Association of Serum Hepatic Enzyme Level with Metabolic Syndrome in Adult Bangladeshi Population

Palash Chowdhury[1*] Md. Hafizul Islam[2] Nayeema Tasnim[2]
Upasana Barua[3] Md. Mezbah Uddin[4] Salma Akter[5]

Abstract

Background: The Metabolic Syndrome (MetS) is now considered as global pandemic. According to the findings from literature data, increased hepatic enzymes may serve as useful indicators of MetS, but there is inconsistency in the results. Current research is designed to determine the association between serum hepatic enzyme level with MetS in adult Bangladeshi population and to find out whether altered hepatic enzyme level can be used as potential biomarker for early detection of MetS.

Materials and methods: This analytical cross-sectional study included 50 subjects with MetS from Chittagong Medical College Hospital between January 2022 to December 2022. Fifty apparently healthy subjects who did not fulfilled the MetS criteria were selected for Control group. We used the modified National Cholesterol Education Program Adult Treatment Panel III criteria to diagnose MetS. Serum concentrations of Alanine Aminotransferase (ALT) Aspartate Aminotransferase (AST) Alkaline Phosphatase (ALP) and γ-glutamyl transferase (GGT) were measured and compared between groups.

Results: The participants with MetS had significantly higher mean ALT, AST, ALP and GGT levels than the non-Mets control group. The mean AST/ALT ratio was 0.67±0.19 and 0.82±0.12, respectively, in participants with and without MetS ($p<0.001$). The adjusted Odds Ratios (OR) were 6.16, 7.316 and 0.115 for elevated ALT, GGT and AST/ALT ratio respectively for MetS.

Conclusion: ALT, GGT levels and AST/ALT ratio are easy and efficient serum marker of MetS and may be helpful for epidemiological screening.

1. Clinical Pathologist of Laboratories Medicine
Chittagong Medical College, Chattogram.
2. Professor of Biochemistry (Retired)
Chittagong Medical College, Chattogram.
3. Lecturer of of Biochemistry
Chittagong Medical College, Chattogram.
4. Lecturer of Biochemistry
Rangamati Medical College, Rangamati.
5. Assistant Professor of Biochemistry
Central Medical College, Cumilla.

***Correspondence:** **Dr. Palash Chowdhury**
Cell : 01983 41 75 51
E-mail: dr.palash.chowdhury.pc@gmail.com

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Introduction

MetS is a constellation of clinical conditions, including central obesity, raised blood pressure, fasting blood glucose and atherogenic dyslipidemia co-occurring in a single individual.[1] A high prevalence of MetS is observed (Estimated pooled prevalence was 30%) and it is rising in Bangladesh.[2] Compared to adults without MetS, those with the condition have a three fold increased risk of experiencing severe cardiovascular events and a two fold increased risk of dying from them. Against this backdrop, MetS is considered a global public health issue.[3]

As per systematic review and meta-analysis, MetS has been related to a elevated risk of hepatic events, such as acute hepatic failure, hepato-cellular carcinoma, liver cirrhosis, end-stage liver diseaseand liver-related mortality.[4] The pooled evaluation revealed that patients with MetS had an overall 86% higher risk of liver-related events.[4]

Liver enzymes are commonly used biological markers to assess liver function. ALT, AST, ALP and GGT act as sensitive indicators to identify hepatocyte injury.[5] These enzymes have emerged as a topic of interest in risk assessment for diagnosing MetS. The hazards of metabolic disorders in connection with elevated levels of several liver enzymes have been investigated by an increasing number of researchers.[6,7] However, it is still up for debate which liver enzymes are more accurate markers of MetS.[8] Multiple reasearch were carried out worldwide to find out the relationship between hepatic enzyme levels and MetS, but results are conflicting.[6-11] Moreover, there was not enough information available in Bangladesh to evaluate the relationship between liver enzymes and MetS.[12-16] So this study investigated the association between liver enzymes and MetS in the adult Bangladeshi population.

Materials and methods

An cross-sectional study with analytical focus was carried out at Chittagong Medical College Hospital, Chattogram, Bangladesh from January 2022 to December 2022. The ethical review committee of Chittagong Medical College approved the study protocol (Certificate of approval no: CMC/PG/2022/854; Date 16/06/2022). After describing the study objectives and role of the participants in the study,written informed consent was obtained from the participants.

Participants were selected from Department of Endocrinology and Department of Medicine of Chittagong Medical College Hospital. According to modified NCEP ATP III criteria, MetS is diagnosed when ≥3 out of the following 5 components are present:-

i) Abdominal obesity:-Waist circumference ≥90 cm in men, ≥80 cm in women (For Asian people)

ii) Elevated fasting blood sugar :-FPG 100 mg/dl (or 5.6 mmol/L) or on drug therapy for elevated glucose.

iii) Elevated blood pressure :-SBP ≥ 130 mmHg or DBP ≥ 85 mmHg or on drug therapy for elevated blood pressure.

iv) Elevated triglycerides:-TG ≥ 150 mg/dl or on drug therapy for elevated Triglyceride.

v) Low HDL-C:- HDL-C<40 mg/dl in men, <50 mg/dl in women or on drug therapy for low HDL-C.

Adult subjects (Age >18-60 years) with or without MetS as per the modified NCEP ATP III criteria were included in this study and based on the presence of MetS, study samples were classified in two groups: Group A (Subjects who fulfilled MetS criteria) and Group B (Subjects who didn't fulfill MetS criteria).[17] Patients with known cardiovascular disease, liver disease ,renal disease, pulmonary disease, acute severe septic condition, chronic severe debilitating, diseases (e.g. Malignancy, HIV infection) were excluded. Individuals with history of alcoholism and/or smoking, who were under steatogenic drugs (e.g Amiodarone, Calciumchannel blocker, Estrogen, Tamoxifen, Valproic acid etc) and subjects receiving drugs that affect liver enzymes (e.g Salicylates, Diuretics, Ethambutol, Pyrazinamide) were also excluded.

Data were collected by a structured proforma. Physical examinations for anthropometric measurements of each subject were done. Fasting blood samples were collected from all participants and serum was separated by centrifugation in Biochemistry Department of Chittagong Medical College. Sample was be stored at 2 - 8°C for up to 7 days. Estimation of Fasting Blood Sugar (FBS) lipid profile [Total Cholesterol (TC) Triglyceride (TG) Low-Density Lipoprotein (LDL-C) and High-Density Lipoprotein (HDL-C)] Liver Enzymes (ALT, AST, ALP and GGT) were done in the laboratory by using Dimension EXL 200-Siemens, Germany and Beckman Coulter AU 480, OMC, USA.

Data were processed and analyzed by SPSS Windows version 23.0. Qualitative variables were expressed as frequency (Percentage) and compared between groups by Chi-square test. Quantitative data were expressed as mean ±SD and independent sample t test was used to test the difference between two means. Unconditional logistic regression analysis was performed to determine the odds of hepatic enzyme level status in predicting MetS. Pearson correlation was used to determine the correlation between two quantitative variables. p value <0.05 was considered statistically significant.

Results

A total number of 100 subjects with the age range of 18-60 years according to inclusion criteria were included. Fifty subjects with MetS were taken as Group A and 50 apparently healthy individuals without MetS, were taken as Group B. Table I shows that the mean age of the participants with MetS were 46.3±10.2 years, which was significantly higher than the mean age of the participants without MetS (37.1±9.6 years). Both groups were similar regarding gender distribution. Mean Body Mass Index (BMI) and Waist Circumference (WC) were significantly higher among participants with MetS than their counterparts. A significantly higher proportion of the participants with MetS reported positive family history of obesity than the control group. Mean blood pressure and proportion of participants with elevated blood pressure were significantly higher among participants with MetS than their counterpart.

Table I Demographic and clinical of the participants with and without MetS

Variables	Group A (n=50)	Group B (n=50)	p value
Age, years	46.3±10.2	37.1±9.6	<0.001†S
Sex			
Male	24 (48.0)	26 (52.0)	0.689*NS
Female	26 (52.0)	24 (48.0)	
BMI, kg/m^2	26.3±2.1	22.0±0.8	<0.001†S
WC, cm	99.8±7.8	81.1±5.0	<0.001†S
SBP, mmHg	142.2±9.2	119.3±11.2	<0.001†S
DBP, mmHg	86.7±4.5	74.4±5.5	<0.001†S
On antihypertensive	10 (20.0)	0 (0)	0.001‡S
F/H of hypertension	20 (40.0)	5 (10.0)	<0.001‡S

Data were expressed as mean ± SD or frequency (%). †Independent sample t-test, *Chi-square test. S: Significant statistically, NS: Not Significant statistically.

Table II shows that the mean FBS, TC, TG and LDL-C levels were significantly higher among the among participants with MetS than their counterpart and opposite trend was observed regarding the mean HDL-C level.

Table II Blood sugar and lipid profile levels of the participants with and without MetS

Variables	Group A (n=50)	Group B (n=50)	p value
FBS, mg/dl	145.4±48.5	97.6±13.8	<0.001†S
TC, mg/dl	199.3±38.4	149.3±24.3	<0.001†S
TG, mg/dl	262.6±86.6	115.2±29.7	<0.001†S
LDL-C, mg/dl	126.4±33.0	87.1±24.6	<0.001†S
HDL-C, mg/dl	37.8±7.0	45.7±5.8	<0.001†S

Data were expressed as mean ±SD. †Independent sample t-test, S: Significant statistically.

Table III shows that, mean serum levels of ALT, AST, ALP and GGT were higher in Group A than Group B. All the differences were significant statistically ($p<0.05$). Significantly higher proportion of the participants with MetS had elevated level of serum ALT, AST and GGT level than the participants without MetS ($p<0.05$).

Table III Liver enzyme of the participants with and without MetS

Variables	Group A (n=50)	Group B (n=50)	p value
ALT, U/L	41.7±12.6	27.2±8.9	<0.001†S
ALT category			
Normal	21 (42.0)	49 (98.0)	<0.001‡S
Elevated	29 (58.0)	1 (2.0)	
AST, U/L	28.12±9.8	22.4±7.0	<0.001†S
AST category			
Normal	10 (20.0)	23 (46.0)	0.001‡S
Elevated	40 (80.0)	27 (54.0)	
ALP, U/L	79.8±25.6	70.7±14.8	0.031†S
ALP category			
Normal	47 (94.0)	50 (100.0)	0.242*NS
Elevated	3 (6.0)	0 (0)	
GGT, U/L	48.7±14.4	25.9±8.1	<0.001†S
GGT category			
Normal	20 (40.0)	49 (98.0)	<0.001‡S
Elevated	30 (60.0)	1 (2.0)	

Data were expressed as mean ± SD or frequency (%). †Independent sample t-test;, *Chi-square test. S: Significant statistically, NS: Not Significant statistically

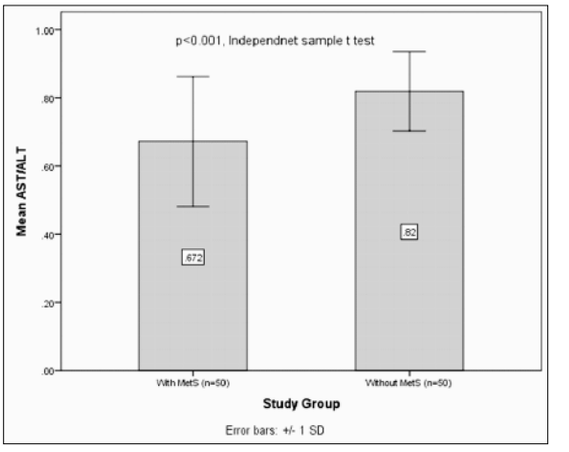

Figure 1 Mean AST/ALT ratio between participants with and without MetS

Figure 1 shows that the mean AST/ALT was 0.67±0.19 and 0.82±0.12 in the participants with and without MetS respectively.

In the whole sample, serum levels of ALT, AST, ALP and GGT significantly correlate significantly with WC, DBP, SBP, FBS and TG. On the other hand, HDL-C has a significant negative correlation with serum levels of ALT, AST, ALP and GGT. AST/ALT ratio has a significant negative correlation with WC, DBP, SBP, FBS and TG and a significant positive correlation with HDL-C level (Table IV). The total components of MetS of individuals had a positive correlation with serum ALT level ($r=0.508$, $p<0.001$) AST level ($r= 0.426$, $p<0.001$) ALP level ($r= 0.280$, $p=0.005$) and GGT level ($r= 0.612$, $p<0.001$). They negatively correlated with serum AST/ALT ratio ($r= -0.396$, $p<0.001$).

Table IV Relation of liver enzymes (ALT, AST, ALP and GGT), and AST/ALT ratio with components of MetS

Components of MetS		Liver enzymes				
		ALT	AST	ALP	GGT	AST/ALT
WC	r value	.537	.470	.376	.692	-0.327
	p value	<0.001	<0.001	<0.001	<0.001	<0.001
DBP	r value	.516	.465	.287	.641	-0.373
	p value	<0.001	<0.001	.004	<0.001	<0.001
SBP	r value	.510	.451	.322	.652	-0.341
	p value	<0.001	<0.001	<0.001	<0.001	<0.001
FBS	r value	.441	.278	.309	.468	-0.240
	p value	<0.001	.005	.002	<0.001	<0.001
TG	r value	.507	.441	.259	.634	-0.427
	p value	<0.001	<0.001	.009	<0.001	<0.001
HDL-C	r value	-.326	-.348	-.297	-.428	0.214
	p value	.001	<0.001	.003	<0.001	<0.001

r= Pearson correlation coefficient.

Table V shows the logistic regression analysis results for the presence of MetS in relation to liver enzymes adjusting for age and gender. The normal level of liver enzymes is set as the reference value, and elevated ALT and GGT levels showed a statistically significant increased risk of MetS. Compared with the normal ALT group, participants with elevated ALT had a 6.16 higher chance of having MetS. The highest effect size was detected for GGT, for which the OR value for the elevated versus normal level was 7.316, as a continuous variable with a lower AST/ALT ratio had more chance of MetS.

Table V Logistic regression analysis for the presence of MetS in relation with liver enzymes

Variables	β	OR	95% CI for OR		p value
			Lower	Upper	
ALT (Normal vs. elevated)	1.89	6.619	2.416	24.791	0.002
AST (Normal vs. elevated)	0.675	1.964	.081	5.378	0.340
ALP (Normal vs. elevated)	0.018	1.018	0.903	1.116	0.430
GGT (Normal vs. elevated)	1.99	7.316	3.878	33.553	0.003
AST/ALT ratio (Continuous)	-2.15	0.115	0.008	0.674	0.032

β : Beta coefficient, OR: Odds Ratio, CI: Confidence Interval.

Discussion

Study results showed that there was a statistical difference of hepatic enzymes levels between individuals with Mets and those without MetS. Significant associations were detected for elevated level of ALT, AST and GGT. Regression analyses revealed independent association of MetS with elevated ALT, GGT level and AST/ALT ratio. It provided more evidence that the likelihood of developing MetS and raised hepatic enzyme levels are related.

In the present study, the participants with MetS was comparatively older than the control group. Similar observation was reported by Zhang et al. where the mean age was 44.9±10.4 and 42.1±8.7 years, respectively in MetS and control groups. Advanced age is an independent predictor of MetS in previous study.[18,19]

Previous study from Bangladesh found that, GGT level, not the ALT level was significantly higher in subjects with MetS than the healthy controls.[20] In contrast, from the data presented in the current study, there was an association between the increases in four liver enzymes (ALT, AST, ALP and GGT) and MetS when compared with adults not fulfilling the diagnostic criteria of MetS. Similar results were reported from other geographic regions.[6-9] Hepatocytic fat deposition appears to be related to the development of NAFLD, especially in cases where obesity, diabetes and hypertriglyceridemia cause oxidative stress, damage and inflammation in the liver tissue. In the present research, independent association between MetS and increased ALT supports these findings. Patel et al. showed hepatic insulin resistance and NAFLD were linked to increased visceral fat deposition, raised liver enzymes and MetS.[21]

In the present study, positive linear correlations with MetS and liver enzymes were found. Moreover, given the growing quantity of the MetS constituents, the study observed significantly higher number of the subjects with elevated ALT and GGT level. Perera1 et al. and Salama et al. found thata higher chance of developing MetS is linked to elevated liver marker (ALT, AST and ALP) concentrations.[9,10] They noticed not only positive linear correlation with MetS but also with the increasing number of the MetS components.[9,10] Aliabadi et al. found that there is significant association betweenelevated ALT level and MetS components, but regarding AST level, they discovered that there are no significant associations between AST level and any of the MetS components.[22] These results suggested that, compared to AST, ALT level is more accurate liver marker for diagnosis of MetS.

After being corrected for age and sex, the results have demonstrated that the association between high ALT, GGT level and lower AST/ALT ratio were statistically significant ($p < 0.05$). In the logistic regression analysis, the highest effect size was observed for elevated GGT level in the present study (OR: 7.316). Since oxidative stress and subclinical inflammation are significant aspects of MetS, elevated GGT level may serve as a diagnostic for both conditions. A meta-analysis of prospective cohort studies demonstrates positive association between increased GGT levels and the risk of development of MetS, regardless of alcohol intake. When combined with consistency in mechanistic studies, GGT can be a useful indicator for MetSprediction.[23] The favourable positive association between GGT and MetS could be attributed to a number of different processes. Firstly, GGT is positively associated with IR and abdominal obesity measures in non-diabetic people, while the pathophysiology of MetS is likely to be significantly influenced by both abdominal obesity and IR.[24,25] Furthermore, future levels of inflammatory markers, including fibrinogen, F2- isoprostanesand C–reactive protein can be predicted by GGT.[26]

Other than the ALT and GGT level, AST/ALT ratio had an independent association with MetS in the current study. Moreover, this ration had a significant negative correlation with the number of MetS component in the present study population. Changes in ALT and AST indicates hepatocyte damage and liver disorder. In this scenario, although both ALT and AST activity accelerates, but their serum level doesnot elevate in parallel. Raised serum transaminase level is viewed as an expression of hepatic dysfunction. On the other hand, severity and prognosis of liver diseases are correlated with AST/ALT ratio. Researchers have demonstrated that AST/ALT can be utilized as a useful marker of MetS both in adolescent and adult. [27-30]

Limitations

The study was conducted in only one center, which may only represent part of the population. The study's cross-sectional design was another limitation, which couldn't demonstrate the temporal relationship between MetS and elevated liver enzymes. The absence of hepatotrophic virus screening and USG evaluation of HBS made it impossible to exclude the influence of other factors as the cause of raised hepatic enzymes.

Conclusion

In conclusion, elevated liver enzymes, especially ALT and GGT and low AST/ALT ratio are associated with MetS and correlated with many components of MetS. So, its measurements could be used as simple tests in the early diagnosis of MetS in daily medical practice and epidemiological screening. The daily medical practice in Bangladesh incorporates liver enzymes, particularly ALT and AST, in routine labs. Depending on its simplicity, affordable price and reproducibility, liver enzyme estimation may be of value to predicting MetS.

Recommendations

Based on the present findings, it is recommended to include routine screening of serum ALT and GGT levels in individuals at risk of MetS for early detection and intervention. Lifestyle modifications such as weight loss, healthy diet, regular physical activity and exercise should be prioritized to improve metabolic health. Public awareness campaigns and health care provider training programs are crucial for highlighting the link between liver enzymes and MetS. Policy initiatives should support regular health check up and integrated care approaches for managing these patients. Further research is essential to validate findings and develop targeted management strategies.

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Contribution of authors

PC-Conception, study design, data collection, data analysis, manuscript writing and final approval.
MHI-Interpretation of data, critical revision & final approval.
NT-Interpretation of data, critical revision & final approval.
UB-Acquisition of data, drafting & final approval.
MMU-Interpretation of data, drafting & final approval.
SA-Data analysis, drafting & final approval.

Disclosure

All the authors declared no conflict of interest.

References

1. Alberti KGMM, Zimmet P, Shaw J. IDF Epidemiology Task Force Consensus Group. The metabolic syndrome: A new worldwide definition. Lancet. 2005; 366(9491):1059-1062.

2. Chowdhury MZ, Anik AM, Farhana Z, Bristi PD, Abu Al Mamun BM, Uddin MJ et al. Prevalence of metabolic syndrome in Bangladesh: A systematic review and meta-analysis of the studies. BMC public health. 2018;18:1-4.

3. Jaiswal BS. A review on metabolic syndrome: a new enemy of public health. International Journal of Pharmaceutical Sciences and Research. 2012;3(8):2371.

4. Ren H, Wang J, Gao Y, Yang F, Huang W. Metabolic syndrome and liver-related events: a systematic review and meta-analysis. BMC endocrine disorders. 2019;19:1-3.

5. Gowda S, Desai PB, Hull VV, Math AA, Vernekar SN, Kulkarni SS. A review on laboratory liver function tests. The Pan African medical journal. 2009 22;3:17.

6. Kim HR, Han MA. Association between serum liver enzymes and metabolic syndrome in Korean adults. International journal of environmental research and public health. 2018;15(8):1658:1-9.

7. Liu CF, Zhou WN, Fang NY. Gamma-glutamyl transferase levels and risk of metabolic syndrome: A meta-analysis of prospective cohort studies. Int J Clin Pract. 2012; 66:692–698.

8. Lee K, Yang JH. Which liver enzymes are better indicators of metabolic syndrome in adolescents: the Fifth Korea National Health and Nutrition Examination Survey, 2010. Metabolic syndrome and related disorders. 2013;11(4):229-235.

9. Perera S, Lohsoonthorn V, Jiamjarasrangsi W, Lertmaharit S, Williams MA. Association between elevated liver enzymes and metabolic syndrome among Thai adults. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2008;2(3):171-178.

10. Salama RI, Emara MH, Eldeep AA. Relationship between Elevated Liver enzymes and Metabolic syndrome among Egyptian adults. Afro-Egyptian Journal of Infectious and Endemic Diseases. 2019;9(3):199-206.

11. Chen S, Guo X, Yu S, Zhou Y, Li Z, Sun Y. Metabolic syndrome and serum liver enzymes in the general Chinese population. International journal of environmental research and public health. 2016;13(2):223-226.

12. Hossain IA, Shah MM, Rahman MK, Ali L. Gamma glutamyl transferase is an independent determinant for the association of insulin resistance with nonalcoholic fatty liver disease in Bangladeshi adults: Association of GGT and HOMA-IR with NAFLD. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2016;10(1): S25-29.

13. Islam S, Rahman S, Haque T, Sumon AH, Ahmed AM, Ali N. Prevalence of elevated liver enzymes and its association with type 2 diabetes: A cross-sectional study in Bangladeshi adults. Endocrinology, diabetes & metabolism. 2020;3(2): e00116.

14. Kathak RR, Sumon AH, Molla NH, Hasan M, Miah R, Tuba HR et al. The association between elevated lipid profile and liver enzymes: A study on Bangladeshi adults. Scientific Reports. 2022;12(1):1-8.

15. Ali N, Sumon AH, Fariha KA, Asaduzzaman M, Kathak RR, Molla NH et al. Assessment of the relationship of serum liver enzymes activity with general and abdominal obesity in an urban Bangladeshi population. Scientific Reports. 2021;11(1):1-9.

16. Rahman S, Islam S, Haque T, Kathak RR, Ali N. Association between serum liver enzymes and hypertension: A cross-sectional study in Bangladeshi adults. BMC cardiovascular disorders. 2020;20(1):1-7.

17. Expert Panel on Detection E. Executive summary of the third report of the National Cholesterol Education Program (NCEP) expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (adult treatment panel III). Jama. 2001;285(19):2486-2497.

18. Zhang L, Ma X, Jiang Z, Zhang K, Zhang M, Li Y, et al. Liver enzymes and metabolic syndrome: A large-scale case-control study. Oncotarget. 2015;6(29):26782-26788.

19. Gouveia ÉR, Gouveia BR, Marques A, Peralta M, França C, Lima A, et al. Predictors of metabolic syndrome in adults and older adults from Amazonas, Brazil. International Journal of Environmental Research and Public Health. 2021;18(3):1303.

20. Amiruzzaman M, Roy MN, Lopa AR, Chanda M, Rahman MA, Akram A. Association of serum Gamma-Glutamyl transferase level with metabolic syndrome and insulin resistance in adults. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(1):631-642.

21. Patel DA, Srinivasan SR, Xu JH, Chen W, Berenson GS. Persistent elevation of liver function enzymes within the reference range is associated with increased cardiovascular risk in young adults: The Bogalusa Heart Study. Metabolism. 2007; 56(6): 792–798.

22. Aliabadi PK, Sohrab M, Hessami A, Afshari M, Kashi Z, Kheradmand M et al. Association between liver enzymes and metabolic syndrome: Results of the enrollment phase of Tabari cohort. Irish Journal of Medical Science. 2022;191(3):1201-1208.

23. Liu CF, Zhou WN, Fang NY. Gamma-glutamyl transferase levels and risk of metabolic syndrome: A meta-analysis of prospective cohort studies. Int J Clin Pract. 2012; 66:692–698.

24. Thamer C, Tschritter O, Haap M, Shirkavand F, Machann J, Fritsche A et al. Elevated serum GGT concentrations predict reduced insulin sensitivity and increased intrahepatic lipids. Hormone and metabolic research. 2005;37(04):246-251.

25. Ortega E, Koska J, Salbe AD, Tataranni PA, Bunt JC. Serum γ-glutamyl transpeptidase is a determinant of insulin resistance independently of adiposity in Pima Indian children. The Journal of Clinical Endocrinology & Metabolism. 2006;91(4):1419-1422.

26. Lee DH, Jacobs Jr DR, Gross M, Kiefe CI, Roseman J, Lewis CE et al. γ-glutamyl transferase is a predictor of incident diabetes and hypertension: The Coronary Artery Risk Development in Young Adults (CARDIA) Study. Clinical chemistry. 2003;49(8):1358-1366.

27. Lin S, Tang L, Jiang R, Chen Y, Yang S, Li L, Li P. The relationship between aspartate aminotransferase to alanine aminotransferase ratio and metabolic syndrome in adolescents in northeast China. Diabetes, metabolic syndrome and obesity: Targets and therapy. 2019;12:2387.

28. Yadav D, Choi E, Ahn SV, Baik SK, Cho YZ, Koh SB et al. Incremental predictive value of serum AST-to-ALT ratio for incident metabolic syndrome: The ARIRANG Study. PLoS One. 2016;11(8):e0161304.

29. Kawamoto R, Kohara K, Kusunoki T, Tabara Y, Abe M, Miki T. Alanine aminotransferase/aspartate aminotransferase ratio is the best surrogate marker for insulin resistance in non-obese Japanese adults. Cardiovascular diabetology. 2012;11(1):1-8.

30. Lu Q, Liu X, Liu S, Xie C, Liu Y, Ma C. The relationship between AST/ALT ratio and metabolic syndrome in Han young adults-AST/ALT ratio and metabolic syndrome. Recent Adv. Cardiovasc. Risk Factors. 2012;247-255.