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Comparative assessment of adiponectin and insulin resistance markers in obese and non-obese individuals in Owerri, Southeastern, Nigeria

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Abstract

Background: The overwhelming rise in obesity is a disturbing public health concern in Nigeria. The superimposition of westernized diet on the existing high glycaemic traditional diet in the population is worrisome. In obese, adipose tissue dysfunction is characterized with dysregulations of adipokines (including adiponectin) and insulin resistance. Owerri, the capital of Imo State, Nigeria and slogan-labelled "entertainment capital of Nigeria" is highly an obesogenic environment with traditional perception of obesity as a mark of wellness and prosperity. The dearth of data on adiponectin and insulin resistance markers in this population is the spur for this research.

Aim: To evaluate the variations in adiponectin and insulin resistance markers in the obese and non-obese Nigerians.

Methods: A total of 140 individuals (70 obese and 70 non obese) aged between 25 and 60 years participated in this study. Fasting plasma glucose (FPG), insulin and adiponectin were analyzed using standard laboratory techniques and insulin resistance indices (HOMA-IR and HOMA-AD) were mathematically determined.

Results: Obese subjects had significantly lower adiponectin ($p<0.05$) but higher FPG ($p<0.05$) and insulin ($p<0.05$). Also, significant higher values of HOMA-IR ($p<0.05$) and HOMA-AD ($p<0.05$) were observed. Strong inverse associations were found between adiponectin and HOMA-AD ($r = -0.699$, $p<0.01$) and BMI correlated positively with all insulin resistance markers {($r = 0.266$, $p<0.05$), HOMA-IR ($r = 0.298$, $p<0.05$) and HOMA-AD ($r = 0.392$, $p<0.05$)}.

Conclusion: The findings of this study shows that the obese individuals may be at risk of future obesity related metabolic complications.

Keywords: Obesity; Adiponectin; Insulin Resistance; Nigeria

1. Introduction

The overwhelming increase in obesity has become one of the most serious public health challenges for societies and healthcare systems [1]. Obesity, a resultant effect of energy imbalance is a complex multifactorial relapsing condition that is difficult-to-treat with significant morbidities and mortalities [2, 3, 4].

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The 2022 World Health Organisation (WHO) report showed that 2.5 billion adults aged 18 years and older were overweight, including over 890 million adults who were living with obesity [5]. This corresponds to 43% of adults aged 18 years and over (43% of men and 44% of women) who were overweight; an increase from 1990, when 25% of adults aged 18 years and over were overweight. About 16% of adults aged 18 years and older worldwide were reported as obese in 2022 [5]. The worldwide prevalence of obesity has more than doubled between 1990 and 2022 [5]. Additionally, the World Obesity Atlas 2022, published by the World Obesity Federation, predicts that one billion people globally, including 1 in 5 women and 1 in 7 men, will be living with obesity by 2030 [6].

In Nigeria, a recent systematic review and meta-analysis of cross-sectional population-based studies among adult Nigerians on the prevalence of obesity (defined by body mass index) published from January 2010 to December 2020 showed that the estimated prevalence of obesity was 14.5% with the prevalence of 10.9% and 23.0% among men and women respectively. Furthermore, the prevalence of obesity in the 6 geopolitical zones of Nigeria (South-south 24.7%, Southeast 15.7%, Southwest 13.9%, Northwest 10.4%, North-central 10.2%, Northeast 6.4%) showed that Southeastern Nigeria is second most obese geopolitical zone [7].

Adiponectin, a 244-amino acid protein also known as (AdipoQ, APM1, ACRP30), is secreted exclusively by white adipose tissues. Its biological functionality as anti-diabetic, anti-atherogenic and anti-inflammatory factor has spurred the growing interest of researchers who seek to understand its pathophysiological roles in metabolic disorders [8]. However, in obesity, dysfunctional adipose tissues create microvascular imbalance that increases the secretion of pro-inflammatory adipokines with decreased levels of circulating anti-inflammatory adipokines including adiponectin [9], thereby favouring atherogenic dyslipidemia and insulin resistance that leads to several metabolic diseases.

WHO 2023 report showed that each year, 17 million people die from a non-communicable diseases (NCD) including diabetes, cardiovascular diseases before age 70 and 86% of these premature deaths occur in low- and middle-income countries including Nigeria. Obesity has been identified as one of the major metabolic changes that increases the risk of NCDs. [10]. Numerous studies have demonstrated lower levels of adiponectin in obesity and NCDs and an inverse relationship has been established between serum adiponectin and markers of these diseases [11, 12,13,14] signalling the possible predictive, monitoring and therapeutic utility of adiponectin in the management of these diseases [8]. Insulin resistance, characterized by impaired glucose response to insulin, has been identified as the common denominator underpinning these numerous NCDs. [11]

A growing body of literature has shown that lower adiponectin concentration is inversely related to insulin resistance [12, 13,14]. Adiponectin and insulin resistance are influenced by several factors including race (ethnicity) [15], diet with high glycaemic index [15], sex [16,17], genetics [18]. Africans are noted to be more resistant to insulin and with lower adiponectin levels than Caucasians [19]. Also, the nutritional shift from traditional to westernized diets has created a worrisome obesogenic environment in African population with consequent rise in non-communicable diseases [20]. The study area is predominantly populated with civil servants who by virtue and nature of their works are prone to sedentary lifestyle with poor exercising habit. Their available traditional foods are of high glycaemic index and the superimposition of westernized diet with wrong traditional perception of obesity as mark of wellness and prosperity is endangering. Additionally, clinicians diagnose insulin resistance routinely by estimation of serum insulin or C-peptide but research has shown that serum insulin is not a good measure of insulin resistance, rather the measure of the risk markers is more diagnostic [21]. Finally, there is a dearth of local data on adiponectin and insulin resistance markers in this population and this study aims at finding the variations of adiponectin and markers of insulin resistance in obese and normal weight subjects in order to delineate their risk vulnerability to obesity related metabolic complications.

2. Material and methods

Owerri is the capital of Imo State in Nigeria, set in the heart of Igboland. It is also the state's largest city and consists of three Local Government Areas including Owerri Municipal, Owerri North and Owerri West. It has an estimated population of about 1,022, 922 as of 2024 and is approximately 100 square kilometres (40 sq m) in area. Owerri houses Federal University Teaching Hospital, Federal University of Education, Federal and state secretariat, Imo State University, Federal Polytechnic etc. It is predominantly a civil servant dominant area. It is currently referred to as the entertainment capital of Nigeria because of its high density of spacious hotels, high street casinos, production studios and high quality centres of relaxation that attract people from other states and countries.

2.1. Study Design

This was a cross sectional study in which the study population made up of 140 obese and non-obese adults; aged 25-60years were selected by convenient sampling. The obese had a BMI ≥30 kg/m^2 while the non-obese had a BMI of 18 kg/m^2-24.9 kg/m^2 with waist circumference of less than 94cm and 80cm for men and women respectively. Metabolic syndrome screening was done using the criteria of Joint Interim Statement by Alberti *et al*, [22]. Participants with tumor or malignancy, physical or mental inability and with history of liver or kidney disease, smokers, alcoholics, hypertensive, diabetic, arthritis patients and pregnant or intending to be pregnant within the research duration were excluded.

2.2. Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and ethical approval of the study protocol was obtained from Ethics and Research Committee of Imo State University Teaching Hospital, Orlu (IMSUTH/CS/121). The study design and protocol were explained to each participant and informed consent obtained from all subjects prior to participation.

2.3. Data Collection

2.3.1. Anthropometric Measurements

Standard questionnaires were used to collect participants socio-demographic data obtained through a face-to-face personal interview. The anthropometric parameters such as (weight [kg], height [m^2] and waist circumference) of the participants were measured using weighing scale, stadiometer and measuring tape respectively.

The weight was then recorded in kilograms to the nearest 0.1 kg. Body mass index (BMI) was calculated by dividing weight (in kilograms) by the square of height (in meters) and expressed in kg/m^2. Based on the values of BMI, the participants with BMI ≥ 30 kg/m^2 and 18 —24.9 kg/m$^{2.}$ were classified as obese and non-obese and were enrolled. Waist circumference (WC) was measured to the nearest 0.1 cm using a measuring tape that is 1 cm in width and made of a material that does not stretch and cut-off values of >94 cm (male subjects) and >80 cm (female subjects) were used to define abdominal obesity.

2.3.2. Sample Collection and Preparation

Eight (8ml) of venous blood was collected aseptically after 10-12 hours overnight fast. 2ml and 6ml were dispensed into fluoride oxalate and plain tubes respectively. The sample in plain container was allowed to clot, retract and centrifuged at 3000rpm for 10 minutes. The serum was separated, kept away from sunlight and stored at -20^{0}C until analysed. Sample analysis was batched trice within the two months of collection to avoid loss of bioactivity.

2.3.3. Sample Analysis.

Adiponectin and insulin were analysed with ELISA technique using reagents acquired from Melsin Medical Company Ltd, China (LOT NO: P20210430, CAT NO: EKHU-0843 and LOT NO: P20210430, CAT NO: EKHU-1751 respectively). Plasma glucose was analysed by glucose oxidase method while insulin resistance indices were mathematically determined (HOMA-IR = (Fasting insulin x Fasting glucose)/22.5 and HOMA-AD = HOMA/Adiponectin).

2.4. Statistical Analysis

Statistical analysis was carried out with SPSS version 21. Frequencies and percentages were used to present categorical data. Continuous data were reported as means ± standard deviations (SD) for variables with a parametric distribution, and geometric mean (95%CI) and median interquartile ranges (IQR) for variables with a non-parametric distribution. The student t-test was used to compare means of parametric quantitative variables between two groups while Mann-Whitney U test was utilized for non-parametric numeric variables between two groups. Spearman's correlation coefficient was employed for non-parametric variables. A significance level of $p < 0.05$ was considered statistically significant.

3. Results

Table 1 Anthropometric parameters of the study population

Parameter	Obese (n = 70)	Non-obese (n = 70)	P-value[a]
Age (yrs)	39.73 ± 10.28	38.99 ± 10.85	0.895
BMI (kg/m^2)	34.97 ± 3.41	22.81 ± 1.28	0.001
WC (cm)	91.17 ± 3.08	81.83 ± 3.25	0.001
Height (m)	1.62 ± 0.07	1.69 ± 0.7	0.921
Weight (kg)	91.77 ± 7.59	65.01 ± 6.22	0.001
Systolic (mmHg)	122.21 ± 9.47	113.71 ± 7.55	0.010
Diastolic (mmHg)	82.57 ± 6.00	76.14 ± 5.53	0.001
Occupation			
Civil Servants	37 (52.9%)	42 (60%)	
Artisans	15 (21.5%)	11 (15.7%)	
Traders	18 (25.7%)	17 (24.3%)	
Education			
Tertiary	45 (64.3%)	50 (71.4%)	
Secondary	17 (24.3%)	12 (17.1%)	
Primary	7 (10%)	6 (8.6%)	
Non Formal	1(1.4%)	1 (1.4%)	
Exercise			
Always	14 (20%)	11 (15.7%)	
Frequent	18 (25.7%)	21 (30%)	
Seldom	38 (54.3%)	37 (52.9%)	
Nutrition			
Starchy	25 (35.7%)	22 (31.4%)	
Protein	14 (20%)	15 (21.4%)	
Ultra-Processed	20 (28.6%)	26 (37.1%)	
Fruits	11 (15.7%)	7 (10%)	

Mean ± SD; a= $p<0.05$

Table 2 Adiponectin and Insulin Resistance Characteristics of Obese and Non-Obese Subjects

Parameter	Obese (n = 70)	Non-obese (n = 70)	P-valuea
FPG (mmol/L)b	4.64 (4.49, 4.78)	3.91 (3.79, 4.03)	0.016
Insulin (miu/L)c	11.08 (9.30 – 13.11)	6.34 (5.15 – 7.49)	0.001
HOMA-IRc	2.27 (1.82 – 2.72)	1.13 (0.86 – 1.25)	0.005
HOMA-ADc	0.15 (0.12 – 0.23)	0.06 (0.05 – 0.07)	0.001
Adiponectin (µg/ml)b	14.68 (11.09, 17.08)	18.00 (15.15, 21.15)	0.028

a = p values are based on Mann Whitney-U test for median and student t-test for geometric means; b = geometric means (95% confidence interval) is presented; c= Median (IQR) is presented. FPG = Fasting plasma glucose; HOMA-IR = Homeostatic model assessment-estimated insulin resistance; HOMA-AD = Homeostatic model assessment Adiponectin.

Table 3 Spearman's rho correlation between Adiponectin, BMI, Weight and Insulin Resistance Parameters (Insulin, FPG, HOMA IR, HOMA-AD) in Obese participants

Parameters	Adipo-nectin	BMI	Weight	HOMA IR	HOMA AD	Insulin	FPG
Adiponectin	1.000	-.140	-.136	-0.144	-.699**	-.170	-.074
BMI		1.000	.617**	.298*	.392*	.266*	.084
Weight			1.000	.185	.221	.257*	.081
HOMA-IR				1.000	.520**	.881**	.424**
HOMA-AD					1.000	.414**	.262*
Insulin						1.000	.-023
FPG							1.000

** = p < 0.01; * = p < 0.05. BMI= Body mass index; FPG = Fasting plasma glucose; HOMA-IR = Homeostatic model assessment-estimated insulin resistance; HOMA-AD = Homeostatic model assessment Adiponectin.

3.1. Anthropometric characteristics of the population

One hundred and forty individuals were recruited for this study. The mean age of the obese and non-obese were 39 ± 10.28 and 38.99 ± 10.85. Significant differences (p<0.05) were observed in BMI, waist circumference, weight, systolic and diastolic between the obese and non-obese. The population is predominantly civil servants with sedentary lifestyle and high glycaemic index food consumption (Table 1).

3.2. Serum adiponectin concentration

The mean serum adiponectin level was significantly lower in the obese individuals {95%CI 14.68 µg/ml (11.09,17.08)} compared to the non-obese participants {95%CI 18.00 µg/ml (15.15, 21.15), P < 0.05} (Table 2)

3.3. Insulin resistance parameters.

The fasting plasma glucose (FPG) was elevated in the obese mean (95% CI) 4.64 (4.49 - 4.47) than the non-obese 3.91(3.79 - 4.03) and significant at p=0.016, while the insulin concentrations of the obese was (95% CI) 11.0 (9.30 - 13.11) and statistically higher (p=0.001) than the controls (non-obese) 6.34 (5.15 - 7.49). Also significant (p<0.05) higher median (IQR) values for HOMA-IR: 2.27 (1.82 –2.27) and HOMA-AD: 0.15 (0.12 – 0.23) were observed in obese compared to non-obese {1.13 (0.6 -1.25) and 0.06 (0.0 - 0.07)} respectively (Table 2).

3.4. Associations amongst adiponectin, adiposity and insulin resistance markers.

Adiponectin correlated strongly and negatively with HOMA-AD (r = -0.699, p<0.01). BMI was positively correlated with weight (r = 617. P<0.01) and moderately with insulin (r = 0.266, p<0.05), HOMA-IR (r = 0.298, p<0.05) and HOMA-AD (r = 0.392, p<0.05). Additionally, insulin was very strongly and positively associated with HOMA-IR (r = 0.881, p<0.01) and HOMA-AD (r = 0.414, p<0.01) while FPG maintained a related relationship with HOMA-IR (r = 0.424, p<0.01) and HOMA-AD (r = 0.262, p<0.05) (Table 3).

4. Discussion

Adiponectin is an adipocyte-secreted polypeptide hormone with modulatory effects on a number of metabolic processes including improvement of insulin sensitivity and energy homeostasis, as well as glucose and lipid metabolism [23, 24]. In Nigeria, several studies have investigated serum adiponectin levels on different life stages and conditions including pre-pubertals [8], Children [25], diabetics [26], obese/overweight [27] with lower adiponectin observed in the obese than non-obese. This study also observed a lower serum adiponectin in the obese compared with the non-obese and is consistent with results of other investigators in different countries. Jonas *et al*., [28] observed a significant lower adiponectin levels in obese subjects than normal weight individuals in Poland. Also, a related finding was demonstrated in a Tehran lipid and glucose study in Iran with higher adiponectin levels recorded in non-obese than obese [29]. Similar observations have established that adiponectin level are lower in obese individuals (particularly those with central / abdominal obesity) and in those with cardiometabolic diseases [12, 30, 31]. This finding also agrees with Chinese population results where adiponectin expression in obese subjects was lower than the non-obese with remarkable

significant decrease observed in the subjects with increased obesity and hypertension [32] and metabolic syndrome components [33].

The mechanism of adiponectin dysregulation in obesity has been partly attributed to inflammatory processes as enhanced oxidative stress and pro-inflammatory activity in adipose tissue has been identified as potential mechanisms underlying decreased adiponectin synthesis in obesity [34, 35]. An obese state is a situation of chronic inflammation of adipose tissue characterized by a marked increase in the levels of inflammatory cytokines IL6, IL8 and TNFα which are directly known to inhibit adiponectin transcription [35]. The nutritional exposure of the population may be causal to the finding of this study as the study area is in Southeastern Nigeria, which has been identified in a review and meta-analysis as the most overweight and second most obese geopolitical zone of Nigeria [7]. Also, high calorie foods have been reported to cause decreased adiponectin concentration [36] and the traditional diets of the study area comprises high glycaemic index foods superimposed with westernised diet.

Obesity is associated with multiple metabolic alterations that are risk factors for glucose homeostasis abnormalities and at its base is the common denominator of insulin resistance [37]. The observation of this research showed a significant higher fasting plasma glucose (FPG) concentration in obese subjects compared with the non obese, which may be a pointer to glycaemic dysregulation. The finding is consistent with the evidences that blood glucose increases in obese state in children [38], young adults [39] and adults [40].

Additionally, dysfunctional obese adipose tissue plays a pivotal role in the development of insulin resistance (IR) and an increased serum insulin with higher values of insulin resistance indices (HOMA-IR, HOMA-AD) were noted in the obese population of this study. The findings are in consonance with the observations in Nigeria and other country [41, 42]. HOMA IR has been validated as a surrogate measure of insulin resistance and is widely used in clinical, experimental and epidemiological studies [43, 44]. The strong correlation of BMI with HOMA-IR and insulin but without FPG suggests that increased adiposity can create insulin resistant state in the obese and the presence of normal plasma glucose may not necessarily exclude insulin resistance. Research findings have implicated the adoption of westernized lifestyle and consumption of calorie-rich diets and ultra-processed foods as the major causes of hyperinsulinemia with concomitant insulin resistance in obesity as calorie-rich diets have been observed to cause postprandial inflammation and hyperinsulinaemia [45, 46, 47] while continuous excess nutrition has been shown to more than doubled the basal insulin levels, even without elevating basal glucose levels and later cause insulin resistance [48].

HOMA-IR assumption of hepatic insulin resistance (IR) as equal to peripheral IR has led to inclusion of adiponectin (which is a measure of adiposopathy and an indirect measure of peripheral IR) into its skeleton. The strong negative association of adiponectin with HOMA-AD ($r = -0.677$, $p<0.01$) and positive correlation of BMI with HOMA-AD ($r= 0.392$, $p<0.05$) than HOMA-IR ($r = 0.298$, $p<0.05$) respectively showed that HOMA-AD may be a better marker of risk identification of insulin resistance than HOMA-IR. The same observation has been recorded in obese children where HOMA-AD was high and possessed a higher predictive value for screening metabolic complications than HOMA-IR and adiponectin alone [49]. The observed increment of the these glycaemic markers should be worrisome especially in such population without obvious clinical signs of metabolic complications but possessing a traditional perception of obesity as mark of wellness and prosperity.

5. Conclusion

In conclusion, lower adiponectin with higher insulin resistance indices were observed among the obese compared to the non-obese in this current study, indicating latent insulin resistance in the obese population and a pointer to future metabolic derangements.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Koliaki C, Dalamaga M, Liatis S. Update on the Obesity Epidemic: After the Sudden Rise, Is the Upward Trajectory Beginning to Flatten?. Current Obesity Report. 2023; 12, 514–527.

[2] Chait A, den Hartigh LJ. Adipose tissue distribution, inflammation and its metabolic consequences, including diabetes and cardiovascular disease. Frontier Cardiovascular Medicine. 2020; 7:22. doi: 10.3389/fcvm.2020.00022.

[3] Purnell JQ. Definitions, Classification, and Epidemiology of Obesity. [Updated 2023 May 4]. In: Feingold K.R, Anawalt B, Blackman M.R, et al., editors. Endotext [Internet]. South Dartmouth (MA):MDText.com, Inc.;2000. Https://www.ncbi.nlm.nih.gov/books/NBK279167/.

[4] Volpe M, Gallo G. Obesity and cardiovascular disease: An executive document on pathophysiological and clinical links promoted by the Italian Society of Cardiovascular Prevention (SIPREC). Frontier of Cardiovascular Medicine, 2023; doi.org/10.3389/fcvm.2023.1136340.

[5] World Health Organization. Obesity and overweight [internet]. Geneva (Switzerland). © 2022 https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.

[6] World Obesity Atlas [Internet].©2022. Available from https://www.worldobesity.org/resources/resource-library/world-obesity-atlas-2022.

[7] Chukwuonye II, Ohagwu KA, Ogah OS, Collins J, Oviasu E, Anyabolu EN, Okpechi I, et al. Prevalence of overweight and obesity in Nigeria: Systematic review and meta-analysis of population-based studies. Plos Sustainability and Transformation. 2022; doi.org/10.1371/ journal.pgph.0000515.

[8] Nri-Ezedi CA, Ulasi T, Chukwuka J, Okpara H, Ofiaeli O, Nwaneli E, Ulasi A. Serum total adiponectin in healthy pre-pubertal Nigerian school children. Nigerian Journal of Clinical Practice. 2021; 24:821-827.

[9] Yang HY, Joonoh K, Baek-Kyung K, Hyun JS, Ju-Young K, Joo-Eun L, Jaewon L, et al. Resistin Regulates Inflammation and Insulin Resistance in Humans via the Endocannabinoid System. Research. 2024; 7:0326.DOI:10.34133/research.0326.

[10] World Health organization. Non Communicable Diseases. © 2023. Available from https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases#).

[11] James DE, Stöckli J, Birnbaum MJ. The aetiology and molecular landscape of insulin resistance. Nature Reviews Molecular Cell Biology. 2021; 202122:112021;22:751–71.https://doi.org/10.1038/s41580-021-00390-6.

[12] Abudalo R, Alqudah A, Qnais E, Athamneh RA, Oqal M, Alnajjar A. Interplay of adiponectin and resistin in type 2 diabetes: Implications for insulin resistance and atherosclerosis. Pharmacia. 2024; 71:1-8.

[13] Abdelgadir M, Karlsson AF, Berglund L et al. Low serum adiponectin concentrations are associated with insulin sensitivity independent of obesity in Sudanese subjects with type 2 diabetes mellitus. Diabetology and Metabolic Syndrome. 5, 15 (2013). https://doi.org/10.1186/1758-5996-5-15.

[14] Begum M, Choubey M, Tirumalasetty, MB, Arbee S, Mohib MM, Wahiduzzaman M, Mamun, MA, Uddin MB, Mohiuddin MS. Adiponectin: A Promising Target for the Treatment of Diabetes and Its Complications. Life. 2023;13, 2213. https://doi.org/10.3390/life13112213.

[15] Mente A, Razak F, Blankenberg S, Vuksan V, Davis AD, Miller R, Teo K, Gerstein H, Sharma AM, Yusuf S. Study of the Health Assessment and Risk Evaluation; Study of the Health Assessment and Risk Evaluation in Aboriginal Peoples Investigators. Ethnic variation in adiponectin and leptin levels and their association with adiposity and insulin resistance. Diabetes Care. 2010 Jul;33(7):1629-34. doi: 10.2337/dc09-1392. Epub 2010 Apr 22. PMID: 20413520; PMCID: PMC2890372.

[16] Arner P, Viguerie, N, Massier L, Ryden M, Astrup A, Blaak E, et al. Sex differences in adipose insulin resistance are linked to obesity, lipolysis and insulin receptor substrate 1. International Journal of Obesity. 2024 48, 934–940. https://doi.org/10.1038/s41366-024-01501-x.

[17] Becerril S, Rodríguez A, Catalán V, Ramírez B, Mentxaka A, Neira G, Gómez-Ambrosi J, Frühbeck G. Sex- and Age-Dependent Changes in the Adiponectin/Leptin Ratio in Experimental Diet-Induced Obesity in Mice. Nutrients. 2022 Dec 23;15(1):73. doi: 10.3390/nu15010073.

[18] Howlader M, Sultana MI, Akter F, Hassain MM. Adiponectin gene polymorphisms associated with diabetes mellitus: A descriptive review. Heliyon. 2021, 8: e07851.

[19] Kodama K, Tojjar D, Yamada S, Toda K, Patel CJ, Butte AJ. Ethnic differences in the relationship between insulin sensitivity and insulin response: a systematic review and meta-analysis. Diabetes Care. 2013 Jun;36(6):1789-96.

[20] Chukwu E, Dogbe W. The cause and effect of the nutrition transition in Nigeria: analysis of the value of indigenous knowledge and traditional foods in Enugu State, Igboland. J. Ethn. Food. 2023; 10, 30. https://doi.org/10.1186/s42779-023-00198-z.

[21] Katherine S, Aidan M, Stephen MT, Joseph P, John BP, Timothy AW, Paul Z, Donald JC, Lesley VC. Insulin levels in insulin resistance: phantom of the metabolic opera? Medical Journal of Australia. 2006; 185 (3): 159-161. || doi: 10.5694/j.1326-5377.2006.tb00506.x.

[22] Alberti KG, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, Fruchart JC, James WP, Loria CM, Smith SC Jr. International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; International Association for the Study of Obesity. Harmonizing the metabolic syndrome: a joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention; National Heart, Lung, and Blood Institute; American Heart Association; World Heart Federation; International Atherosclerosis Society; and International Association for the Study of Obesity. Circulation. 2009; 120(16):1640-1645.

[23] Khoramipour K, Chamari K, Hekmatikar AA, Ziyaiyan A, Taherkhani S, Elguindy NM, Bragazzi NL. Adiponectin: Structure, Physiological Functions, Role in Diseases, and Effects of Nutrition. Nutrients. 2021 Apr 2;13(4):1180. doi: 10.3390/nu13041180.

[24] Ramakrishnan N, Auger K, Rahimi N, Jialal I. Biochemistry, Adiponectin. [Updated 2023 Jul 30]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537041/

[25] Nri-Ezedi, C., Okpara, H., Okeke, K., Nwaneli, E., Edokwe, E., Echendu, S. and Ulasi, T. Exploring the Relationship between Adiponectin and Blood Pressure in Nigerian Children. Open Journal of Endocrine and Metabolic Diseases. 2022; 12, 9-19. doi: 10.4236/ojemd.2022.122002.

[26] Agu NC, Ogbuabor AO, Okwuosa CN, Achukwu PU. Some Serum Cytokines (Adiponectin, Apolipoprotein B, hsCRP, IL-6) in a Cohort of Type 2 Diabetes Mellitus Patients. International Journal of Health Sciences and Research. 2022; 12(12). doi.org/10.52403/ijhsr.20221216.

[27] Ciroma FL, Ayo JO, Mohammed A, Akor-Dewu MB, Ana MA, Kase SN. Association between Adiponectin, Serum Lipids and Obesity in a University Setting in Nigeria. Nigerian Journal of Physiological Science. 2017; 30,32(1):69-74.

[28] Jonas, MI, Kurylowicz A, Bartoszewics Z, Lisik W, Jonas M, Domienik-Karlowics J, Puzianowska-Kuznicka. Adiponectin/resistin interplay in serum and in adipose tissue of obese and normal-weight individuals. Diabetology and Metabolic Syndrome. 2017; 9:95.

[29] Nezhadali M, Mesbah-Namin SA, Hedayati M, AKbarzadeh M, Bonab LNH, Daneshpour MS. Serum adiponectin and cortisol levels are not affected by studied ADIPOQ gene variants: Tehran lipid and glucose study. 2022; 22,104: doi.org/10.1186/s12902-022-01020-8.

[30] Fiorotti AM, Gomes ACA, Bortoli AM, Brito BB, Nunes KZ, Haraguchi FK, Bolsoni-Lopes A. Dynamic Changes in Adiponectin and Resistin Drive Remission of Cardiometabolic Risk Biomarkers in Individuals with Obesity Following Bariatric Surgery. Pharmaceuticals. 2024; 17, 215. https://doi.org/10.3390/ph17020215.

[31] He L, Xuan W, Liu D, Zhong J, Luo H, Cui H, Zhang X Chen W. The role of adiponectin in the association between abdominal obesity and type 2 diabetes: a mediation analysis among 232,438 Chinese participants. Frontier Endocrinology. 2024;15:1327716. doi: 10.3389/fendo.2024.1327716.

[32] Wu O, Lu X, Leng J, Xang X, Liu W, Yang F, Zhang H, Li J, Hederzadeh S, Liu X, Yuan, C. (2024). Reevaluating Adiponectin's impact on obesity hypertension: a Chinese case-control study. BMC Cardiovascular Disorders. 2024; 24, 208. https://doi.org/10.1186/s12872-024-03865-4.

[33] Singhal A, Punia VS, Bharti A, Mittal S, Mishra PR, Kumar PA. Study of Correlation of Adiponectin Levels in Metabolic Syndrome. European Medical Journal. 2022; DOI/10.33590/emj/10146572. https://doi.org/10.33590/emj/10146572.

[34] Choi HM, Doss HM, Kim KS. Multifaceted Physiological Roles of Adiponectin in Inflammation and Diseases. International Journal of Molecular Scienc. 2020; 21:1219. https://doi.org/10.3390/ijms21041219.

[35] Savulescu-Fiedler I, Mihalcea R, Dragosloveanu S, Scheau C, Baz RO, Caruntu A, Scheau AE, Caruntu C Benea SN. The Interplay between Obesity and Inflammation. Life. 2024; 14, 856. https://doi.org/10.3390/life14070856.

[36] Janiszewska J, Ostrowska J, Szostak-Węgierek D. The Influence of Nutrition on Adiponectin-A Narrative Review. Nutrients. 2021 Apr 21;13(5):1394. doi: 10.3390/nu13051394. PMID: 33919141; PMCID: PMC8143119.

[37] Barber TM, Kyrou I, Randeva HS, Weickert MO. Mechanisms of Insulin Resistance at the Crossroad of Obesity with Associated Metabolic Abnormalities and Cognitive Dysfunction. International Journal of Molecular Sciences. 2021; 22(2):546. https://doi.org/10.3390/ijms22020546.

[38] Lu J, Gu Y, Wang L, Li W, Zhang S, Liu H, Leng J, Liu J, Wang S, Baccarelli AA, Hou l, Hu G. (2020). Glucose metabolism among obese and non-obese children of mothers with gestational diabetes. BMJ Open Diabetes Research and Care. 2020; 8:e000822.doi: 10.1136/bmjdrc-2019-000822.

[39] Chaudhari A, Gujarathi S, Bhatia G. (2020). Comparison of blood glucose in obese and non-obese students in a medical college. International Journal of Research in Medical Sciences. 2020; 8(11), 3916–3919.

[40] Lundqvist MH, Pereira MJ, Eriksson JW. Glucose-dependent inflammatory responses in obese compared to lean individuals. Endocrine, 2023; 81(3):464-476. doi: 10.1007/s12020-023-03433-4.

[41] Agbogu-Ike UO, Ogoina D, Onyemelukwe GC. Leptin Concentrations in Non-Obese and Obese Non-Diabetes Nigerian-Africans. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy. 2021;14: 4889-4902.

[42] Elrayess MA, Rizk NM, Fadel AS, Kerkadi A. Prevalence and Predictors of Insulin Resistance in Non-Obese Healthy Young Females in Qatar. International Journal of Environmental Resource and Public Health. 2020; 17(14): 5088.

[43] Barreiro-Ribeiro F, Vasques AC, da Silva CC, Zambon MP, Rodrigues AM, Camilo DF, et al. Hypertriglyceridemic waist phenotype indicates insulin resistance in adolescents according to the clamp technique in the BRAMS study. Child Obesity. 2016; 12(6):446–454.

[44] da Silva, CC, Vasques ACJ, Zambon MP, Camilo DF, De Bernardi Rodrigues AM, Antonio M. Sagittal abdominal diameter resembles waist circumference as surrogate marker of insulin resistance in adolescents-Brazilian Metabolic Syndrome Study. Paediatric Diabetes. 2018; 19(5):882–891.

[45] Herieka M, Erridge C. (2014). High-fat meal induced postprandial inflammation. Molecular and Nutrition Food Resource. 2014; 58:136–46.

[46] Janssen JA.M. Overnutrition, Hyperinsulinemia and Ectopic Fat: It Is Time for A Paradigm Shift in the Management of Type 2 Diabetes. International Journal of Molecular Science. 2024; 25, 5488. https://doi.org/10.3390/ijms25105488.

[47] Papakonstantinou E, Oikonomou C, Nychas G, Dimitriadis GD. (2022). Effects of Diet, Lifestyle, Chrononutrition and Alternative Dietary Interventions on Postprandial Glycemia and Insulin Resistance. Nutrients. 2022; 14(4):823. doi: 10.3390/nu14040823.

[48] Boden G, Homko, C, Barrero CA, Stein TP, Chen X, Cheung P. (2015). Excessive caloric intake acutely causes oxidative stress, GLUT4 carbonylation, and insulin resistance in healthy men. Science of Translational Medicine. 2015; 7:304-307.

[49] Bajpai A. (2021). HOMA-AD and Metabolic Syndrome—The Homecoming of Adiponectin in Pediatric Obesity. Indian Journal of Pediatrics. 2021; 88, 322–323.