

Non-invasive assessment of liver steatosis in children: The role of steatometry and metabolic markers

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ABSTRACT

Aim: The aim of this study was to assess the prevalence and staging of steatotic liver disease among overweight adolescents using non-invasive diagnostic methods, as well as to analyse metabolic correlations and the effectiveness of lifestyle interventions.

Materials and Methods: The study included 42 overweight children aged 12-18. Disease was diagnosed using ultrasound steatometry, shear wave elastography and biochemical indicators. Correlation analysis was performed. A six-month lifestyle modification programme was implemented, including dietary modification, physical activity and psychological support. Changes in the degree of steatosis, metabolic parameters were monitored before and after.

Results: Metabolic dysfunction-associated steatotic liver disease was detected in 88% of participants, of which 52.4% were in stage S1, 35.7% in stage S2, and 11.9% in stage S3. No fibrosis was detected in any patient. Stage S1 steatosis was asymptomatic, while stages S2 and S3 were associated with metabolic disorders, insulin resistance and micronutrient deficiencies. After the intervention, there was a significant reduction in hepatic fat accumulation, with the attenuation coefficient decreasing by 40%. Patients with stage S3 showed improvement in triglyceride levels, insulin sensitivity, and normalisation of liver enzymes.

Conclusions: Steatometry is an effective non-invasive method for diagnosing early-stage metabolic dysfunction-associated steatotic liver disease. Lifestyle interventions, including dietary correction, physical activity, and psychological support, significantly improve liver condition and metabolic parameters in adolescents. Early detection and treatment are crucial for preventing disease progression and related metabolic complications in adulthood.

KEY WORDS: steatometry, children, liver steatosis

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INTRODUCTION

Steatotic liver disease (SLD) and metabolic dysfunction-associated steatotic liver disease (MASLD) have become the most common chronic liver disease among children and adolescents [1]. The new nomenclature reflects the close relationship between the disease and metabolic dysfunction, obesity, and insulin resistance. The prevalence of MASLD in the paediatric population is increasing in parallel with the global obesity epidemic, affecting up to 40% of obese children [2].

Unhealthy diet, sedentary lifestyle, and genetic predisposition are the provocative factors in the complex and multifactorial pathogenesis of MASLD in children [3]. According to recent studies, children may have a more aggressive form of the disease than adults, with a higher likelihood of developing liver fibrosis and metabolic dysfunction-associated steatohepatitis (MASH) [4]. Routine screening of high-risk paediatric groups, especially those with obesity, type 2 diabetes or a family history of metabolic disorders, is important

for early detection and treatment, as MASLD is often asymptomatic in its early stages [5].

Lifestyle modifications, including weight loss, optimisation of diet and eating habits, and increased physical activity, are the basis for the treatment of MASLD in children [6]. Recent clinical studies have investigated pharmacological treatments, such as glucagon-like peptide-1 receptor agonists (GLP-1RAs), which have shown promise in treating obesity and related liver problems [7]. Despite these advances, lifestyle modification remains the cornerstone of therapy.

Given the trend of MASLD spreading among the paediatric population, there is an urgent need to raise awareness, implement effective screening programmes, and develop evidence-based treatment strategies to mitigate delayed liver-related complications [8].

The use of steatometry in paediatric ultrasound diagnostics

Steatometry, a non-invasive ultrasound technique, has become a useful tool in paediatric hepatology for

assessing liver steatosis. This method determines the amount of fat in the liver and provides a reliable assessment of the severity of steatosis by measuring the attenuation of ultrasound waves as they pass through liver tissue [9-12].

Steatometry has a number of significant advantages in clinical practice with paediatric patients. It is a quick, bedside procedure that does not require sedation, making it particularly suitable for children [13]. It also avoids the risks associated with ionising radiation and invasive liver biopsy. Studies have shown its effectiveness in detecting and quantifying liver fat in children with metabolic dysfunction-associated steatotic liver disease (MASLD), a condition that is increasingly common in the paediatric population [14].

The standardisation and validation of ultrasound methods for measuring liver fat have been greatly facilitated by the work of G. Ferraioli, V. Cantisani, R. Bar, I. Sporea, S. Wilson and others. Their research demonstrates the importance of standardising procedures and training operators to ensure accurate and repeatable measurements in both adults and children [10, 14-19]. Liver disease in children is often assessed using ultrasound methods such as quantitative ultrasound (QUS) and controlled attenuation parameter (CAP). The degree of attenuation of the ultrasound wave caused by fat deposition in the liver is measured using CAP, which is integrated into transient elastography devices and has been validated against liver biopsy results [16]. Modern QUS methods, such as reverse scattering and ultrasound attenuation coefficients, have also shown promise in detecting liver steatosis in children [17].

In addition, children at risk for metabolic dysfunction-associated steatotic liver disease (MASLD) should undergo regular screening and monitoring for liver disease, including the use of non-invasive imaging methods such as steatometry, in accordance with European and American medical clinical guidelines [18].

Thus, steatometry is an important achievement in paediatric hepatology, as it provides a non-invasive, consistent and child-friendly way to assess liver fat levels. The introduction of steatometry into clinical practice can help control liver disease in children, and thus improve treatment outcomes.

AIM

The aim of this study was to assess the prevalence and staging of steatotic liver disease among overweight adolescents using non-invasive diagnostic methods, as well as to analyse metabolic correlations and the effectiveness of lifestyle interventions.

MATERIALS AND METHODS

Place and time of the study – the study was conducted at the Children's Clinical City Hospital (Uzhhorod, Ukraine) during the period 2023–2025.

Characteristics of the study and control group – the study included 42 adolescents aged 12–18 years with excess body weight. Inclusion criteria were: the presence of excess body weight or obesity (BMI >85th percentile for age and sex), as well as informed consent of patients and their parents. Exclusion criteria: viral hepatitis, autoimmune liver diseases, hereditary and metabolic liver diseases, use of hepatotoxic drugs. The study group included adolescents of both sexes (29 boys, 13 girls).

Description of the method – all patients underwent a comprehensive examination, including: laboratory methods: complete blood count (hemoglobin, erythrocytes, leukocytes, ESR, leukocyte formula), biochemical parameters: total protein, albumin, urea, creatinine, bilirubin and its fractions, ALT, AST, thymol test, fasting glucose, insulin, HOMA-IR index, lipid profile (total cholesterol, triglycerides, HDL, LDL), electrolytes and trace elements (potassium, sodium, calcium, magnesium, iron, zinc, selenium, etc.), blood pH level, urinalysis, stool examination for helminth eggs, rheumatic tests.

Instrumental methods: ultrasound of abdominal organs, liver, thyroid gland, spleen, heart, urinary system, ECG, EEG, steatometry and liver elastography by shear wave method using the Soneus P7 device (Ukraine).

The degree of steatosis was determined by the attenuation coefficient of the ultrasound wave.

After the initial examination, all patients underwent a 6-month lifestyle modification program, including: diet therapy according to the "Healthy Eating Plate" principle (recommendations of the Ukrainian Association of Dietitians), keeping a food diary, regular physical activity with cardiac monitoring, psychological counseling and motivational support, correction of micronutrient deficiencies.

Patients with stage S3 additionally received: therapy of depressive conditions, correction of functional disorders of the gastrointestinal tract and endocrine disorders, administration of ursodeoxycholic acid (UDCA) at a dose of ½ of the standard therapeutic dose for a long period, up to 3–4 months depending on the condition.

Assessment of parameters was carried out before and after 6 months of observation.

The study shows that metabolic disorders increase with the progression of the disease and, as a rule, are absent at the early stages. Steatometry is an informative non-invasive method for early diagnosis of liver steatosis in adolescents with excess body weight, allowing to quantitatively assess the degree of fatty infiltration of the liver.

Table 1. Characteristics of steatosis stages according to the number of patients, attenuation coefficient and presence of liver fibrosis

Stages of steatosis	Number of patients, %	Attenuation coefficient, dB/cm ³	Fibrosis, kPa
S1 (2.0 - 2.2 dB/cm ³)	52.4±7.7%	2.2±0.043	3.0± 0.04
S2 (2.3 - 2.9 dB/cm ³)	35.7±7.4%	2.6±0.052	3.4± 0.06
S3 (3.0 dB/cm ³ and above)	11.9±5.0%	3.0± 0.089	4.6± 0.09

Source: compiled by the authors of this study

ETHICS

This work complies with the principles of the Declaration of Helsinki.

RESULTS

STEATOMETRY AND STAGING

According to the results of steatometry at the beginning of the study, 88% (37) of participants were diagnosed with hepatic steatosis. The distribution by stages was as follows (Table 1):

- Stage S1 (mild steatosis): 52.4± 7.7%
- Stage S2 (moderate steatosis): 35.7± 7.4%
- Stage S3 (severe steatosis): 9± 5.0%.

According to the classification, steatometry indicators correlate well with the results of histological examination, where 5-33% fat corresponds to stage S1 steatosis, 34-66% to stage S2, and more than 66% to stage S3.

Shear wave elastography did not reveal any fibrotic changes in any of the patients (Table 1).

LABORATORY TEST RESULTS

In patients with MASLD, general clinical laboratory tests were uninformative. While metabolic disorders were observed in stages 2 and 3, no deviations from the norm were observed in stage S1. Biochemical indicators of liver function in patients with 0-2 steatosis remained within the reference ranges. Although bilirubin and its fractions mostly remained within normal limits, patients with stage S3 steatosis had minor deviations, such as a moderate increase in ALT and AST levels.

CORRELATION ANALYSIS

Multivariate correlation analysis revealed several key patterns:

- Stage S1 steatosis (Fig. 1) was asymptomatic, associated with an unbalanced diet ($r=0.8$), an increase in BMI after 10 years ($r=0.8$), and sometimes accompanied by carbohydrate metabolism disorders (HOMA index 3.0, $r=1$) and a slight decrease in vitamin D levels ($r=0.7$).
- Stage S2 steatosis (Fig. 2) correlated with increased BMI from 2-3 years of age (BMI > 30 at the time of inclusion in the study, $r=0.7$), hereditary factors (one parent with

obesity, $r=0.8$), eating disorders ($r=0.8$), depression ($r=0.6$), dyspeptic symptoms (bloating, constipation, epigastric discomfort, $r=0.8$), HOMA index 8.0 ($r=0.8$), impaired glucose tolerance (IGT), elevated triglyceride levels ($r=0.8$) and significant micronutrient deficiencies (zinc, selenium, magnesium, iron, vitamin D).

- Stage S3 steatosis was associated with the development of early obesity (0-3 years, $r=0.8$), parental obesity (one or both parents, $r=0.7$), eating disorders with uncontrolled cravings for sweets ($r=0.7$), depression ($r=0.8$), sleep disorders ($r=0.5$), BMI > 30 <math>t/ > at the time of inclusion ($r=0.9$), digestive and systemic symptoms (epigastric discomfort, bloating, constipation, headache, dizziness, weakness, arterial hypertension, $r=0.8$), HOMA index > 10.0 ($r=0.9$), impaired glucose tolerance (IGT), elevated triglyceride and cholesterol levels ($r=0.8$) and signs of steatohepatitis (elevated AST ($r=0.8$), ALT and inflammatory markers such as ASL-O, CRP > 2 mg/l).

LIFESTYLE INTERVENTION AND FOLLOW-UP

After the initial examination, patients with MASLD received therapeutic intervention and lifestyle modification. To encourage a healthy lifestyle, they received information sessions, participated in motivational consultations with a psychologist, and kept a food diary for a month. For six months, they followed the dietary recommendations of the Ukrainian Association of Dietitians (the 'Healthy Eating Plate'). Each of them was given a structured physical activity programme with cardiovascular monitoring, as well as psychological support to overcome emotional distress and prevent relapses. Micronutrient status was also corrected.

Patients with stage S3 MASLD were prescribed additional treatment for depressive symptoms, functional disorders of the gastrointestinal tract, endocrine disorders, and cardiovascular risk factors. To improve bile rheology, half the usual dose of ursodeoxycholic acid (UDCA) was prescribed for a prolonged period.

FURTHER ASSESSMENT

Testing of the control group showed that adherence to lifestyle modifications and dietary recommendations

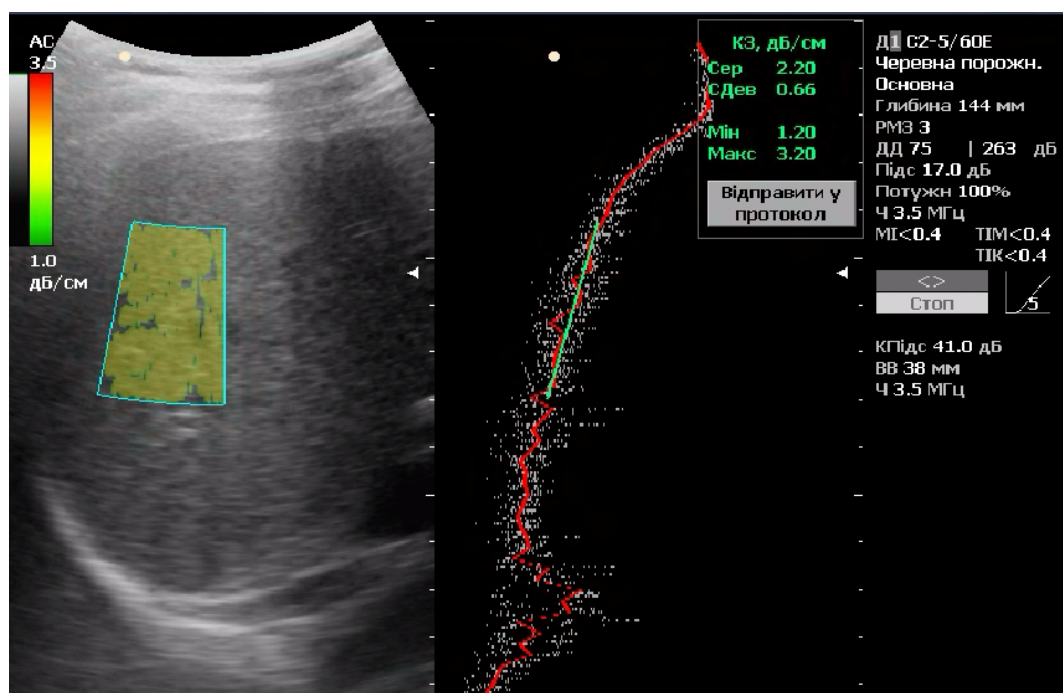


Fig. 1. Quantitative ultrasound liver steatometry, stage S1 steatosis
Picture taken by the authors

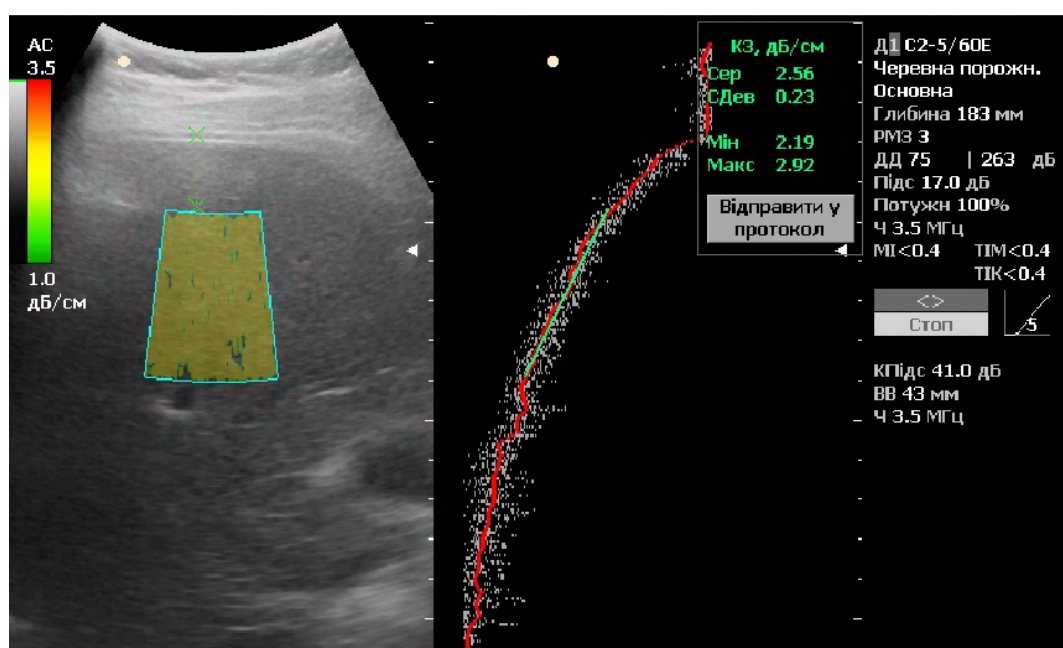


Fig. 2. Quantitative ultrasound liver steatometry, stage S2 steatosis
Picture taken by the authors

contributed to a significant improvement in liver condition, especially in patients with stage S1-2 steatosis. Steatometry data showed a probable 40% reduction ($r=1.0$) in the attenuation coefficient, as well as a reduction in triglyceride levels and the HOMA index. In patients with stage S3 steatosis, ALT and AST levels normalised, which also indicates an improvement in liver function.

The results obtained prove the value of early lifestyle modification in the treatment of mild and moderate steatotic liver disease in adolescents and the need for a multidisciplinary approach in more severe cases.

DISCUSSION

Formerly known as non-alcoholic fatty liver disease (NAFLD), metabolic dysfunction-associated steatotic liver disease (MASLD) has become the most common chronic liver disease in children and adolescents and is closely associated with the increase in obesity and metabolic syndrome worldwide [21]. 88% of participants in our study aged 12-18 who were overweight were diagnosed with steatotic liver disease; They were distributed as follows: 52.4% had mild steatosis (stage S1), 35.7% had moderate steatosis (stage S2), and 11.9% had severe steatosis (stage S3). These results are gener-

ally consistent with previous studies that have shown a strong association between adolescent obesity and the development of MASLD [22].

Among other things, no fibrotic changes were detected in any of the participants based on shear wave elastography results. These observations are consistent with reports that steatosis is common in obese adolescents, but fibrosis remains a less frequent but serious problem due to the potential for rapid progression of steatosis to fibrosis, and then to cirrhosis and complications related to liver function [23].

According to laboratory analyses, general clinical tests were proved ineffective for patients with MASLD. In patients with stages 0-2 steatosis, liver function markers remained within reference ranges, and only at stage 3 was there a moderate increase in ALT and AST. These results emphasise the need for imaging methods for early diagnosis and are consistent with previous studies, where researchers suggested that liver enzyme levels may remain within normal limits in the early stages of MASLD [24].

Our multiparametric correlation analysis revealed several key patterns:

- Stage S1 steatosis was asymptomatic, associated with an unbalanced diet, an increase in BMI after 10 years, and a slight decrease in vitamin D levels
- Stage S2 steatosis correlated with an increase in BMI at the age of 2-3 years, familial obesity, eating disorders, depression, dyspeptic symptoms, prediabetes (HOMA index 8.0), elevated triglyceride levels, and significant micronutrient deficiencies (zinc, selenium, magnesium, iron, vitamin D)
- Stage S3 steatosis was associated with early onset of obesity (at 0-3 years of age), parental obesity, intense craving for sweets, sleep disorders, arterial hypertension, severe insulin resistance (HOMA index >10.0), elevated triglyceride and cholesterol levels, and signs of steatohepatitis (elevated AST, ALT, C-reactive protein >2 mg/L).

The results obtained highlight the multifaceted aetiology of MASLD, which encompasses metabolic disorders, early-onset weight gain, dietary practices, psychological factors, and genetic predisposition [25]. Therefore, a multidisciplinary approach is necessary for the effective prevention and treatment of such patients.

Evidence has been obtained that diet and physical interventions aimed at lifestyle changes can improve steatosis and the risk of liver fibrosis in children. Our study used a 6-month programme that included structured physical activity, psychological support, and the 'Healthy Eating Plate' developed by the Ukrainian Association of Dietitians. Assessments conducted after the intervention showed that patients with stage S3

steatosis had normalised ALT and AST levels, reduced triglyceride levels, improved insulin sensitivity (reduced HOMA index) and a 40% reduction in the attenuation coefficient. These results are consistent with previous studies that have shown how effective lifestyle modification can be in influencing the course of MASLD in children and adolescents [24].

It is noteworthy that even a moderate reduction in excess weight significantly improved liver steatosis and metabolism, indicating that diet quality and increased physical activity play a key role in the treatment of MASLD. Similarly, previous studies have shown that lifestyle interventions significantly improve BMI, aminotransferase levels, and liver steatosis for children with MASLD [24].

The absence of fibrotic changes in the liver among the patients included in the study may be due to the relatively short duration of the disease and early intervention in this cohort. Longitudinal studies are needed to assess the long-term impact of lifestyle changes on the development of fibrosis in children with MASLD. In addition, more studies should be conducted in different populations to investigate genetic factors, such as PNPLA3 polymorphisms, which are associated with an increased risk of MASLD and fibrosis [22].

The study confirms the importance of early lifestyle intervention for the treatment of MASLD in adolescents. The implementation of comprehensive programmes targeting dietary habits, physical activity and psychological well-being can lead to significant improvements in liver health and metabolic function. Early detection and intervention are crucial to preventing disease progression and related complications. Future research should focus on identifying risk groups, elucidating the genetic and environmental factors that contribute to the development of MASLD, and developing individualised intervention strategies to effectively combat this growing problem in the healthcare system.

CONCLUSIONS

1. Steatometry is a modern, non-invasive and accurate ultrasound quantitative method for assessing liver fat content. It is practically the only method available for quantitative assessment of stage S1 steatosis in overweight children when biochemical markers remain unchanged and clinical symptoms are absent.
2. Assessment of the attenuation coefficient before and after treatment is useful for monitoring liver recovery and evaluating therapeutic efficacy.
3. Dietary adjustments, sleep hygiene, and appropriate physical activity during adolescence can significantly improve attenuation coefficient (AC) values

in stage S1 and S2 steatosis, even with minimal BMI reduction, without pharmacological intervention. Improvements in liver enzyme function, lipid profile, and micronutrient status in stage S2 and S3 steatosis contribute to the stabilisation or reduction of AC.

4. MASLD is an important but currently missing link in the clinical trajectory of overweight patients, although early diagnosis and treatment can prevent metabolic syndrome, steatohepatitis, and other complications in adulthood.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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