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Implications of bilirubin testing and the prevalence of abnormal liver function tests among rural adults in Mae Ka Subdistrict, Chiang Mai, Thailand

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ABSTRACT

Background: Liver function tests (LFTs) measure the levels of specific enzymes and proteins in the blood that can change when the liver is damaged. Bilirubin, a byproduct of heme degradation, primarily from red blood cell breakdown (approximately 80%), is commonly included in these assessments. Although bilirubin and liver enzymes are well-established markers of liver function, they do not always indicate the presence of liver lesions. Therefore, for accurate diagnosis, changes in liver enzyme and bilirubin concentrations should be interpreted in the context of baseline characteristics such as pesticide exposure, alcohol consumption, and medication use.

Objectives: To investigate the prevalence of abnormal LFTs and alterations in bilirubin concentrations among adults in Mae Ka Subdistrict, Chiang Mai, Thailand.

Materials and methods: A descriptive cross-sectional study was conducted at the Department of Medical Technology, Faculty of Associated Medical Sciences, Chiang Mai University, from January to March 2024. Adults from Mae Ka Subdistrict participated in the study. A total of 102 subjects, aged 23 to 75 years (mean age 56.88±11.26 years), were included. Liver function tests, including ALT, AST, ALP, ALB, total bilirubin, and direct bilirubin, were performed using an automated analyzer (BA 400). The ALBI score and Pearson correlation were used to evaluate the relationships between liver enzymes, bilirubin levels, and baseline characteristics. A $p \leq 0.05$ was considered statistically significant. Data analysis was performed using SPSS version 17 and Microsoft Excel.

Results: A strong correlation was observed between the use of medications for diabetes mellitus, hypertension, or hyperlipidemia and abnormal LFTs. Medication use was associated with elevations in total bilirubin (TB), ALBI score, ALT, and ALP. However, not all individuals with elevated bilirubin levels had abnormal liver enzymes, and not all individuals with abnormal liver enzymes had elevated bilirubin levels. The ALBI score identified two individuals with normal liver enzyme and albumin (ALB) levels who may require closer monitoring and further investigation for potential liver disease.

Conclusion: Medication use was associated with abnormal LFTs, potentially serving as an early warning sign. The underlying non-communicable diseases (NCDs) that necessitate medication use may be the primary contributors. Early diagnosis and treatment of liver disease, along with prevention of NCDs and metabolic syndrome, may improve health outcomes in this community.

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Introduction

Liver disease remains one of the leading causes of death in Thailand. In rural areas, the most common causes of liver abnormalities include alcohol consumption, metabolic syndrome related to overweight and obesity, and chronic viral hepatitis B and C.[1] Despite medical advances, significant challenges remain in the diagnosis and management of liver disease. Early and regular monitoring through liver function tests (LFTs) is essential for preventing or reducing the risk of disease progression.[2] Recent technological developments, such as the application of artificial intelligence (AI), have enhanced the diagnostic capabilities for liver diseases.[3] However, in rural and low- to middle-income settings, the adoption of advanced healthcare technologies remains limited, primarily due to a shortage of trained healthcare professionals.[4] As a result, routine clinical chemistry tests, including LFTs, continue to be a practical and accessible tool for liver disease screening in these communities.[2]

In routine health check-ups, bilirubin testing is often not performed unless clinical symptoms such as jaundice, dark urine, pale stools, or abdominal pain are present. Some studies suggest that elevated total bilirubin could serve as a reflex indicator, reducing the need for direct (conjugated) bilirubin testing. Specifically, conjugated bilirubin measurement may not be necessary in apparently healthy males with total bilirubin levels below 21.0 µmol/L (<1.23 mg/dL) and females with levels below 17.0 µmol/L (1.0 mg/dL).[5] Bilirubin testing also has wider diagnostic and prognostic applications. For instance, Yamashita et al. introduced the albumin-bilirubin (ALBI) score as a simple method to assess primary biliary cholangitis in a large Japanese cohort. [6] In this context, bilirubin levels less than or equal to 0.6 times the upper limit of normal, or normal alkaline phosphatase (ALP), were associated with the lowest risk of liver transplantation or death.[7] Beyond its role in liver function testing, the albumin-to-bilirubin (ALB/BIL) ratio has been explored as a predictor of disease severity in patients with glaucoma.[8] Although an isolated increase in conjugated bilirubin with normal total bilirubin may not always be clinically significant, it can occasionally indicate underlying liver disease. Such isolated conjugated hyperbilirubinemia is often linked to adverse drug reactions.[9]

Although abnormalities in LFTs can be non-specific and occur in a variety of clinical conditions, they may represent the earliest indication of potentially serious disease in otherwise asymptomatic individuals. It is essential that such findings be interpreted within the context of the patient's overall clinical presentation and supported by other laboratory investigations. When LFT abnormalities are detected, further evaluation may be warranted to determine the underlying cause. This may include repeat liver function testing, imaging studies, and, in some cases, liver biopsy for definitive diagnosis.

Monitoring liver function abnormalities at the community level is especially important in populations with known risk factors such as pesticide exposure in agricultural settings or prevalent alcohol consumption. Early identification of individuals at risk for advanced fibrosis or cirrhosis could enable timely lifestyle interventions and treatment, thereby potentially halting disease progression and reducing both morbidity and mortality.[10]

This study aims to investigate the prevalence of abnormal LFTs among adults in Mae Ka Subdistrict, Chiang Mai, Thailand. The findings may inform public health strategies and educational initiatives aimed at reducing exposure to liver disease risk factors and promoting liver health in the community.

Materials and methods

Study population

A cross-sectional study was conducted with 102 participants residing in 14 villages within the Mae Ka Subdistrict, Chiang Mai Province, Thailand. Mae Ka Subdistrict is geographically located at approximately 19°19'58"N latitude and 98°57'00"E longitude. Inclusion criteria included individuals aged 18 years or older who were native residents of the selected villages. Individuals with a prior diagnosis of liver disease were excluded. Sample collection was conducted on Sunday afternoons in February 2024, and participant interviews were carried out by internship Medical Technology students. The purpose of the study was explained to all participants in the local language, and written informed consent was obtained in accordance with the ethical principles outlined in the Declaration of Helsinki (1975). The study protocol was approved by the Clinical Research Ethics Committee of the Faculty of Associated Medical Sciences, Chiang Mai University.

Data collection

A structured questionnaire was administered to collect information on participants' demographic and health-related characteristics. Data collected included age, sex, weight, height, occupation, alcohol consumption, exposure to pesticides, family history of disease, known medical conditions, and details of current medication use. The questionnaire was administered through face-to-face interviews conducted by internship Medical Technology students.

Blood chemistry analysis

A total of 5 mL of non-fasting venous blood was collected from each participant. Serum was separated by centrifugation at 2,500 rpm for 10 minutes on the same afternoon as the sample collection. All liver function tests were performed on non-fasting serum samples using an automated chemistry analyzer (BA 400). Six biochemical parameters related to liver function were assessed in this study: albumin (ALB), albumin-bilirubin (ALBI) score, total bilirubin (TB), direct bilirubin (DB), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP). The analytical principles of these assays were summarized in Table 1.

Table 1. Assay principles.

Test	**Principle** (BioSystems)
ALP (alkaline phosphatase)	Hydrolysis of 4-nitrophenylphosphate to 4-nitrophenol and 2-amino-2-methyl-1-propanol; absorbance of 4-nitrophenol measured at 405 nm.
ALT (alanine aminotransferase)	Transfer of the amino group from alanine to 2-oxoglutarate to form pyruvate and glutamate; pyruvate is reduced to lactate by lactate dehydrogenase with concomitant oxidation of NADH to NAD^+; rate of NADH depletion measured at 340 nm.
AST (aspartate aminotransferase)	Transfer of the amino group from aspartate to 2-oxoglutarate to form oxaloacetate and glutamate; oxaloacetate is reduced to malate by malate dehydrogenase with concomitant oxidation of NADH to NAD^+; rate of NADH depletion measured at 340 nm.
ALB (albumin)	Formation of a colored complex between albumin and bromocresol green; absorbance measured at 640 nm.
DB (direct bilirubin)	Reaction of conjugated bilirubin with 3,5-dichlorophenyl diazonium salt to form a diazo complex; absorbance measured at 535 nm.
TB (total bilirubin)	Coupling of both unconjugated and conjugated bilirubin with diazonium reagent in the presence of cetrimide; absorbance measured at 535 nm.

ALBI calculations

The ALBI score was calculated using a previously established formula: $(\log_{10}[\text{bilirubin}] \times 17.1 \times 0.66) + (\text{albumin} \times 10 \times -0.085)$, where bilirubin was measured in mg/dL and albumin in g/dL. ALBI grade cut-off points were defined as follows: a score ≤-2.60 was classified as grade 1; a score >-2.60 to ≤-1.39 was classified as grade 2; and a score >-1.39 was classified as grade 3. [6, 11]

Statistical analysis

Liver function test values were presented as mean±SD, and baseline characteristics were summarized as percentages. The Kolmogorov–Smirnov test was used to assess the normality of continuous data. Pearson correlation analysis was employed to evaluate associations between LFT parameters and questionnaire-derived variables. Group comparisons of LFT parameters by baseline characteristics were conducted using the independent Student's t-test and the Mann–Whitney U test. All statistical analyses were performed using SPSS version 17 (IBM Corp., Armonk, NY, USA) and Microsoft Excel (Microsoft Corp., Redmond, WA, USA), with p values ≤ 0.05 considered statistically significant.

Results

Clinical characteristics of participants

The clinical and baseline characteristics of the 102 participants were summarized in Table 2. The mean age at enrollment was 57.6 years for men and 55.8 years for women, with men comprising 61.8% of the cohort. All participants were asymptomatic for liver disease at the time of sampling. Sixty-three percent reported regular alcohol consumption, 47% reported occupational or environmental pesticide exposure, and 39% were receiving medications for diabetes mellitus, hypertension, or hyperlipidemia.

Table 2. Demographic data (N=102).

Characteristic	**N** (%)	**BMI** (mean±SD)
Gender		
Male	63 (61.8)	23.7 (±2.8)
Female	39 (38.2)	24.2 (±4.4)
Male age		
<50	16 (15.69)	24.6 (±2.8)
51-60	17 (16.67)	24.4 (±3.2)
>60	30 (29.41)	22.7 (±2.2)
Female age		
≤50	12 (11.76)	24.9 (±6.2)
51-60	12 (11.76)	24.1 (±3.4)
>60	15 (14.71)	23.8 (±3.4)
Behavior characteristics and underlying disease		
Agriculture exposed to pesticide	46 (45.1)	-
Alcohol consumption	63 (61.8)	-
Medication (diabetes mellitus/ hypertension/ hyperlipidemia)	39 (38.2)	-

Frequency distribution of self-reported alcohol consumption among study participants (N=63) was shown in Table 3. Most drinkers reported consuming alcohol one to three times per week (N=20; 31.7%), followed by occasional consumption (N=18; 28.6%). Less frequent patterns included three to five times per week (N=10; 15.9%), daily intake (N=9; 14.3%), and almost daily intake (N=6; 9.5%).

Table 3. Alcohol consumption frequency.

Alcohol consumption frequency	Count (N)
1-3 times per week	20
Occasionally	18
3-5 times per week	10
Daily	9
Almost daily	6
Total	63

The biochemical results for the cohort were presented in Table 4. Mean±SD values for each parameter were as follows: ALT 29±16 U/L, AST 26±12 U/L, ALP 94 ± 29 U/L, total bilirubin 0.50±0.27 mg/dL, direct bilirubin 0.22±0.14 mg/dL, and albumin 4.60±0.26 g/dL.

Table 4. Biochemical data of the subjects (N=102).

Parameters	Mean (±SD)		
	Males	Females	Total
ALT (U/L)	34 (±18)	21 (±8)	29 (±16)
AST (U/L)	28 (±13)	21 (±6)	26 (±12)
ALP (U/L)	97 (±32)	89 (±24)	94 (±29)
TB (mg/dL)	0.5 (±0.28)	0.4 (0.21)	0.5 (±0.27)
DB (mg/dL)	0.24 (±0.16)	0.17 (± 0.09)	0.22 (±0.14)
ALB (mg/dL)	4.6 (±0.27)	4.6 (±0.24)	4.6 (±0.26)

ALBI calculations

ALBI scores were calculated as described previously, with a mean score of -8.0535 (Table 5). Most participants (98.0%, N=98) were classified as ALBI grade 1 (score ≤-2.60), whereas two subjects (2.0%) fell into ALBI grade 2 (score >-2.60 to ≤-1.39). Both grade 2 subjects were male and had normal AST, ALT, ALP, and albumin levels but elevated total and direct bilirubin.

Table 5. ALBI score of the patients (N=102).

Parameters	Mean (±SD)
ALBI score	-8.0535 (±2.4498)
Male ALBI score	-7.4288 (±2.2582)
Female ALBI score	-9.0625 (±2.4369)
Minimum	-12.8328
Maximum	-2.1397

The subject with the highest ALBI score (-2.1397) was overweight (body mass index [BMI] 26.5 kg/m²), reported hypertension and hyperlipidemia but was not on related medications, and had histories of alcohol consumption and pesticide exposure. The second subject (ALBI -2.5887; BMI 22.5 kg/m²) was a 36-year-old male with diabetes mellitus who was receiving treatment and exhibited no liver enzyme elevations. ALBI grade cut-off values were defined as follows: ≤-2.60 (grade 1), >-2.60 to ≤-1.39 (grade 2), and >-1.39 (grade 3).[6]

Correlation between liver function tests

TB exhibited a strong positive correlation with DB, with a Pearson correlation coefficient of r=0.937 (p<0.001; Figure 1A). Given that the ALBI score was derived in part from TB, a similarly strong correlation was observed between ALBI score and DB (r=0.935; p<0.001; Figure 1B).

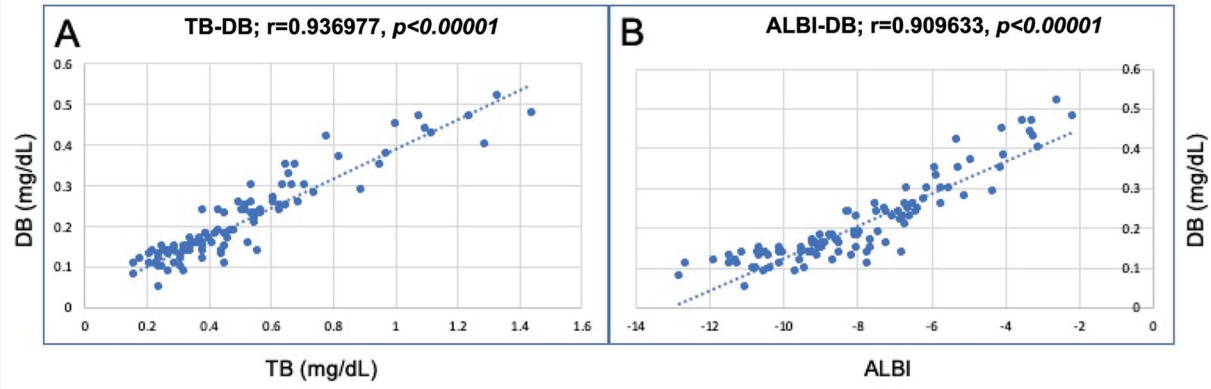


Figure 1. *Scatter plots with fitted regression lines illustrating the relationships among total bilirubin (TB), direct bilirubin (DB), and albumin-bilirubin (ALBI) score in 102 participants. A: TB versus DB (r=0.937, p<0.0001), B: ALBI score versus DB (r=0.910, p<0.0001).*

The relationship between serum AST and ALT levels in 102 adult participants from Mae Ka Subdistrict, Chiang Mai, Thailand was shown in Figure 2. Each point represents an individual's paired AST and ALT values, with the dashed line indicating the linear regression fit (r=0.783, *p*<0.0001). The moderate positive correlation suggests that elevations in AST tend to coincide with elevations in ALT, although several outliers were present at higher values of AST (up to approx. 190 U/L) and ALT (up to ~145 U/L). This association reflects concurrent hepatocellular enzyme release in response to liver injury or stress, reinforcing the utility of assessing both enzymes together in clinical screening.

In contrast, weak positive associations were found (Figure 3) between DB and AST (r=0.215; *p*=0.028), DB and ALT (r=0.198; *p*=0.041), ALT and ALP (r=0.184; *p*=0.053), and AST and ALP (r=0.162; *p*=0.075;). ALB levels were inversely related to ALP (r=-0.238; *p*=0.015) and showed a negligible negative association with AST (r=-0.031; *p*=0.742).

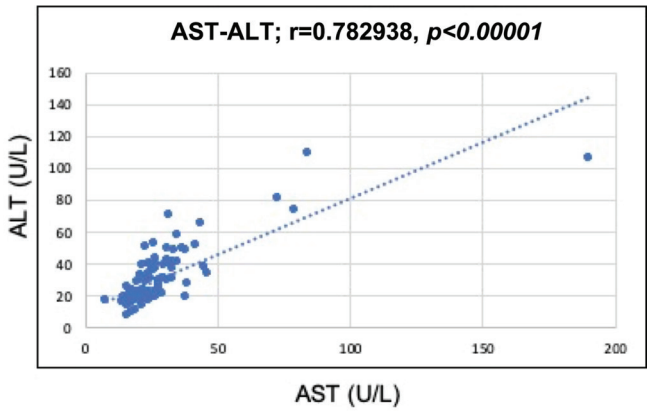


Figure 2. *Scatter plot showing the moderate positive correlation between serum AST and ALT levels in 102 participants (r=0.783, p<0.0001).*

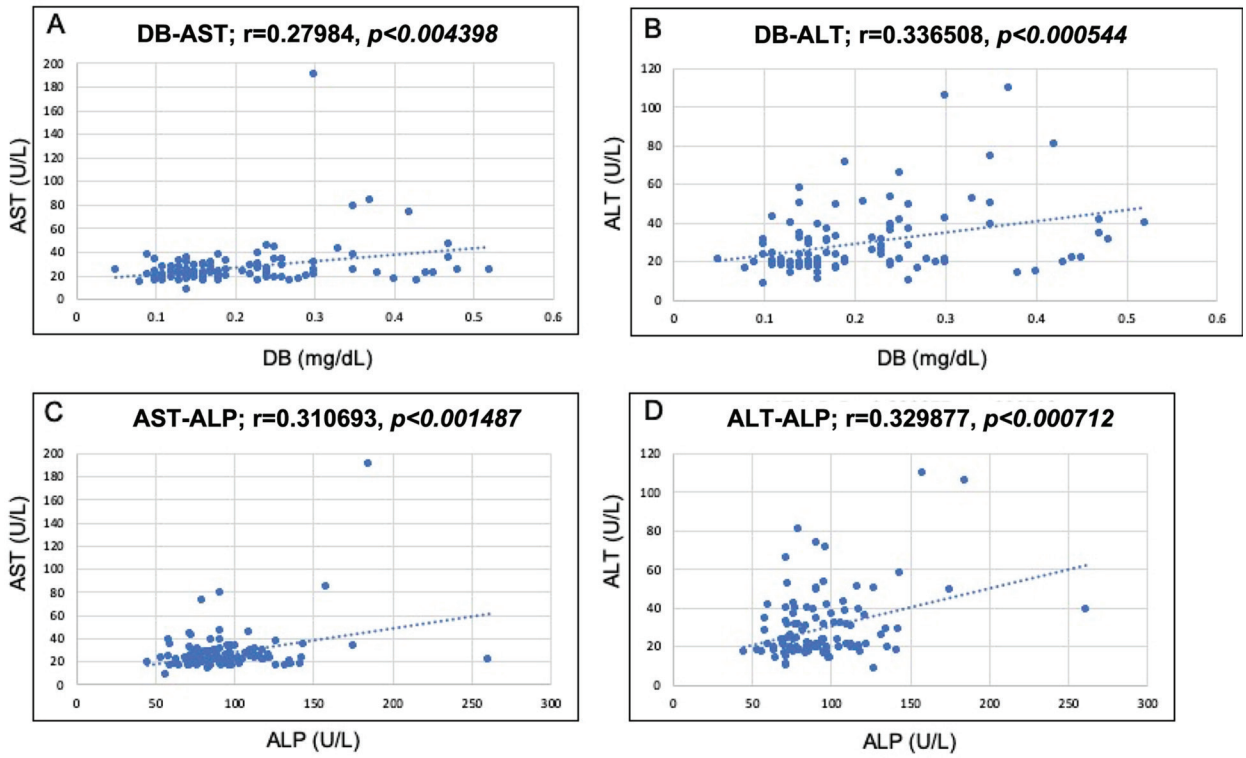


Figure 3. *Scatter plots with fitted regression lines illustrating weak positive associations among liver function parameters in 102 participants. Panel A: DB versus AST (r=0.280, p=0.004), Panel B: DB versus ALT (r=0.337, p=0.001), Panel C: AST versus ALP (r=0.311, p=0.001), Panel D: ALT versus ALP (r=0.330, p=0.001).*

Association between baseline characteristics and abnormal biochemical data

The frequency and distribution of abnormal biochemical parameters among the 102 participants were summarized in Table 6. Elevated ALT (>41 U/L) was observed in 14.7% of participants (N=15), while 6.9% (N=7) had AST levels above the reference threshold (>40 U/L). Elevated ALP was found in 11.8% of male participants (cut-off >115 U/L) and 7.8% of female participants (cut-off >105 U/L). Additionally, 6.9% (N=7) showed albumin levels exceeding 5.0 g/dL.

For bilirubin parameters, 5.9% (N=6) had elevated total bilirubin (>1.0 mg/dL), and 41.2% (N=42) had elevated direct bilirubin (>0.2 mg/dL). Notably, 14.7% (N=15) of participants showed elevated direct bilirubin while their total bilirubin remained within the normal range, suggesting a pattern of isolated conjugated hyperbilirubinemia. A total of six participants had both total and direct bilirubin elevated.

Table 6. Frequency of abnormal biochemical parameters among 102 participants. Cut-off values were based on standard laboratory reference ranges.

Biochemical (cut-off value)	**N (%)**
High ALT (>41 U/L)	15 (14.71)
High AST (>40 U/L)	7 (6.86)
High ALP male (>115U/L)	12 (11.76)
High ALP female (>105 U/L)	8 (7.84)
High ALB (>5.0 mg/dL)	7 (6.86)
High TB (>1.0 mg/dL)	6 (5.88)
High DB (>0.2 mg/dL)	42 (41.18)
High TB & high DB	6 (5.88)
High DB & other parameters & normal TB	15 (14.71)

***Note**: ALP values were sex specific. "High DB & other parameters & normal TB" refers to participants with elevated direct bilirubin and at least one other abnormal parameter, while total bilirubin remained within the normal range.*

Association between baseline characteristics and abnormal biochemical data were analyzed. Participants were stratified by alcohol consumption, pesticide exposure, and use of medications for noncommunicable diseases (NCDs: diabetes mellitus, hypertension, or hyperlipidemia). No significant differences in any liver function parameters were observed between alcohol drinkers and non-alcohol drinkers, nor between participants with and without pesticide exposure. In contrast, participants receiving NCD medications (N=40) exhibited significantly higher total bilirubin (TB), ALBI score, ALT, and ALP levels compared with those not on such medications (N=62) (Figure 4). Albumin and AST were normally distributed, so both the independent Student's t-test (for normally distributed variables) and the Mann-Whitney U test (for non–normally distributed variables) were applied to assess differences between groups. All tests with $p \leq 0.05$ considered statistically significant.

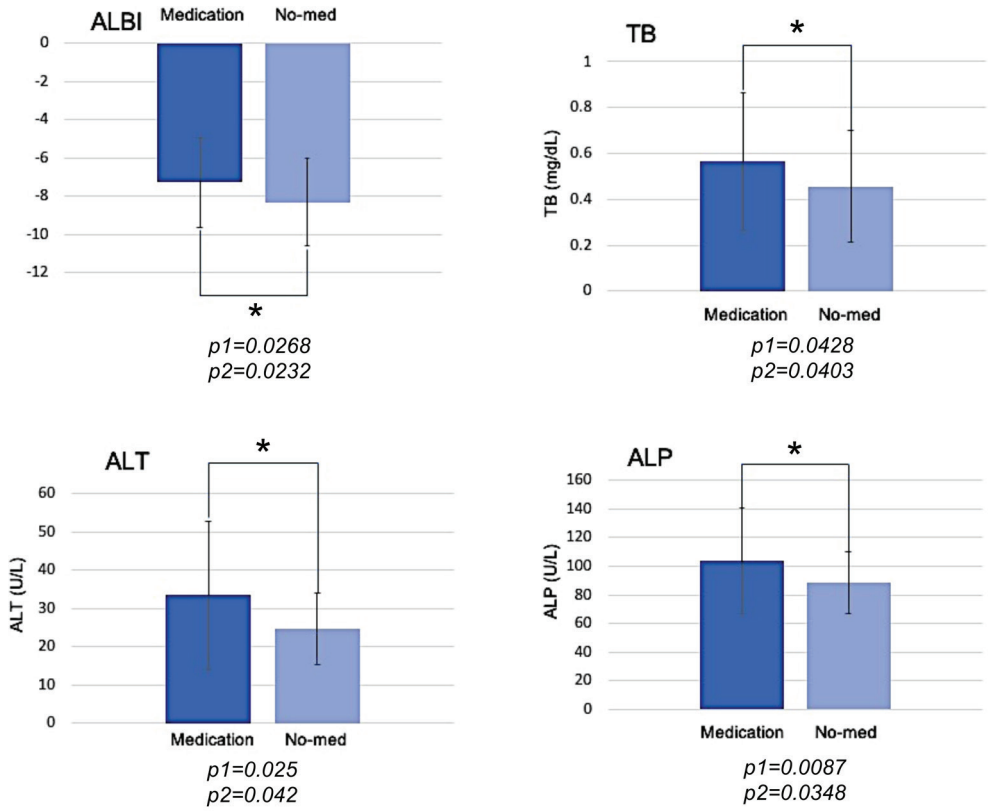


Figure 4*. Comparison of liver function parameters between participants receiving medications for diabetes mellitus, hypertension, or hyperlipidemia (Medication) and those not receiving such medications (No-med).*

Note*: Bars represent mean±SD for ALBI score (top left), total bilirubin (TB; top right), alanine aminotransferase (ALT; bottom left), and alkaline phosphatase (ALP; bottom right).* p_1 *indicates the independent Student's t-test and* p_2 *the Mann-Whitney U test.*

Discussion

The prevalence of asymptomatic abnormal LFTs varies by population and the specific assays employed.[12] In the general population, up to 8% may exhibit elevated LFTs, with rates increasing with age and in the presence of risk factors such as alcohol abuse, obesity, and chronic viral hepatitis.[2,13] Persistent LFT abnormalities are associated with an elevated risk of serious liver complications, including cirrhosis and hepatocellular carcinoma,[14] as well as extrahepatic sequelae such as fluid retention and cognitive impairment.[15,16] Identification of abnormal LFTs is therefore critical to prompt investigation of underlying causes and to guide interventions ranging from lifestyle modification to pharmacotherapy.[17] Notably, several commonly prescribed medications including antihypertensives (e.g., amlodipine, losartan),[18-20] lipid-lowering agents, and antihyperglycemic drugs,[21-23] have been implicated in drug-induced liver enzyme elevations. In addition, hypertension itself may contribute to increased levels of ALT and ALP.[24]

The liver plays a crucial role in processing and eliminating bilirubin from the body. Elevated bilirubin levels, known as hyperbilirubinemia, can indicate underlying hepatic conditions such as hepatitis, inflammation, cirrhosis, biliary obstruction, or hemolytic anemia. Occasionally, a paradoxical pattern is observed in which conjugated (direct) bilirubin is elevated while total bilirubin remains within the normal range. Typically, an increase in total bilirubin reflects elevations in both unconjugated and conjugated fractions. However, in some instances, an isolated rise in direct bilirubin may occur despite a normal total bilirubin level.

This paradoxical result can be difficult to interpret and often requires further investigation. While the exact mechanisms are not fully understood, possible contributing factors include mild cholestasis, early hepatocellular dysfunction, and analytical variability. A previous report described cases in which total bilirubin appeared normal while direct bilirubin levels were higher than total bilirubin, attributed to assay interference by paraproteins in patients with multiple myeloma.[25] It is important to note that conjugated bilirubin is produced within hepatocytes. Previous studies have suggested that direct bilirubin may be more useful than total bilirubin in predicting clinical outcomes in patients with liver cirrhosis.[26] In the absence of analytical interference such as paraproteins, elevated direct bilirubin may serve as an early indicator of liver dysfunction, even when other liver enzymes such as ALT, AST, ALP, and albumin remain within the reference range.

Based on our findings, it is recommended that both total and direct bilirubin be included in routine LFT screening, particularly in populations with known risk factors such as noncommunicable diseases, pesticide exposure, or alcohol consumption. In this study, 14.71% of participants showed elevated direct bilirubin levels despite having total bilirubin within the normal range, reinforcing the clinical value of assessing both parameters.

In this study, the ALBI score was calculated based on a previously established model originally developed for grading the risk of hepatocellular carcinoma.[27] It has also been validated as a prognostic tool in patients with primary biliary cholangitis.[6,28] At first glance, the ALBI score appeared to have limited applicability in this cohort, as all participants were asymptomatic for liver disease. However, two notable cases were identified with ALBI scores within grade 2.

The participant with the highest ALBI score was a 60-year-old male with a score of -2.1397 and a body mass index (BMI) of 26.5 kg/m². He showed no elevation in liver enzymes, yet his questionnaire responses indicated a history of hypertension and hyperlipidemia, though he was not receiving any medications. The second case was a 36-year-old male with an ALBI score of -2.5887 and a BMI of 22.5 kg/m². He also had normal liver enzyme levels but reported having diabetes and was on antidiabetic medication. Both individuals demonstrated elevated total and direct bilirubin levels. These findings highlight the potential utility of bilirubin-related markers, such as the ALBI score, in detecting sub-clinical liver dysfunction, particularly in individuals with relevant baseline characteristics, even when traditional liver enzyme levels are normal.

Furthermore, this study found no significant association between pesticide exposure and abnormal LFTs. This may reflect effective training and preventive practices promoted by Agricultural Extension Officers in the region. Similarly, alcohol consumption was not significantly associated with abnormal liver function parameters. This could be due to variability in alcohol type, quantity, and frequency of intake (Table 3), which may have attenuated any observable biochemical effects in this cohort.

Limitations

This study had several key limitations: its cross-sectional design offered only a one-time snapshot and could not establish cause and effect; enrolling just 102 people from one rural subdistrict meant the results had limited statistical power and generalizability; reliance on a single, non-fasting blood draw meant enzyme and bilirubin levels could vary based on recent meals; self-reported data on alcohol use, pesticide exposure, and medication intake were vulnerable to recall bias; and the absence of screening for hepatitis, fatty liver, or other liver diseases meant undiagnosed conditions could have confounded the results. Future studies should employ larger, more diverse cohorts, fasting samples, comprehensive health screenings, and multivariable analysis.

Conclusion

The use of medications for the treatment of diabetes mellitus, hypertension, or hyperlipidemia was the primary factor associated with abnormal liver function tests (LFTs) in adults residing in Mae Ka Subdistrict, Chiang Mai, Thailand. The ALBI score successfully identified two asymptomatic cases with elevated bilirubin levels despite normal liver enzyme values. Both individuals had underlying metabolic conditions, specifically hyperlipidemia in one case and diabetes in the other. These findings highlight the potential utility of the ALBI score and bilirubin testing in detecting subclinical liver dysfunction. A comprehensive clinical evaluation and appropriate follow-up investigations remain essential to determine the clinical significance of such abnormalities in individual patients.

Ethical approval

This study is part of the Medical Technology internship for students enrolled in the Community Medical Technology course (510408) and forms part of the MOU between the Faculty of Medical Technology and the Mae Ka community, for which ethical approval has already been obtained.

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Conflict of interest

The authors declare no conflicting interests.

CRedit authorship contribution statement

Fahsai Kantawong: conceptualization, methodology, investigation (field work), formal analysis, writing – original draft, writing – review and editing, manuscript submission; **Khanittha Punturee:** investigation (field work), project administration, volunteer recruitment, coordination; **Suwatsin Kittikunnathum:** investigation (sample analysis); **Pharisa Nanthawong:** investigation (sample analysis), **Kanya Preechasuth:** manuscript editing, investigation (field work); **Chayada Sitthidet Tharinjaroen, Witida Laopajeon, Rujirek Chaiwongsa, Nutjeera Intasai, and Tanyarat Jomgeow**: investigation (field work).

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