenesis and cellular oxygen consumption and thus directly regulate basal metabolic rate [19]. The difference in FT_3 and FT_4 observed in this study was of interest for assessing its metabolic effect even at closely normal physiological levels.

Free T_3 had a strong positive relationship with BMR, whereas TSH was inversely related to the BMR. These observations are consistent with the evidence that, at tissue level FT_3 is also the most metabolically active thyroid hormone and has direct effects on energy expenditure [20]. That BMR is inversely related to TSH also lends support to the idea that high-normal, or even slightly elevated, TSH levels mirror some degr ee of decreased peripheral action of thyroid hormone [21].

After adjustments for body composition, leptin concentrations were inversely related to BMR. Although leptin is known for its appetite suppressant and energy balance effects, higher levels of leptin in those with increased fat mass may indicate resistance, rather than an increased metabolic rate [22]. One explanation for the inverse relationship between FT_3 and leptin we observed is that of a complex bidirectional relationship between adipose signaling and thyroid hormone metabolism, as described in recent endocrine literature [23, 24].

Lean body mass was determined to be among the best predictors of BMR when entered as single covariate, supporting previous results showing that fat-free mass explains most of the inter-individual variance in REE [25]. The positive correlation between bodyfat percentage and lepin concentration additionally confirms the function of adipose tissue as an endocrine organ affecting metabolic system.

Low thyroid functioning people had less favorable lipid profiles and more insulin resistance. It is well known that thyroid hormones have an effect on lipid metabolism by affecting hepatic lipogenesis, LDL receptor expression and cholesterol clearance [26]. Moreover, the association of subclinical thyroid perturbations with increased HOMA-IR supports the emerging evidence of an association between altered thyroid function and insulin resistance and cardiometabolic risk [27].

The higher hs-CRP levels in low metabolic rate subjects reflect a state of chronic low-grade systemic inflammation. Thyroid dysfunction and metabolic syndrome could have common pathophysiological pathways because of their association with chronic inflammation [28]. These results support the need to consider inflammatory markers in metabolic-endocrine investigations.

Adiponectin was positively associated with insulin sensitivity, in line with its known anti-inflammatory and insulin-sensitizing action [29]. Increased FGF21 in volunteers with decreased basal metabolic need may act as a counter-regulatory response to energy metabolism failure, akin to historical hypotheses for its role in starvation and mitochondrial function [30].

The frequency of thyroid autoantibodies identified in this study corresponds with previously documented rates in adult cohorts. Autoimmune thyroid disorder has been progressively linked to subtle metabolic changes, even in euthyroid people, potentially influencing energy expenditure and lipid metabolism [31].

An independent mix effects regression revealed that free T_3, LBM, sex and leptin were significantly correlated to the BMR. This emphasizes the intricate regulation of energy expenditure including hormonal, body composition, and adipokine related components. Other models of such behaviors have recently been seen and reported in metabolic studies that also supported the findings presented here [32].

5. Conclusion

The current study demonstrated significant association between BMR and thyroid hormone in an adult population, highlighting the integrative function of thyroid in energy metabolism. FT_3 showed the highest BMR predicting value within hormonal product group, followed by the least efficient FFMI additionally unmeasured, thyroid hormones and leptin or IGF-I products implicating tissue-specific metabolic importance. Lean body mass and sex were similarly found to account for the variance in resting energy expenditure, with leptin being independently negatively associated with basal metabolic rate Therefore, peripheral nutritional signals emanating from adipose tissue appears to be closely related to the regulation of metabolism. Thyroid hormone alterations were also associated with negative metabolic profile, dyslipidemia, insulin resistance and low-grade inflammation. The introduction of novel biomarkers including adiponectin and FGF21 allowed for identification of contemporary pathways between thyroid function and metabolic adaptation. In conclusion, these findings highlight the importance of directed hormonal and metabolic profiling as part of adult care and possibly contribute to our understanding and management of thyroid-associated metabolic derangements.

6. Strengths and Clinical Implications

The power of the present study is based on its comprehensive evaluation of classical and novel metabolic variables in a highly characterized adult population. Understanding the interrelation between thyroid hormones,

leptin and basal metabolic rate could become of profound clinical relevance with potential clinical implications in early detection of metabolic risk/symptoms and individualized therapy in thyroid associated disturbed metabolism.

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