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Original Research Article

Association of serum zinc levels with the atherogenic index in obese adults

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ABSTRACT

Background: Obesity is associated with dyslipidemia and micronutrient imbalances, including altered serum zinc levels. The atherogenic index of plasma (AIP) is an emerging biomarker of cardiovascular risk. This study evaluated the association between serum zinc and AIP in obese adults.
Methods: In this comparative cross-sectional study at Sylhet MAG Osmani Medical College, Bangladesh (July 2022–June 2023), 60 participants were enrolled and divided by body mass index (BMI) according to WHO Asian guidelines: group A (obese, BMI ≥25 kg/m², n=30) and group B (healthy, BMI 18.5–24.9 kg/m², n=30). Serum zinc, triglycerides (TG), and high-density lipoprotein cholesterol (HDL-C) were measured, and AIP was calculated as $\log_{10}$ (TG/HDL-C).
Results: The mean BMI was significantly higher in group A compared to group B (30.13±2.39 versus 21.88±1.87 kg/m²; p<0.001), while age and gender distribution were similar. Group A exhibited higher TG (188.53±36.93 versus 145.30±32.22 mg/dl; p<0.001) and lower HDL-C (39.43±5.93 versus 47.43±7.93 mg/dl; p=0.001). Serum zinc was significantly reduced (10.15±1.03 versus 13.13±1.34 µmol/l; p<0.001), and AIP was higher (0.32 versus 0.12; p<0.001) in obese participants compared to healthy subjects. Regression analyses showed a strong negative correlation between BMI and serum zinc (r=−0.797, p<0.001), a moderate negative correlation with TG (r=−0.591, p<0.001), and a moderate positive correlation with HDL-C (r=0.616, p<0.001).
Conclusion: Obese adults exhibited lower serum zinc levels and elevated AIP. BMI and lipid parameters, particularly TG and HDL-C, significantly predicted serum zinc status, highlighting the interrelationship between obesity, dyslipidemia, and micronutrient deficiency.

Keywords: Obesity, BMI, Serum zinc, AIP, Triglycerides, HDL cholesterol, Cardiovascular risk

INTRODUCTION

Obesity is a systemic chronic disease characterized by excessive and abnormal accumulation of adipose tissue in the body.[1] Globally, the number of individuals living with obesity has reached approximately 700 million, and this figure continues to rise rapidly, creating a substantial economic burden on healthcare systems and societies.[2] Alarmingly, the prevalence of overweight and obesity is increasing at younger ages.[3] It has been estimated that even a 1% reduction in overweight and obesity rates among 16 to 17 year old could result in 52,821 fewer obese individuals in the future.[4]

Obesity is widely recognized as an inflammatory condition, marked by increased adipose tissue mass and reduced adiponectin levels, which diminishes the body's ability to suppress inflammation and perpetuates a chronic inflammatory state.[5-7] Several studies have demonstrated that disruptions in the metabolism of individual lipid components, variations in non-traditional lipid markers, or alterations in derived lipid indices are strongly associated

with obesity in children and adolescents. Indices such as the triglyceride/high-density lipoprotein cholesterol ratio (TG/HDL-C), triglyceride-glucose index (TyG), visceral adiposity index (VAI), height-corrected lipid accumulation product (HLAP), and the atherogenic index of plasma (AIP) have been shown to be useful predictors of obesity.[8-10]

In adults, dyslipidemia is commonly observed among individuals with obesity. Evidence indicates that higher BMI is directly or indirectly associated with elevated total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and triglycerides (TG), along with reduced levels of high-density lipoprotein cholesterol (HDL-C).[11] Strong scientific findings further support the association between BMI and lipoprotein abnormalities, particularly increased LDL-C and decreased HDL-C, both of which are recognized as potential cardiovascular risk factors in obese individuals. Consequently, the LDL-C/HDL-C ratio is frequently used to estimate cardiovascular risk.[12] The TC/HDL-C ratio is considered an even more sensitive and specific predictor, with values above 5.5 indicating moderate atherogenic risk.[13] Furthermore, AIP, a relatively novel and highly informative marker has emerged as an important indicator of dyslipidemia and related conditions, including cardiovascular diseases.[14-16]

Over the past two decades, obesity has become one of the most prevalent non-communicable diseases (NCDs) and is now regarded as a global pandemic. A study conducted in 2015 reported that 12% of all adults worldwide, equivalent to 630.7 million individuals, were obese.[17] Projections suggest that by 2030, 2.16 billion adults will be overweight and 1.12 billion will be obese, representing nearly 40% of the global population.[17,18] Although obesity is influenced by multiple factors such as genetic predisposition, dietary habits, imbalances between energy intake and expenditure, consumption of calorie-dense foods, sedentary lifestyles, stress, and certain health conditions, emerging evidence indicates that these traditional factors alone do not fully explain the rising prevalence. Increasing attention is now being directed toward environmental contributors to obesity and metabolic syndrome.[18,19]

Given the growing global burden of obesity and its strong association with dyslipidemia and cardiovascular risk, early identification of reliable lipid-related markers is essential for timely intervention. Among these markers, AIP has emerged as a promising predictor of cardiovascular risk, particularly in obese individuals. However, data on its diagnostic value among the Bangladeshi population remain limited. Therefore, the present study was designed to evaluate AIP and explore its potential as an early indicator of cardiovascular risk among obese adults in Bangladesh.

METHODS

This comparative cross-sectional study was conducted in the Department of Physiology at Sylhet MAG Osmani Medical College, Sylhet, Bangladesh, from July 2022 to June 2023. The study included 60 participants attending various outpatient departments of Sylhet MAG Osmani Medical College Hospital. The participants were enrolled and divided into two groups based on body mass index (BMI) according to the World Health Organization (WHO) guidelines for the Asian population group A (n=30): obese individuals with BMI ≥25 kg/m² and group B (n=30): healthy individuals with BMI between 18.5 and 24.9 kg/m².

Inclusion criteria

Inclusion criteria included healthy and obese adults aged 18–60 years, willingness to participate and provide informed consent and participants without chronic systemic illnesses affecting lipid or zinc metabolism.

Exclusion criteria

Individuals with a history of diabetes mellitus, cardiovascular disease, liver or kidney disorders, known or suspected malignancy and participants taking zinc supplements, antipsychotics, antidepressants, hormonal contraceptives, corticosteroids within the last three months were excluded.

Data collection procedure

After obtaining written informed consent, participants' demographic information, anthropometric measurements (height, weight, BMI), and medical history were recorded. A total of 5 ml of venous blood was drawn from each participant after an overnight fasting period of 8–10 hours to ensure accurate biochemical assessment. Serum TG and HDL-C levels were measured to assess the atherogenic index. Serum triglyceride and serum high-density lipoprotein cholesterol were measured by enzymatic method with a fully automated biochemistry analyzer (Vitros 5600, USA). Serum zinc was measured by photometric method with a fully automated biochemistry analyzer (Konelab Prime 60i, Thermo Fisher Scientific, USA).

Atherogenic index of plasma (AIP) calculation

$$AIP = log_{10}(TG/HDL - C)$$

$$Conversions\ used: TG(mmol/l) = TG(mg/dl) \times 0.01129$$

$$HDL - C(mmol/l) = HDL - C(mg/dl) \times 0.02586$$

Statistical analysis

All data were recorded systematically in a pre-formatted data collection form. Quantitative data were expressed as mean and standard deviation, and qualitative data were expressed as frequency distribution and percentage. Group comparisons were performed using independent t-tests or

Chi-square tests as appropriate. Simple linear regression analysis was conducted to evaluate the predictive relationships between BMI, lipid parameters, and serum zinc levels. A $p<0.05$ was considered significant. Statistical analysis was performed by using statistical package for the social sciences (SPSS) 26. This study was ethically approved by the Institutional Review Committee of Sylhet MAG Osmani Medical College.

RESULTS

Table 1 presents the baseline demographic characteristics of the study participants (n=60), comparing group A and group B. The age distribution was similar between the groups, with the majority of participants falling within the 31–40-year age range in both groups. The mean age did not differ significantly (39.73±10.82 years versus 36.80±6.42 years; p=0.212). Gender distribution was identical across both groups, with 43.3% males and 56.7% females in each group (p=1.000). However, a significant difference was observed in BMI, where group A had a substantially higher mean BMI compared to group B (30.13±2.39 kg/m² versus 21.88±1.87 kg/m²; p<0.001).

Table 2 compares the atherogenic index–related parameters between group A and group B. A significant difference was observed in triglyceride levels, with group A showing markedly higher mean TG values compared to group B (188.53±36.93 mg/dl versus 145.30±32.22 mg/dl; p<0.001). Conversely, HDL-C levels were significantly lower in group A than in group B (39.43±5.93 mg/dl versus 47.43±7.93 mg/dl; p=0.001).

Comparison of AIP between study groups is shown in Table 3.

Table 4 compares the serum zinc levels between group A and group B. The mean serum zinc concentration was significantly lower in group A than in group B (10.15±1.03 µmol/l versus 13.13±1.34 µmol/l; p<0.001). The range of serum zinc levels also differed between the groups, with group A showing a narrower and lower range (9–12 µmol/l) compared to group B (11–16 µmol/l).

Table 1: Distribution of the study participants by age, gender and BMI (n=60).

Variables	Group A (n=30) (%)	Group B (n=30) (%)	P value
Age (years)			
21–30	8 (26.7)	8 (26.7)	1.000
31–40	11 (36.7)	11 (36.7)	
41–50	6 (20.0)	6 (20.0)	
51–60	5 (16.6)	5 (16.6)	
Mean age±SD	39.73±10.82	36.80±6.42	0.212
Gender			
Male	13 (43.3)	13 (43.3)	1.000
Female	17 (56.7)	17 (56.7)	
BMI (kg/m^2)			
Mean±SD	30.13±2.39	21.88±1.87	<0.001

Table 2: Comparison of atherogenic index–related lipid parameters between study groups.

Parameters	Group A (n=30)	Group B (n=30)	P value
TG (mg/dl)	188.53±36.93	145.30±32.22	<0.001
HDL-C (mg/dl)	39.43±5.93	47.43±7.93	0.001

Table 3: Comparison of atherogenic index of plasma (AIP) between study groups.

Group	AIP (mean±SD)	Interpretation	P value
Group A (n=30)	0.32	High atherogenic risk	<0.001
Group B (n=30)	0.12	Low–intermediate atherogenic risk	

Table 4: Comparison of serum zinc level between the study groups (n=60).

Parameter	Group A (n=30)	Group B (n=30)	P value
Serum zinc (µmol/l)	10.15±1.03	13.13±1.34	<0.001
Range (µmol/l)	9-12	11-16	

Figure 1 illustrates the simple linear regression analysis assessing the predictive relationship between BMI and serum zinc levels. A strong negative correlation was observed between BMI and serum zinc (r=−0.797). The fitted regression equation was y=−0.3259x+20.115, indicating that serum zinc levels decrease as BMI increases. The model demonstrated a high level of significance, with r^2=0.6347, F=100.782, and p<0.001, explaining approximately 63% of the variance in serum zinc levels. BMI was found to be a significant predictor of serum zinc (β=−0.797, p<0.001).

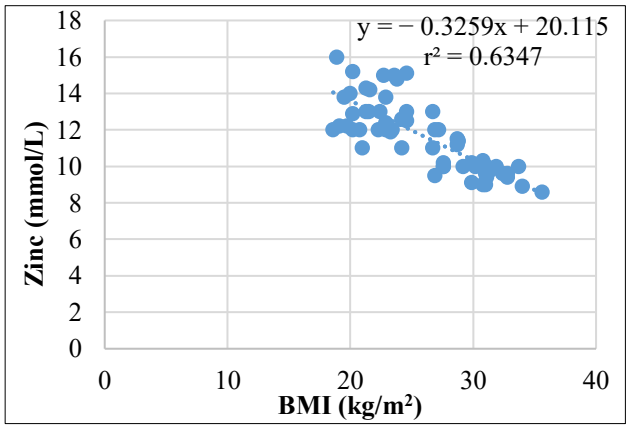

Figure 1: Relationship between BMI and serum zinc level (n=60).

Figure 2 presents the simple linear regression analysis assessing the predictive relationship between serum TG levels and serum zinc concentration. A moderate negative correlation was observed between serum TG and serum zinc (r=−0.591). The fitted regression equation was y=−0.0278x+16.086, indicating that higher TG levels are associated with lower serum zinc levels. The model was statistically significant, with r^2=0.349, F=31.082, and p<0.001, explaining approximately 35% of the variance in serum zinc concentration. Overall, serum TG was found to be a significant predictor of serum zinc levels (β=−0.591, p<0.001).

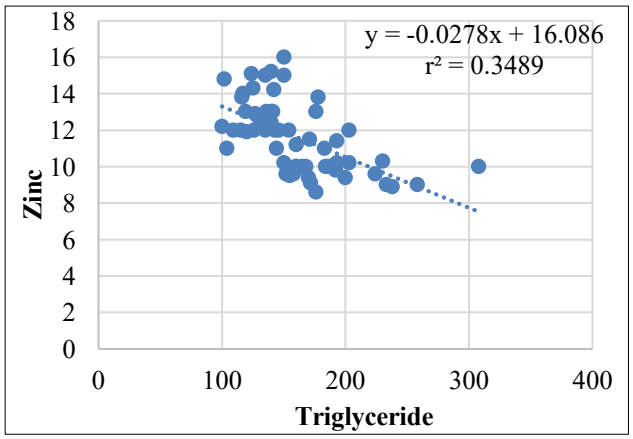

Figure 2: Relationship between triglyceride and serum zinc level (n=60).

Figure 3 shows the simple linear regression analysis evaluating the predictive relationship between serum HDL and serum zinc levels. A moderate positive correlation was observed between serum HDL and serum zinc (r=0.616). The fitted regression equation was y=0.1396x+5.3315, indicating that serum zinc levels increase with higher HDL concentrations. The regression model was statistically significant, with r^2=0.379, F=35.375, and p<0.001, explaining approximately 38% of the variance in serum zinc levels. Overall, serum HDL was found to be a significant predictor of serum zinc concentration (β=0.616, p<0.001).

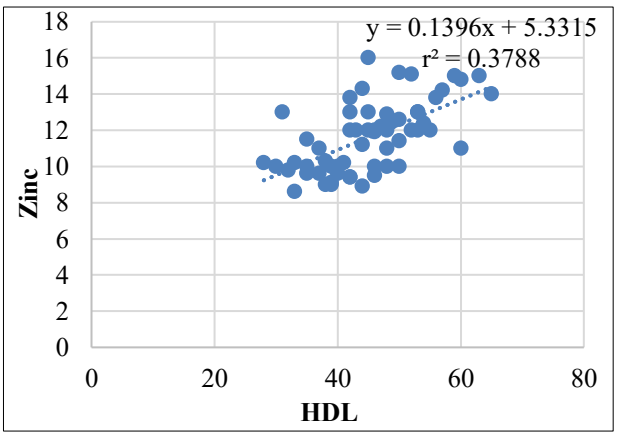

Figure 3: Relationship between HDL and serum zinc level (n=60).

DISCUSSION

Obesity has emerged as one of the most significant public health challenges of the 21st century. Early identification of lipid abnormalities and prompt management of dyslipidemia are crucial, as these indicators may help detect the risk of future obesity and its complications at an early stage. Global data suggest that BMI among children and adolescents has continued to rise over the past 40 years, reflecting an alarming trend in obesity prevalence. Consequently, the growing burden of obesity and its metabolic consequences has drawn increasing attention worldwide. In recent years, the strong association between obesity and alterations in blood lipid profiles has become increasingly evident.[2]

In the present study, the mean age of participants was comparable between the obese and healthy groups (39.73±10.82 years versus 36.80±6.42 years; p=0.212), which is consistent with findings reported by Javardi et al, who observed a mean age of 38.73±9.65 years in both overweight/obese and normal-weight adults.[20] Similarly, Wang et al. reported no meaningful difference in mean age between normal-weight individuals and those with excess weight (20.78±2.19 versus 20.85±2.37 years).[21]

As expected, BMI differed significantly between the two groups in this study, with the obese group demonstrating a notably higher mean BMI (30.13±2.39 kg/m²) compared

to the healthy group (21.88±1.87 kg/m²; p<0.001). This aligns with Wang et al, who reported higher BMI values among overweight individuals relative to those of normal weight.[21]

The present study also revealed significant differences in lipid parameters between the groups. Obese participants exhibited markedly elevated triglyceride levels (188.53±36.93 mg/dl versus 145.30±32.[22] mg/dl; p<0.001) and significantly lower HDL-C levels (39.43±5.93 mg/dl versus 47.43±7.93 mg/dl; p=0.001). AIP, a sensitive marker of atherogenic risk, was markedly elevated in obese individuals. This aligns with studies demonstrating AIP as a strong predictor of subclinical atherosclerosis. These findings are consistent with the well-established relationship between obesity, hypertriglyceridemia, and reduced HDL-C. However, Javardi et al reported no significant differences in TC, TG, LDL, or HDL between overweight/obese and normal-weight adults, although they did observe a significant difference in AIP (p=0.014).[20]

Regression analyses in the present study demonstrated strong and meaningful associations between obesity, lipid parameters, and serum zinc levels. BMI showed a strong negative correlation with serum zinc (r=−0.797, p<0.001), while TG revealed a moderate negative correlation (r=−0.591, p<0.001). Conversely, HDL-C exhibited a moderate positive correlation with zinc (r=0.616, p<0.001). The negative correlations of serum zinc with BMI and TG and its positive correlation with HDL-C indicate intricate interactions between micronutrient status and lipid metabolism.

Several previous studies support the findings of the present research regarding the relationship between obesity, serum zinc status, and lipid parameters. Rios-Lugo et al reported significantly lower serum zinc levels among overweight and obese individuals compared to normal-weight controls, along with a strong negative correlation between BMI and zinc concentration (r=–0.663, p<0.001).[22] Similarly, Soskic et al documented reduced serum zinc levels in obese adults, and further demonstrated that zinc levels were negatively correlated with triglycerides and BMI, but positively correlated with HDL-cholesterol, reinforcing the beneficial association between zinc status and lipid metabolism.[23]

In pediatric populations, Gawad et al observed that obese children and adolescents had markedly lower zinc levels compared to non-obese controls. Their results showed a significant positive correlation between serum zinc and HDL (r=0.511, p<0.05), highlighting the potential protective role of zinc even at younger ages.[24] Zaky et al further contributed to this evidence by demonstrating an inverse relationship between serum zinc and anthropometric markers of adiposity, including BMI and waist circumference, while also reporting a positive association between zinc and HDL-C among obese individuals.[25]

Comparable findings were reported by Javardi et al., who documented positive correlations between BMI and indices such as AI, TI, CSI, SFA, MUFA, PUFA, and the ω-6/ω-3 ratio with AIP, while h/H showed a negative correlation. They also reported a significant correlation between BMI and AIP (p=0.045, R=0.408).[20]

AIP, a relatively new composite lipid marker, has gained recognition for its strong predictive value in assessing cardiovascular risk.[26-29] Previous studies support its role as a sensitive biomarker for atherosclerosis and related cardiovascular disorders. For instance, Karadağ et al reported an AUC of 0.66 for AIP in diagnosing heart failure, with a sensitivity of 68% at a cutoff value of 0.47.[26] Furthermore, AIP has been proposed as a key marker for identifying subclinical atherosclerosis, and Khosravi et al noted a sensitivity close to 90% for detecting unstable coronary plaques at a cutoff value of 0.62.[27-29]

Several studies have further highlighted the strong link between AIP and obesity. Zhang et al demonstrated a significant association between AIP and obesity status, while Zhu et al showed that replacing HDL-C and TG with AIP improved obesity risk prediction significantly (AUC improvement=0.011, p=0.011).[31] These findings are biologically plausible, as obesity-associated insulin resistance is known to drive metabolic dyslipidemia, particularly through mechanisms involving cholesteryl ester transfer proteins (CETP), which alter LDL and HDL particle composition.[32,33]

Javardi et al also reported that overweight and obese individuals frequently exhibit comparable lipid abnormalities, supporting observations from prior studies.[20,34-36] Similarly, Wang et al demonstrated that increases in AIP were strongly associated with higher rates of obesity, suggesting that AIP may act as an independent risk factor for obesity itself.[21,29] Other studies have consistently shown positive correlations between BMI and lipid abnormalities including elevated TC, LDL-C, and TG, which collectively contribute to higher AIP values, alongside a strong negative correlation between HDL-C and AIP.[37-39]

Limitations

This study has several limitations. First, the sample size was relatively small, which may limit the generalizability of the results to the wider population. Second, the study followed a cross-sectional design, preventing the establishment of causal relationships between obesity, lipid profiles, and serum zinc levels. Third, the study relied on single-time biochemical measurements, which may not fully reflect long-term metabolic status.

CONCLUSION

The present study demonstrates a significant association between serum zinc levels and the atherogenic index in obese adults. AIP serves as a strong indicator of

cardiovascular risk. Obese individuals exhibited markedly lower serum zinc concentrations and unfavorable lipid profiles characterized by elevated triglycerides, reduced HDL-C levels, and increased AIP. These findings highlight the importance of monitoring micronutrient levels as part of the clinical evaluation of obese individuals and suggest that zinc deficiency may contribute to the metabolic disturbances commonly observed in obesity. Further studies are needed to explore whether zinc supplementation could improve metabolic outcomes in this population.

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