

Assessment of the Prevalence of Insulin Resistance in Tarhuna City and Its Relationship with Selected Biochemical Indicators such as Lipids, Fasting Blood Glucose, and Glycated Hemoglobin (HbA1c)

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تقييم مدى انتشار مقاومة الإنسولين في مدينة ترهونة وعلاقتها بمؤشرات بيوكيميائية مختارة مثل الدهون، سكر الدم الصائم، والهيموغلوبين السكري

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Abstract:

Insulin resistance (IR) is a key metabolic abnormality that precedes the development of type 2 diabetes mellitus and is strongly associated with obesity, dyslipidemia, and cardiovascular disease. This study aimed to determine the prevalence of insulin resistance among adults in Tarhuna City, Libya, and to examine its association with selected biochemical indicators, including lipid profile, fasting blood glucose (FBS), and glycated hemoglobin (HbA1c). A cross-sectional descriptive study was conducted on 58 adults aged ≥ 18 years. Data were collected using a structured questionnaire covering demographic characteristics, lifestyle factors, and anthropometric measurements. Fasting blood samples were obtained to measure FBS, HbA1c, lipid profile, and fasting insulin. Insulin resistance was assessed using the Homeostatic Model Assessment (HOMA-IR), with a cut-off value >2.5 . Statistical analysis was performed using SPSS version 25, and a p -value <0.05 was considered statistically significant. The findings revealed a high prevalence of insulin resistance (69%) among participants. IR was significantly associated with increased body mass index (BMI), elevated FBS, higher HbA1c levels, and dyslipidemia, particularly increased total cholesterol, LDL-C, and triglycerides. Physical inactivity and obesity were also strongly associated with insulin resistance, whereas HDL-C showed no significant association. In conclusion, insulin resistance is highly prevalent among adults in Tarhuna City and is strongly linked to obesity, impaired glycemic control, and abnormal lipid metabolism. These findings highlight the urgent need for early screening and lifestyle-based interventions to reduce the risk of diabetes and cardiovascular diseases in the Libyan population.

Keywords: Insulin resistance, HOMA-IR, Obesity, Dyslipidemia, HbA1c, Fasting blood glucose, Libya.

الملخص:

تُعد مقاومة الإنسولين من الاضطرابات الأيضية الأساسية التي تسبق الإصابة بداء السكري من النوع الثاني، وترتبط ارتباطاً وثيقاً بالسمنة واضطرابات دهون الدم وأمراض القلب والأوعية الدموية. هدفت هذه الدراسة إلى تحديد مدى انتشار مقاومة الإنسولين بين البالغين في مدينة ترهونة، ليبيا، ودراسة علاقتها ببعض المؤشرات البيوكيميائية، بما في ذلك دهون الدم، وسكر الدم الصائم، والهيموغلوبين السكري (HbA1c). أجريت دراسة وصفية مقطعية على عينة مكونة من 58 مشاركاً من البالغين (18 سنة). جُمعت البيانات باستخدام استبيان منظم شمل الخصائص الديموغرافية ونمط الحياة والقياسات الجسمية. كما تم جمع عينات دم صائم لقياس سكر الدم الصائم، وHbA1c، ودهون الدم، والإنسولين الصائم. تم تقييم مقاومة الإنسولين باستخدام مؤشر HOMA-IR، مع اعتماد قيمة >2.5 كمؤشر على وجود مقاومة الإنسولين. تم تحليل البيانات باستخدام برنامج SPSS الإصدار 25، مع اعتبار مستوى الدلالة الإحصائية $(p < 0.05)$. أظهرت النتائج ارتفاع معدل انتشار مقاومة الإنسولين بنسبة 69% بين المشاركين. كما وُجدت علاقة ذات دلالة إحصائية بين مقاومة الإنسولين وكل من ارتفاع مؤشر كتلة الجسم، وزيادة سكر الدم الصائم، وارتفاع HbA1c، واضطرابات دهون الدم، خاصة الكوليسترول الكلي، والكوليسترول منخفض الكثافة، والدهون الثلاثية. كما ارتبطت قلة النشاط البدني والسمنة بشكل قوي بمقاومة الإنسولين، في حين لم تُظهر مستويات HDL-C علاقة ذات دلالة إحصائية. تخلصت الدراسة إلى أن مقاومة الإنسولين منتشرة بشكل مرتفع بين البالغين في مدينة ترهونة، وترتبط ارتباطاً وثيقاً بالسمنة واضطراب التحكم في سكر الدم ودهون الدم. وتؤكد هذه النتائج على ضرورة تعزيز برامج الفحص المبكر والتدخلات الوقائية القائمة على تعديل نمط الحياة للحد من مخاطر السكري وأمراض القلب في المجتمع الليبي.

الكلمات المفتاحية: مقاومة الإنسولين، HOMA-IR، السمنة، اضطرابات دهون الدم، HbA1c، سكر الدم الصائم، ليبيا.

Introduction:

Insulin resistance (IR) is recognized as a fundamental metabolic abnormality that plays a central role in the pathogenesis of various chronic diseases, including type 2 diabetes mellitus (T2DM), dyslipidemia, and cardiovascular disorders. It is defined as a condition in which peripheral tissues—such as skeletal muscle, adipose tissue, and the liver—exhibit a diminished biological response to circulating insulin, leading to impaired glucose uptake, increased hepatic glucose production, and compensatory hyperinsulinemia. Over time, the failure of this compensatory mechanism contributes to persistent hyperglycemia and the eventual development of overt diabetes (DeFronzo & Tripathy, 2009; Reaven, 2011; Kahn *et al.*, 2020).

At the cellular level, insulin resistance arises from disruptions in the intracellular signaling cascade responsible for mediating insulin action. Under normal physiological conditions, insulin binding activates a sequence of phosphorylation events involving insulin receptor substrate proteins (IRS-1), phosphatidylinositol 3-kinase (PI3K), and protein kinase B (Akt), ultimately facilitating glucose transport via GLUT4. However, in insulin-resistant states, this signaling pathway becomes impaired due to factors such as serine phosphorylation of IRS-1, lipid accumulation, oxidative stress, and chronic low-grade inflammation. Elevated levels of free fatty acids (FFAs) and pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF- α) and interleukin-6 (IL-6), further exacerbate this dysfunction and contribute to metabolic imbalance (Samuel & Shulman, 2016; Hotamisligil, 2017).

The biochemical manifestations of insulin resistance are reflected in disturbances of both lipid and glucose metabolism. A hallmark feature of insulin resistance is atherogenic dyslipidemia, characterized by elevated triglycerides, increased low-density lipoprotein cholesterol (LDL-C), and reduced high-density lipoprotein cholesterol (HDL-C). These alterations result primarily from increased hepatic production of very-low-density lipoprotein (VLDL) driven by enhanced free fatty acid flux from adipose tissue. Such lipid abnormalities not only indicate impaired metabolic regulation but also contribute significantly to cardiovascular risk (Comprehensive Journal of Science, 2025; Grundy, 2016).

In addition, fasting blood glucose (FBG) and glycated hemoglobin (HbA1c) are widely used as key indicators of glycemic control and insulin sensitivity. While FBG reflects short-term glucose regulation, HbA1c provides a measure of average blood glucose levels over an extended period of approximately 8–12 weeks (Dakeal *et al.*, 2025). Furthermore, the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), calculated using fasting glucose and insulin concentrations, serves as a reliable and practical index for estimating insulin resistance in both clinical and epidemiological studies (Matthews *et al.*, 1985). Notably, even modest elevations in HbA1c within the pre-diabetic range have been associated with increased risk of insulin resistance and related metabolic complications (Nowotny *et al.*, 2018).

Globally, the prevalence of insulin resistance has increased substantially over recent decades, largely driven by rising rates of obesity, sedentary lifestyle, and dietary changes. This trend is particularly evident in developing and middle-income countries, including those in the Middle East and

North Africa region. Libya has experienced significant lifestyle transitions characterized by increased consumption of processed foods, reduced physical activity, and heightened psychosocial stress, all of which contribute to the growing burden of metabolic disorders. Current estimates indicate that approximately 14–18% of Libyan adults are affected by T2DM, with an even greater proportion exhibiting obesity or pre-diabetic conditions (Elhadi *et al.*, 2021).

Despite the growing burden of metabolic diseases, research on insulin resistance in Libya remains limited, particularly in semi-urban and rural areas. Most available studies have focused on major cities such as Tripoli and Benghazi, leaving smaller communities underrepresented. Tarhuna City, located in northwestern Libya, represents a unique socio-demographic environment characterized by a combination of urban and rural lifestyles, diverse dietary habits, and varying access to healthcare services. These characteristics may influence the prevalence and determinants of insulin resistance differently from those observed in larger urban centers.

Therefore, there is a clear need for localized epidemiological studies to assess insulin resistance and its associated risk factors within this population. The present study aims to determine the prevalence of insulin resistance among adults in Tarhuna City and to investigate its relationship with selected biochemical indicators, including lipid profile, fasting blood glucose, and glycated hemoglobin (HbA1c). The findings of this study are expected to contribute valuable baseline data to the existing literature and to support the development of effective strategies for early detection, prevention, and management of metabolic disorders in the Libyan context.

Research Problem:

Insulin resistance (IR) is a major metabolic disorder that plays a critical role in the development of type 2 diabetes mellitus and is strongly associated with dyslipidemia and impaired glucose metabolism. In recent years, Libya has experienced notable lifestyle changes, including increased prevalence of obesity, physical inactivity, and unhealthy dietary patterns. These factors are likely to contribute to a rising burden of insulin resistance, particularly in semi-urban areas such as Tarhuna City.

Despite the clinical and public health significance of insulin resistance, there is a lack of localized epidemiological data assessing its prevalence and biochemical determinants within this population. Most existing studies have focused on broader metabolic conditions such as diabetes and obesity, while limited attention has been given specifically to insulin resistance and its association with key biochemical indicators, including lipid profile, fasting blood glucose, and glycated hemoglobin (HbA1c). Accordingly, this study seeks to address this gap by assessing the prevalence of insulin resistance among adults in Tarhuna City and examining its relationship with selected biochemical markers. The findings are expected to provide a scientific basis for early detection and preventive strategies targeting metabolic disorders in the local community.

Research Objectives:

The present study aims to achieve the following objectives:

1. To determine the prevalence of insulin resistance among adults in Tarhuna City.
2. To assess key biochemical parameters, including lipid profile (total cholesterol, triglycerides, HDL-C, and LDL-C), fasting blood glucose (FBS), and glycated hemoglobin (HbA1c).
3. To evaluate the statistical relationship between insulin resistance and selected biochemical indicators.
4. To examine the influence of demographic and anthropometric factors, including age, gender, and body mass index (BMI), on insulin resistance.
5. To provide evidence-based recommendations for early detection and prevention of insulin resistance and its related metabolic complications.

Research Significance:

1. **Scientific Significance:** This study contributes to filling a significant gap in the existing literature by providing baseline epidemiological data on the prevalence of insulin resistance in Tarhuna City. Furthermore, it enhances scientific understanding of the relationship between insulin resistance and key biochemical markers, thereby supporting future clinical and epidemiological research in the Libyan context.
2. **Practical and Public Health Significance:** The findings of this study may assist healthcare providers and policymakers in developing targeted intervention strategies aimed at reducing the burden of insulin resistance and its associated complications. In addition, the results can support the establishment of local screening programs for early identification of individuals at risk of metabolic disorders.
3. **Social Significance:** This study plays an important role in raising public awareness regarding the impact of lifestyle factors, including diet and physical activity, on metabolic health. It also highlights the importance of regular medical check-ups in preventing insulin resistance and its long-term health consequences.

Theoretical Background:

Concept of Insulin Resistance:

Insulin resistance (IR) is defined as a pathological condition in which target tissues, including skeletal muscle, adipose tissue, and the liver, exhibit a diminished biological response to normal or elevated circulating insulin levels. Under physiological conditions, insulin plays a key role in regulating glucose homeostasis by facilitating glucose uptake in peripheral tissues, suppressing hepatic glucose production, and promoting glycogen synthesis. However, when insulin resistance develops, higher concentrations of insulin are required to achieve these metabolic effects, leading to compensatory hyperinsulinemia. Over time, this compensatory mechanism becomes insufficient, resulting in persistent hyperglycemia and ultimately the development of type 2 diabetes mellitus (T2DM) (DeFronzo & Tripathy, 2009; Reaven, 2011).

Insulin resistance is not merely an isolated biochemical abnormality but rather a complex and multifactorial metabolic disorder influenced by genetic predisposition, dietary habits, obesity, physical inactivity, and chronic inflammation. Its clinical significance extends beyond disturbances in glucose metabolism, as it plays a central role in the pathogenesis of a wide range of metabolic conditions, including atherosclerosis, hypertension, non-alcoholic fatty liver disease (NAFLD), and other components of metabolic syndrome (MS) (Grundy, 2016; Kahn *et al.*, 2020).

Mechanisms Underlying Insulin Resistance:

At the molecular level, insulin resistance primarily arises from disruptions in the insulin signaling cascade. Following insulin binding to its receptor, tyrosine phosphorylation of insulin receptor substrate proteins (IRS-1 and IRS-2) activates downstream signaling pathways involving phosphatidylinositol 3-kinase (PI3K) and protein kinase B (Akt). This signaling cascade ultimately promotes the translocation of glucose transporter-4 (GLUT4) to the plasma membrane, enabling glucose uptake into cells. In insulin-resistant states, this pathway is impaired, often due to serine phosphorylation of IRS-1, oxidative stress, and ectopic lipid accumulation within tissues (Samuel & Shulman, 2016; Petersen & Shulman, 2018).

In addition to signaling abnormalities, mitochondrial dysfunction and endoplasmic reticulum (ER) stress play a significant role in the development of insulin resistance. These processes lead to increased production of reactive oxygen species (ROS) and the release of pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF- α) and interleukin-6 (IL-6), which further disrupt insulin receptor function and exacerbate metabolic dysregulation. Consequently, insulin resistance is sustained through a complex interplay of metabolic and inflammatory pathways (Hotamisligil, 2017; Bloch-Damti & Bashan, 2020).

Relationship between Insulin Resistance and Lipid Metabolism:

Insulin plays a crucial role in maintaining lipid homeostasis by inhibiting lipolysis in adipose tissue and promoting lipid synthesis in the liver. When insulin signaling is impaired, these regulatory mechanisms become disrupted, leading to dyslipidemia, a hallmark feature of insulin resistance. Typically, individuals with insulin resistance exhibit elevated levels of triglycerides (TG), increased low-density lipoprotein cholesterol (LDL-C), and reduced high-density lipoprotein cholesterol (HDL-C), a pattern commonly referred to as atherogenic dyslipidemia. This lipid profile is strongly associated with increased cardiovascular risk (Taskinen & Boren, 2015; Zheng *et al.*, 2021).

The underlying mechanisms include hepatic overproduction of very-low-density lipoprotein (VLDL) particles and increased flux of free fatty acids (FFAs) from adipose tissue to the liver. Additionally, qualitative changes in LDL particles, particularly the predominance of small, dense LDL, further contribute to the progression of atherosclerosis and cardiovascular disease (Adiels *et al.*, 2019).

Relationship between Insulin Resistance, Fasting Blood Glucose, and HbA1c:

The association between insulin resistance and fasting blood glucose (FBG) is well established. In the early stages, increased insulin secretion from pancreatic β -cells compensates for reduced insulin sensitivity, maintaining normal glucose levels. However, as β -cell function progressively declines, fasting glucose levels begin to rise, reflecting impaired hepatic glucose regulation and reduced peripheral glucose uptake. The combined measurement of fasting insulin and glucose enables the calculation of the Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), a widely accepted and validated index for assessing insulin sensitivity in clinical and epidemiological studies (Matthews *et al.*, 1985; Wallace *et al.*, 2004).

Glycated hemoglobin (HbA1c) serves as an important biomarker reflecting long-term glycemic control, representing average plasma glucose levels over the preceding two to three months. Elevated HbA1c levels, even within the pre-diabetic range (5.7–6.4%), have been associated with increased insulin resistance and systemic inflammation in non-diabetic individuals. Therefore, the combined assessment of HbA1c, fasting blood glucose, and lipid parameters provides a comprehensive

biochemical profile for early detection of metabolic dysfunction and identification of individuals at high risk of disease progression (Nowotny *et al.*, 2018; Herman *et al.*, 2020).

Review of Related Literature:

Global Studies on the Prevalence of Insulin Resistance:

Globally, a substantial body of research has investigated the prevalence of insulin resistance (IR) and its associated determinants, revealing considerable variation across populations. In the United States, Ford *et al.* (2013) reported that approximately 35% of adults exhibited insulin resistance based on HOMA-IR criteria, identifying obesity, advancing age, and sedentary lifestyle as primary contributing factors. Similarly, Ahn *et al.* (2019) documented a prevalence of 31.5% among Korean adults, with higher rates observed in women and older age groups.

In European populations, Gastaldelli *et al.* (2018) demonstrated a strong relationship between insulin resistance and central obesity indicators, particularly waist circumference and triglyceride levels. These findings collectively emphasize that, despite geographic differences, insulin resistance consistently correlates with adiposity and metabolic imbalance.

In contrast, studies conducted in Middle Eastern countries indicate relatively higher prevalence rates, reflecting rapid urbanization and lifestyle transitions. For instance, Al-Rawi *et al.* (2020) reported that 43% of adults in the United Arab Emirates had insulin resistance, with a significant proportion being overweight or obese. Comparable prevalence rates, ranging from 35% to 50%, have been reported in Saudi Arabia and Egypt, depending on diagnostic criteria (Al-Daghri *et al.*, 2018; El-Said *et al.*, 2021). These regional findings suggest that socio-economic and lifestyle changes play a crucial role in amplifying the burden of insulin resistance.

African and North African Studies:

In sub-Saharan Africa, the prevalence of insulin resistance exhibits notable heterogeneity, largely influenced by variations in genetic background, diet, and physical activity levels. Motala *et al.* (2011) reported a prevalence of 29% among South African adults, whereas Okafor *et al.* (2015) found a slightly higher prevalence of 34% in Nigerian populations using HOMA-IR thresholds. These variations highlight the complex interplay between environmental and genetic determinants of insulin resistance.

Within North Africa, available studies remain relatively limited but provide important insights. Ben Ali *et al.* (2017) reported that 38% of Tunisian adults exhibited insulin resistance, with significant correlations observed between HOMA-IR, triglyceride levels, and waist circumference. Similarly, El-Said *et al.* (2021) identified a prevalence of 41% among non-diabetic Egyptian adults, emphasizing strong associations with dyslipidemia and elevated fasting glucose.

Despite these findings, research specific to Libya remains scarce. Elhadi *et al.* (2021) highlighted a growing burden of metabolic disorders, including increased rates of obesity and glucose intolerance, but did not directly assess insulin resistance. This lack of targeted data underscores a significant research gap and justifies the need for localized studies, particularly in underrepresented areas such as Tarhuna City.

Studies Linking Insulin Resistance with Biochemical Indicators:

A considerable number of studies have explored the relationship between insulin resistance and biochemical markers, consistently demonstrating strong associations with lipid and glycemic parameters. Taskinen and Boren (2015) established a clear pathophysiological link between hepatic lipid metabolism and insulin resistance, identifying elevated triglycerides and reduced HDL-C as key indicators of impaired insulin sensitivity.

Further supporting this relationship, Zhou *et al.* (2019) reported that higher triglyceride-to-HDL ratios were significantly associated with increased HOMA-IR values, suggesting that this ratio may serve as a practical surrogate marker for insulin resistance in clinical settings.

In terms of glycemic markers, Andreadis *et al.* (2015) demonstrated that even modest increases in fasting blood glucose within the normal range were associated with proportional increases in insulin resistance, indicating that early metabolic changes may precede overt disease. Additionally, studies by Nowotny *et al.* (2018) and Herman *et al.* (2020) found significant correlations between HbA1c levels and insulin resistance, even among non-diabetic individuals. These findings highlight the importance of integrating multiple biochemical indicators for early detection of metabolic dysfunction.

Studies Conducted in Libya and Neighboring Regions:

Empirical studies focusing specifically on insulin resistance in Libya are limited, with most research addressing broader metabolic conditions such as diabetes and obesity. Elhadi *et al.* (2021) reported that approximately 18% of Libyan adults have T2DM, while nearly 45% are overweight or obese, indicating a substantial metabolic risk burden. Similarly, Ben-Khader *et al.* (2020) identified a high prevalence of dyslipidemia and elevated fasting glucose among adults in Benghazi, although insulin resistance was not directly measured using indices such as HOMA-IR.

In neighboring countries, comparable patterns have been observed. Ben Romdhane *et al.* (2018) reported a 36% prevalence of metabolic syndrome among Tunisian adults, with insulin resistance identified as a key underlying factor. In Algeria, Boukhari *et al.* (2021) demonstrated significant correlations between HOMA-IR, triglyceride levels, and waist-to-hip ratio, further supporting the link between adiposity and metabolic dysfunction.

Despite the geographic proximity and shared lifestyle characteristics among North African populations, no published study has specifically examined the prevalence of insulin resistance or its biochemical correlates in Tarhuna City. This absence of localized data highlights a critical gap in the literature and reinforces the importance of the present study in providing baseline epidemiological evidence for this region.

Materials and Methods:

1. **Study Design:** This study employed a cross-sectional descriptive design to determine the prevalence of insulin resistance (IR) among adults in Tarhuna City and to examine its association with selected biochemical indicators, including lipid profile, fasting blood glucose (FBS), and glycated hemoglobin (HbA1c). The cross-sectional approach was selected due to its suitability for assessing the distribution of health-related variables and their interrelationships within a defined population at a single point in time.
2. **Study Setting:** The study was conducted in Tarhuna City, located in northwestern Libya, approximately 80 km southeast of Tripoli. Tarhuna represents a semi-urban setting characterized by a combination of urban and rural lifestyles, diverse dietary patterns, and varying socioeconomic conditions. Data were collected from multiple healthcare centers and community sites to ensure representation of individuals from different demographic and occupational backgrounds.
3. **Study Population:** The target population consisted of adult residents of Tarhuna City aged 18 years and above. Participants were recruited from outpatients attending primary healthcare facilities as well as community volunteers who met the study inclusion criteria.
 - A. **Inclusion Criteria:**
 - Adults aged ≥ 18 years.
 - Permanent residents of Tarhuna City.
 - Individuals who provided informed consent.
 - Participants free from acute illness at the time of data collection.
 - B. **Exclusion Criteria:**
 - Pregnant or lactating women.
 - Individuals diagnosed with type 1 or gestational diabetes.
 - Participants receiving insulin therapy or medications affecting glucose metabolism.
 - Individuals with severe hepatic, renal, or endocrine disorders.
4. **Sample Size and Sampling Technique:** The sample size was determined to provide preliminary prevalence estimates of insulin resistance within the study population. A total of 58 participants were enrolled, taking into consideration feasibility and potential non-response. A systematic random sampling technique was employed, whereby participants were selected from different age and gender categories attending primary healthcare centers and community locations in Tarhuna City. Although the sample size was relatively small, it provides preliminary insights into the prevalence of insulin resistance in the study population.
5. **Data Collection Tool:** Data were collected using a structured questionnaire specifically developed for the purpose of this study. The instrument was prepared in both Arabic and English and comprised five main sections covering demographic characteristics, lifestyle factors, anthropometric measurements, biochemical indicators, and medical history. The questionnaire was reviewed by experts in laboratory medicine and epidemiology to ensure content validity, and data were collected through face-to-face interviews and standardized clinical measurements conducted by trained medical personnel.
6. **Data Collection Procedure:** Data collection was conducted following ethical approval and informed consent from participants. **The process involved three sequential stages:**
 - A. **Interview Stage:** Collection of demographic and lifestyle data using the structured questionnaire.
 - B. **Anthropometric Assessment:** Measurement of weight, height, and waist circumference following standardized protocols.
 - C. **Laboratory Analysis:** Collection of fasting blood samples after a 12-hour overnight fast for biochemical evaluation.
7. **Anthropometric Measurements:** Body weight was measured to the nearest 0.1 kg using a calibrated digital scale, with participants wearing light clothing and no shoes. Height was measured to the nearest 0.1 cm using a stadiometer. Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters (kg/m^2).

8. Biochemical Measurements: Blood samples were collected following a 12-hour fasting period and processed within two hours of collection under standardized laboratory conditions.

A. **Fasting Blood Glucose (FBS):** Measured using the glucose oxidase enzymatic method, with results expressed in mg/dL.

B. **Glycated Hemoglobin (HbA1c):** Determined using high-performance liquid chromatography (HPLC), with results reported as percentages.

C. **Lipid Profile:** Serum total cholesterol, triglycerides, HDL-C, and LDL-C were analyzed using automated enzymatic colorimetric assays. **Cut-off values were defined as follows:**

- Total cholesterol ≥ 200 mg/dL.
- Triglycerides ≥ 150 mg/dL.
- HDL-C < 40 mg/dL (men), < 50 mg/dL (women).
- LDL-C ≥ 130 mg/dL.

D. **Fasting Insulin and HOMA-IR:** Fasting insulin levels were measured using enzyme-linked immunosorbent assay (ELISA). Insulin resistance was estimated using the Homeostatic Model Assessment (HOMA-IR) as follows:

$$HOMA - IR = 405 \text{Fasting Insulin} \left(\frac{\mu U}{mL} \right) \times \text{Fasting Glucose} \left(\frac{mg}{dL} \right)$$

A value greater than 2.5 was considered indicative of insulin resistance.

Data Processing and Statistical Analysis:

Data were checked for completeness and entered into SPSS version 26.0 for analysis. Descriptive statistics (means, standard deviations, frequencies, and percentages) were used to summarize variables.

Inferential statistical tests included independent t-test and one-way ANOVA for comparing continuous variables, chi-square test for categorical associations, and Pearson correlation analysis to assess relationships between HOMA-IR and biochemical parameters. Multiple logistic regression analysis was performed to identify independent predictors of insulin resistance. A *p-value* < 0.05 was considered statistically significant.

Validity and Reliability:

Several measures were implemented to ensure the validity and reliability of the study, including calibration of instruments, standardized laboratory procedures, training of data collectors, pilot testing of the questionnaire, and random re-checking of a subset of samples to verify consistency of results.

Study Limitations:

This study is subject to certain limitations. The cross-sectional design limits the ability to establish causal relationships between insulin resistance and associated factors. Additionally, some variables, particularly lifestyle behaviors, were self-reported and may be subject to recall bias. Furthermore, the relatively small sample size may limit the generalizability of the findings.

Despite these limitations, the study provides valuable baseline data on insulin resistance and its biochemical correlates in Tarhuna City, contributing to the limited body of literature in this context.

Results and Statistical Analysis:

Statistical Analysis:

Data were analyzed using SPSS (version 25). Continuous variables were expressed as mean \pm standard deviation (SD). Comparisons among the three study groups (Normal, Early Insulin Resistance, and Insulin Resistance) were performed using one-way analysis of variance (ANOVA). When significant differences were detected, Tukey's Honestly Significant Difference (HSD) post hoc test was applied to identify pairwise group differences. A *p-value* < 0.05 was considered statistically significant.

Table (1): Age Distribution of the Study Population

Age Category	Frequency (n)	Percent (%)
<30 years	6	10.3
30–39 years	12	20.7
40–49 years	6	10.3
50–59 years	17	29.3
≥ 60 years	17	29.3
Total	58	100.0

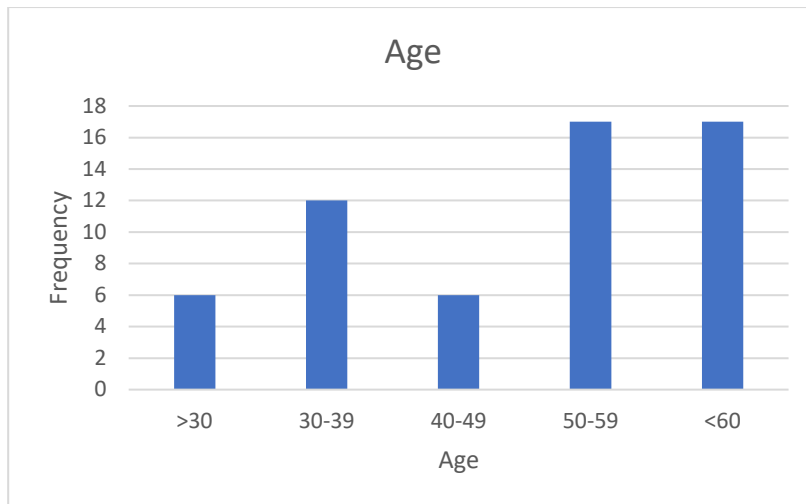


Figure (1): Age Distribution of the Study Population

The age distribution of the study population shows that the largest proportions of participants were in the 50–59 years and ≥ 60 years categories (each $n = 17$; 29.3%), together accounting for more than half of the sample. Younger age groups were less represented, with only $n = 6$; 10.3% participants under 30 years and an equal proportion in the 40–49 years category, while the 30–39 years group comprised $n = 12$; 20.7%.

Table (2): Gender Distribution of the Study Population

Gender	Frequency (n)	Percent (%)
Male	24	41.4
Female	34	58.6
Total	58	100.0

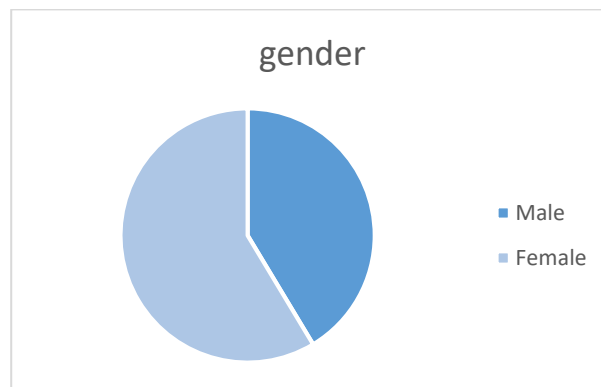


Figure (2): Gender Distribution of the Study Population

The distribution of participants by gender shows that females (58.6%) outnumber males (41.4%) in the sample, with a total of 58 respondents.

Table (3): Regular Exercise Status Among Participants

Exercise Regularly	Frequency (n)	Percent (%)
No	28	48.3
Yes	30	51.7
Total	58	100.0

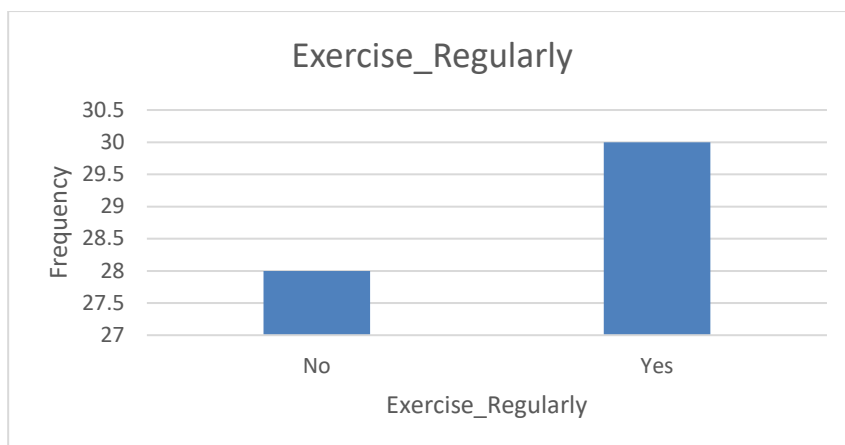


Figure (3): Regular Exercise Status Among Participants

The results indicate that just over half of the participants reported engaging in regular exercise (n = 30; 51.7%), while nearly half did not (n = 28; 48.3%). This balanced distribution suggests that physical activity is relatively common within the study population, yet a substantial proportion remains inactive.

Table (4): Smoking Status of the Study Population

Smoking Status	Frequency (n)	Percent (%)
No	34	58.6
Yes	16	27.6
Former	8	13.8
Total	58	100.0

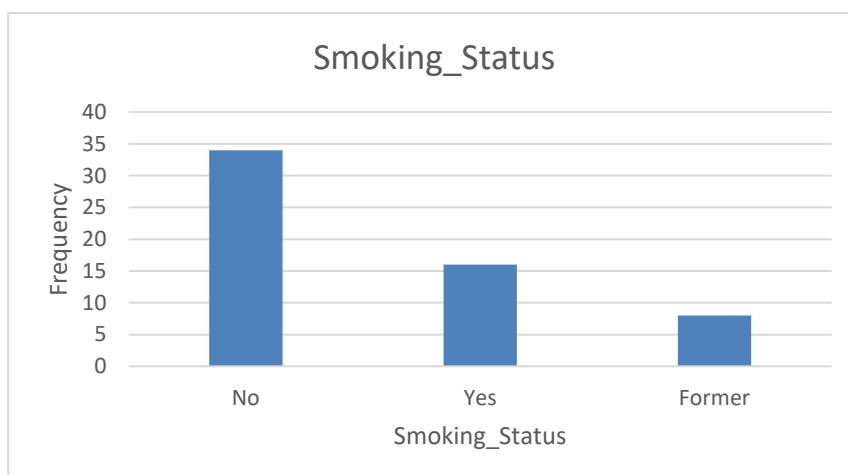


Figure (4): Smoking Status of the Study Population

The findings indicate that more than half of the participants reported no history of smoking (n = 34; 58.6%), while approximately one-quarter were current smokers (n = 16; 27.6%) and a smaller proportion were former smokers (n = 8; 13.8%). This distribution suggests that although non-smoking behavior predominates within the study population, a considerable segment continues to engage in smoking, which represents a significant risk factor for metabolic and cardiovascular complications.

Table (5): Dietary Patterns of the Study Population

Diet Type	Frequency (n)	Percent (%)
High Fat	14	24.1
Balanced	38	65.5
Low Carbohydrate	6	10.3
Total	58	100.0

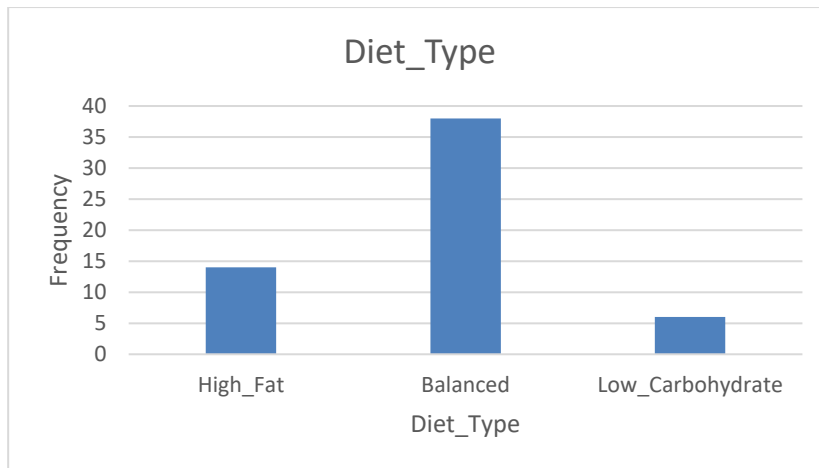


Figure (5): Dietary Patterns of the Study Population

The dietary assessment revealed that the majority of participants reported following a balanced diet (n = 38; 65.5%), while a smaller proportion consumed a high-fat diet (n = 14; 24.1%) and only a minority adhered to a low-carbohydrate diet (n = 6; 10.3%). This distribution suggests that balanced dietary practices are predominant within the study population, although nearly one-quarter of participants reported high fat intake, which contribute to adverse metabolic outcome.

Table (6): Family History of Diabetes and Dyslipidemia

Family History	Frequency (n)	Percent (%)
No	12	20.7
Yes	46	79.3
Total	58	100.0

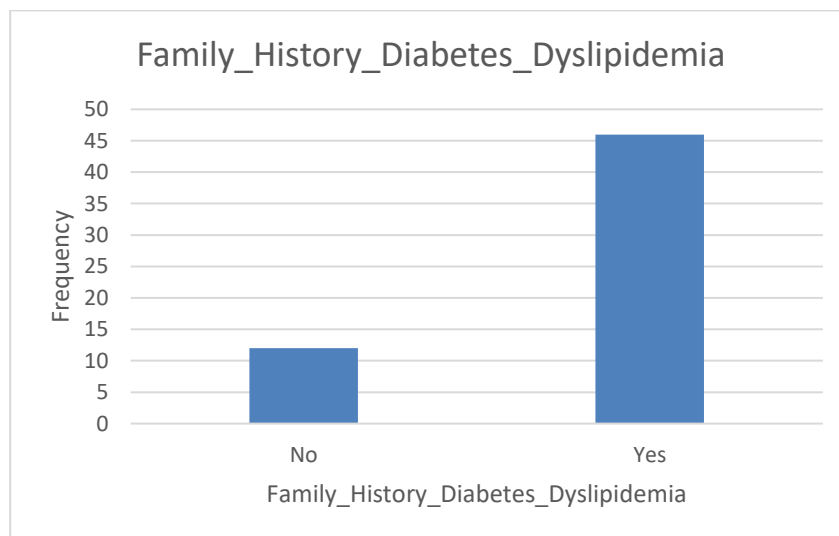


Figure (6): Family History of Diabetes and Dyslipidemia

The findings show that a substantial majority of participants reported a positive family history of diabetes and dyslipidemia (n = 46; 79.3%), while only a minority had no such history (n = 12; 20.7%). This high prevalence of familial risk factors suggests that genetic predisposition and shared lifestyle patterns may play a significant role in the metabolic health of the studied population.

Table (7): Obesity and Overweight Status Among Participants

Obesity/Overweight	Frequency (n)	Percent (%)
No	20	34.5
Yes	38	65.5
Total	58	100.0

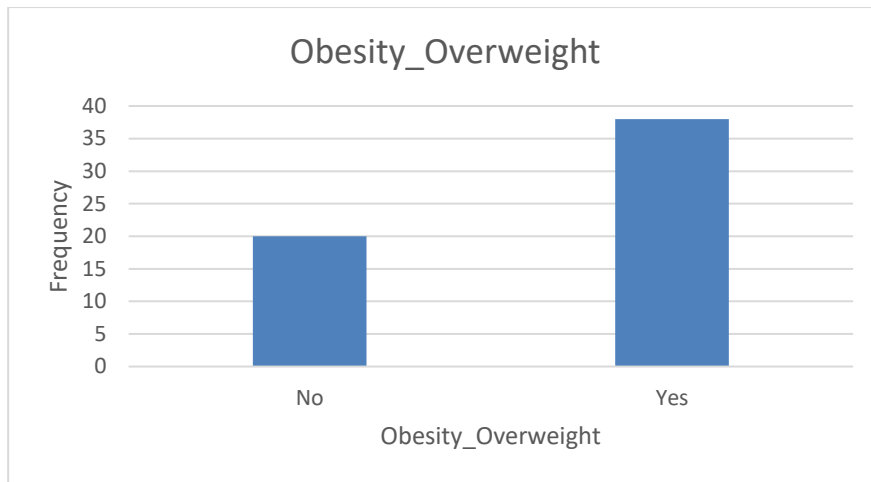


Figure (7): Obesity and Overweight Status Among Participants

Among the study participants ($n = 58$), the majority were classified as obese or overweight ($n = 38$; 65.5%), while a smaller proportion were within the non-obese category ($n = 20$; 34.5%). This distribution demonstrates that nearly two-thirds of the sample carried excess body weight, indicating that obesity and overweight status are dominant characteristics within the cohort. Such a high prevalence suggests that excess body weight may play a central role in the metabolic profile of the studied population.

Table (8): Distribution of Participants by Insulin Resistance Status

Insulin Resistance Group	Frequency (n)	Percent (%)
Normal	6	10.3
Early Insulin Resistance	12	20.7
Insulin Resistance	40	69.0
Total	58	100.0

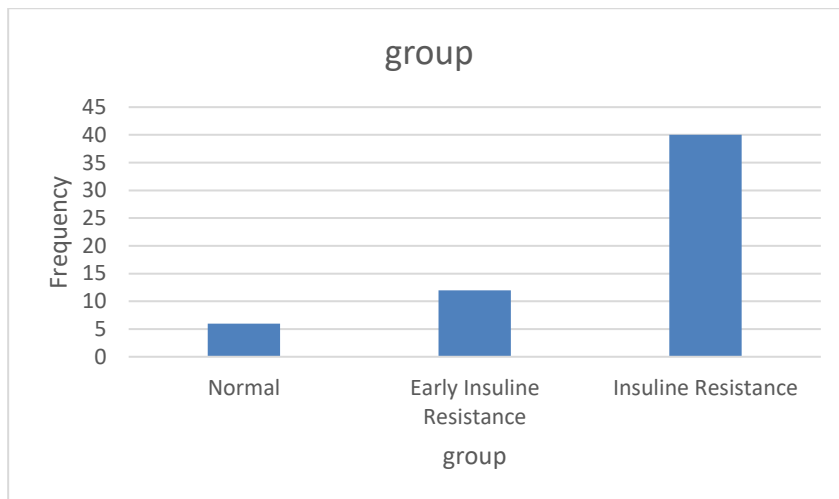


Figure (8): Distribution of Participants by Insulin Resistance Status

The distribution of participants across insulin resistance categories demonstrates a clear predominance of individuals classified with insulin resistance. Out of the total sample ($n = 58$), the majority belonged to the insulin resistance group (69.0%), while a smaller proportion were categorized as early insulin resistance (20.7%), and only a minority were classified as normal (10.3%).

Table (9): Correlation Between Height, Weight, and BMI

Variables	Height (r, p)	Weight (r, p)	BMI (r, p)
Height	1.000	$r = 0.198, p = 0.136$	$r = -0.381^{**}, p = 0.003$
Weight	$r = 0.198, p = 0.136$	1.000	$r = 0.822^{**}, p < 0.001$
BMI	$r = -0.381^{**}, p = 0.003$	$r = 0.822^{**}, p < 0.001$	1.000

- r = Pearson correlation coefficient.
- p = significance (2-tailed).
- N = 58 participants.
- **Correlation is significant at the 0.01 level (2-tailed) → indicated by **.**

The correlation analysis revealed distinct patterns among height, weight, and BMI. Weight demonstrated a strong positive correlation with BMI ($r = 0.822, p < 0.001$), confirming that increased body weight is the primary determinant of higher BMI values. Conversely, height showed a moderate negative correlation with BMI ($r = -0.381, p = 0.003$), indicating that taller individuals tend to have lower BMI when weight is held constant. The relationship between height and weight was weak and statistically non-significant ($r = 0.198, p = 0.136$), suggesting that in this cohort, stature did not predict body weight, these findings validate the mathematical basis of BMI calculation.

Table (9): Association Between Obesity/Overweight and Exercise Regularity

Obesity Status	No Exercise (n, %)	Regular Exercise (n, %)	Total (n, %)
No	2 (3.4%)	18 (31.0%)	20 (34.5%)
Yes	26 (44.8%)	12 (20.7%)	38 (65.5%)
Total	28 (48.3%)	30 (51.7%)	58

The analysis revealed a clear and statistically significant association between obesity/overweight status and regular exercise. Among participants who did not engage in physical activity, the majority were classified as obese or overweight (26 individuals; 44.8% of the total sample). In contrast, those who reported exercising regularly were more frequently in the non-obese category (18 individuals; 31.0%).

The chi-square test confirmed the strength of this relationship ($\chi^2 = 17.910, df = 1, p < 0.001$), indicating that the distribution of obesity across exercise categories was not due to chance. These findings underscore the protective role of regular physical activity against obesity, highlighting that sedentary behavior is strongly linked to excess body weight.

Table (10): Comparative Analysis of the Relationship Between Insulin Resistance and Biochemical Markers

Variable	Normal (n=6) Mean ± SD	Early IR (n=12) Mean ± SD	Insulin Resistance (n=40) Mean ± SD	F-value	p-value
BMI (kg/m ²)	21.20 ± 2.78	27.13 ± 1.83	30.72 ± 2.44	8.440	0.001
FBS (mg/dL)	75.00 ± 25.78	107.78 ± 16.97	140.95 ± 22.57	5.350	0.008
HbA1c (%)	2.25 ± 0.50	6.05 ± 0.33	6.17 ± 0.44	40.726	.000
Cholesterol (mg/dL)	130.50 ± 28.43	185.43 ± 18.71	211.67 ± 24.89	5.678	0.006
LDL-C (mg/dL)	87.50 ± 18.73	101.93 ± 12.33	147.11 ± 16.40	11.342	.000
HDL-C (mg/dL)	42.50 ± 5.91	46.98 ± 3.89	48.65 ± 5.17	0.732	0.486
Triglycerides (mg/dL)	81.50 ± 30.97	175.90 ± 20.39	169.51 ± 27.12	5.662	0.006
Fasting Insulin (µU/mL)	4.50 ± 2.26	7.05 ± 1.49	15.49 ± 1.98	26.743	.000
HOMA-IR	0.95 ± 0.80	1.89 ± 0.53	4.63 ± 0.70	23.196	.000

Table (10) presents the comparative analysis of metabolic and biochemical parameters across three groups: Normal, Early Insulin Resistance (IR), and Established Insulin Resistance. Data are expressed as Mean ± SD, and statistical differences were assessed using one-way ANOVA followed by Tukey HSD post hoc test.

- **BMI:** showed a significant increase across groups ($F=8.440, p=0.001$), indicating a progressive rise in body mass index with worsening insulin resistance.
- **FBS:** also increased significantly ($F=5.350, p=0.008$), reflecting impaired fasting glucose control in the IR group compared to normal subjects.
- **HbA1c:** demonstrated the strongest difference ($F=40.726, p<0.001$), with markedly lower values in the normal group and elevated levels in both IR groups, confirming poor long-term glycemic control.
- **Cholesterol** and **LDL-C:** were significantly higher in the IR group ($F=5.678, p=0.006$; $F=11.342, p<0.001$, respectively), supporting the association between insulin resistance and dyslipidemia.
- **HDL-C:** did not differ significantly among groups ($F=0.732, p=0.486$), suggesting that HDL may be less sensitive to insulin resistance in this cohort.
- **Triglycerides:** were significantly elevated in both IR groups compared to normal ($F=5.662, p=0.006$), consistent with the typical lipid abnormalities seen in insulin resistance.

- **Fasting Insulin ($\mu\text{U/mL}$):** showed a highly significant increase across the three groups ($F=26.743$, $p<0.001$). Mean values rose from 4.50 ± 2.26 in the normal group to 7.05 ± 1.49 in the early insulin resistance group, reaching 15.49 ± 1.98 in the established insulin resistance group. This progressive elevation reflects hyperinsulinemia as a compensatory mechanism in response to declining insulin sensitivity, and highlights fasting insulin as a robust marker of insulin resistance.
- **HOMA-IR:** values also demonstrated a strong and significant difference among groups ($F=23.196$, $p<0.001$). The index increased from 0.95 ± 0.80 in the normal group to 1.89 ± 0.53 in early insulin resistance, and further to 4.63 ± 0.70 in the insulin resistance group. This clear gradient validates the classification of subjects into normal, early, and established IR categories, and confirms HOMA-IR as a reliable indicator of insulin resistance severity.

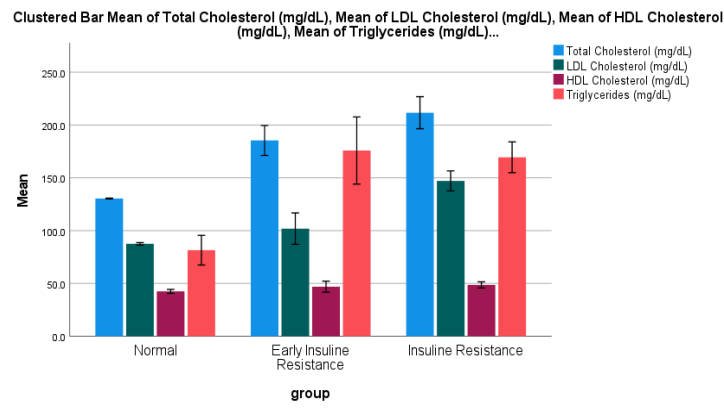


Figure (9): Mean Values of Total Cholesterol, LDL, HDL, and Triglycerides Across Normal, Early, and Established Insulin Resistance Groups

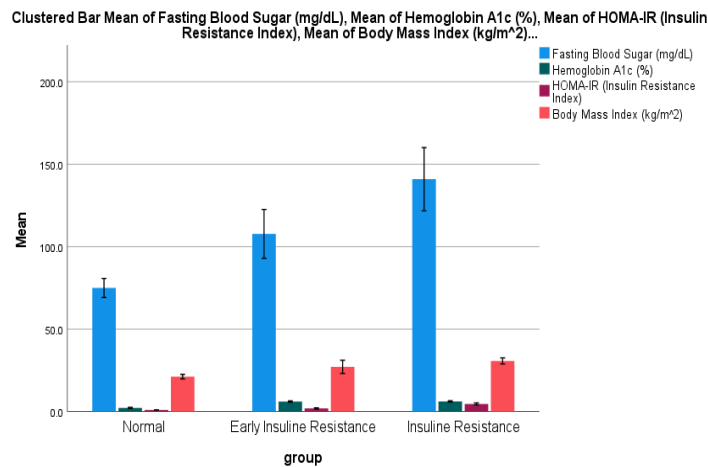


Figure (10): Mean Values of Fasting Blood Sugar, HbA1c, HOMA-IR, and BMI Across Normal, Early, and Established Insulin Resistance Groups

Discussion:

1. General Characteristics of the Study Population:

The present study revealed that the majority of participants were aged 50 years and above, with individuals in the age groups 50–59 years and ≥ 60 years constituting more than half of the sample. This age distribution is physiologically relevant, as aging is associated with a progressive decline in insulin sensitivity due to increased visceral fat accumulation and reduced skeletal muscle mass. These findings are consistent with previous studies that reported a higher prevalence of insulin resistance among older adults (Kahn *et al.*, 2020; Ford *et al.*, 2013).

Furthermore, females represented a larger proportion of the study population. This pattern may be attributed to hormonal factors, differences in fat distribution, and lower physical activity levels observed among women in certain Middle Eastern and North African contexts. Similar trends have been documented in studies conducted in Tunisia and Korea, where insulin resistance was more prevalent among females (Ahn *et al.*, 2019; Ben Ali *et al.*, 2017).

2. Lifestyle and Behavioral Factors:

The study findings demonstrated that a substantial proportion of participants were physically inactive, while nearly two-thirds were classified as overweight or obese. A highly significant association was observed between physical inactivity and obesity ($p < 0.001$), highlighting the role of sedentary behavior in the development of metabolic risk.

These results support existing evidence indicating that physical inactivity promotes visceral fat accumulation and increases circulating free fatty acids, which impair insulin signaling pathways. Previous studies have similarly reported strong associations between low physical activity levels and elevated insulin resistance indices (Reaven, 2011; Grundy, 2016; Al-Daghri *et al.*, 2018; El-Said *et al.*, 2021).

3. Prevalence of Insulin Resistance:

One of the most notable findings of this study is the high prevalence of insulin resistance, which reached 69% among participants. This prevalence is considerably higher than that reported in international and regional studies, where rates typically range between 30% and 50% (Ford *et al.*, 2013; Ben Ali *et al.*, 2017; El-Said *et al.*, 2021).

This elevated prevalence may be attributed to several interacting factors, including the older age structure of the sample, high obesity rates, and the remarkably high proportion of participants with a family history of metabolic disorders. These findings align with the concept that genetic susceptibility combined with adverse lifestyle factors accelerates the development of insulin resistance in populations undergoing rapid lifestyle transitions (Kahn *et al.*, 2020).

4. Insulin Resistance and Body Mass Index (BMI):

The study demonstrated a clear and progressive increase in BMI across insulin resistance categories, with the highest values observed in individuals with established insulin resistance. This finding confirms that obesity, particularly excess adiposity, is a key determinant of insulin resistance.

Previous research has shown that lipid accumulation in muscle and liver tissues disrupts insulin signaling pathways, particularly through inhibition of the PI3K/Akt pathway. Additionally, central obesity has been identified as a stronger predictor of insulin resistance than overall body weight (Samuel & Shulman, 2016; Gastaldelli *et al.*, 2018).

5. Insulin Resistance and Glycemic Indicators:

Significant increases in fasting blood glucose (FBS) and HbA1c levels were observed with increasing severity of insulin resistance, indicating progressive impairment in glycemic control. These findings suggest that insulin resistance contributes to both short-term and long-term dysregulation of glucose metabolism.

Consistent with previous studies, even modest elevations in fasting glucose were associated with higher insulin resistance indices. Similarly, HbA1c has been identified as a sensitive marker for early metabolic dysfunction, even among non-diabetic individuals (Andreadis *et al.*, 2015; Nowotny *et al.*, 2018; Herman *et al.*, 2020).

6. Insulin Resistance and Lipid Profile:

The study identified significant elevations in total cholesterol, LDL-C, and triglycerides among individuals with insulin resistance, reflecting the characteristic pattern of atherogenic dyslipidemia. In contrast, HDL-C levels did not differ significantly between groups. These findings are consistent with established evidence demonstrating that insulin resistance promotes hepatic overproduction of VLDL particles, thereby contributing to elevated triglycerides and LDL-C concentrations (Kassab *et al.*, 2025). The absence of a significant variation in HDL-C may be explained by the relatively small sample size or population-specific metabolic characteristics. Comparable results were reported by Taskinen and Borén (2015), who emphasized the central role of hepatic lipid metabolism in insulin-resistant states, and by Zhou *et al.* (2019), who highlighted the triglyceride-to-HDL-C ratio as a surrogate marker of insulin resistance. Similarly, Ben-Khader *et al.* (2020) documented dyslipidemia patterns in Libyan adults, noting persistent elevations in triglycerides and LDL-C, while HDL-C changes were less pronounced. Taken together, these findings suggest that while the lipid abnormalities observed in Tarhuna align with global pathophysiological mechanisms, certain population-specific differences—particularly regarding HDL-C—warrant further investigation.

7. Interpretation in the Libyan Context:

The findings of this study reveal a concerning metabolic profile among adults in Tarhuna City, characterized by a high prevalence of insulin resistance, obesity, and dyslipidemia. Importantly, these abnormalities were observed even among individuals without a prior diagnosis of diabetes, underscoring a substantial hidden burden of metabolic risk. Comparable biochemical disturbances have been documented in previous investigations conducted among patients with chronic kidney disease and diabetic kidney disease undergoing hemodialysis in Tarhuna (Kassab *et al.*, 2025; Dakeal *et al.*,

2025), suggesting that metabolic dysregulation is pervasive across different clinical populations in this region.

These results highlight the urgent need for early screening strategies and preventive interventions in Libya. Incorporating simple markers such as BMI, HbA1c, triglycerides, and HOMA-IR into routine clinical practice may facilitate the early identification of high-risk individuals and reduce the future burden of metabolic diseases. This recommendation is consistent with the epidemiological evidence reported by Elhadi *et al.* (2021), who emphasized the growing prevalence of obesity and diabetes in Libyan adults. Taken together, these findings reinforce the necessity of localized, population-specific approaches to metabolic risk assessment and prevention, while also aligning with global evidence that underscores the central role of insulin resistance in the pathogenesis of cardiometabolic disorders.

Conclusions:

The present study demonstrated a high prevalence of insulin resistance (69%) among adults in Tarhuna City, indicating that insulin resistance represents a significant and underrecognized metabolic health issue in this population.

The findings confirmed strong associations between insulin resistance and obesity, impaired glycemic control, and dyslipidemia, emphasizing the multifactorial nature of this condition. In particular, elevated BMI, increased fasting blood glucose, and higher HbA1c levels were identified as key indicators of metabolic dysfunction.

Moreover, lifestyle factors such as physical inactivity were found to play a critical role in the development of insulin resistance, further highlighting the importance of behavioral interventions.

Overall, the study provides valuable baseline data and underscores the need for early detection and preventive strategies to reduce the future burden of diabetes and cardiovascular diseases in Libya.

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