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Original Article

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Comparison of Non-invasive Methods for Diagnosis of Non-alcoholic Fatty Liver Disease Before Bariatric Surgery and Postoperative Follow-up in Obese Patients

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ABSTRACT

Purpose: This study aims to identify the most accurate and useful non-invasive method to replace liver biopsy for the diagnosis of non-alcoholic fatty liver disease (NAFLD) before bariatric surgery and postoperative follow-up in morbidly obese patients.
Materials and Methods: This single-center study is a retrospective analysis of prospectively collected data from 68 morbidly obese patients who underwent laparoscopic sleeve gastrectomy with intraoperative liver biopsy. Preoperative non-invasive diagnostic methods, including fatty liver index, NAFLD fibrosis score, enhanced liver fibrosis score, FibroScan, magnetic resonance imaging-proton density fat fraction (MRI-PDFF), magnetic resonance spectroscopy (MRS)-PDFF, and magnetic resonance elastography (MRE) were compared against liver biopsy results. Diagnostic performance was assessed using Spearman's correlation and receiver operating characteristic (ROC) curve analysis.
Results: Liver biopsy confirmed the presence of steatosis in 92.7% of patients, Nonalcoholic Steatohepatitis (NASH) in 64.7%, and liver fibrosis (≥F1) in 72.0%. MRI-PDFF and MRS-PDFF demonstrated the highest diagnostic accuracy for NASH, with the strongest correlation with histological findings. For liver fibrosis, MRE showed the strongest correlation with histological fibrosis stage, while FibroScan-Liver Stiffness Measurement (LSM) demonstrated better diagnostic performance in ROC analysis. However, the overall diagnostic quality of non-invasive methods for fibrosis assessment remained modest, with no method achieving a quality value above 0.6.
Conclusion: MRI-PDFF and MRS-PDFF were the most accurate noninvasive methods for diagnosing NASH in morbidly obese patients. For liver fibrosis, FibroScan-LSM may be more suitable for detection, while MRE may better reflect fibrosis severity. Further studies are needed to assess the cost-effectiveness and clinical applicability of these methods.

Keywords: Nonalcoholic steatohepatitis; Liver fibrosis; Magnetic resonance imaging; Morbid obesity; Bariatric surgery

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Conflict of Interest
None of the authors have any conflict of interest.

Author Contributions
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INTRODUCTION

Non-alcoholic fatty liver disease (NAFLD) is a condition characterized by the accumulation of fat in the liver, exceeding 5%, as observed through imaging or histological tests, without significant alcohol consumption, steatogenic medications, or other chronic liver diseases. NAFLD is a spectrum that includes simple steatosis, known as NAFL, non-alcoholic steatohepatitis (NASH), and NAFLD-related cirrhosis. The condition is strongly associated with metabolic syndrome components, such as obesity and type 2 diabetes, making it a growing public health concern as the global obesity epidemic continues to rise [1-3].

The prevalence of NAFLD has increased in parallel with obesity worldwide, including in South Korea [4,5]. Estimates suggest that NAFLD affects up to 30% of the general population, 80% of individuals with obesity, and nearly 90% of patients with morbid obesity undergoing bariatric surgery [6,7]. The severity of obesity is closely linked to NAFLD progression, with more advanced stages of liver fibrosis associated with poorer prognosis. However, sustained weight loss, particularly following bariatric surgery, has been shown to significantly reduce liver fat and reverse disease progression, emphasizing the importance of weight management in treating NAFLD [8].

Accurate diagnosis and monitoring of NAFLD is critical for preventing its progression to more severe liver conditions in patients with obesity. While liver biopsy remains the gold standard for diagnosis, its invasive nature makes it unsuitable as a method for ongoing monitoring of NAFLD after surgery. In addition, regular screening and follow-up of NAFLD after bariatric surgery is often not emphasized, with the assumption that significant weight loss leads to significant improvement in NAFLD. However, because some patients may still progress to end-stage liver disease, such as cirrhosis or hepatocellular carcinoma, careful screening and timely intervention is critical. Therefore, it is important to utilize non-invasive diagnostic methods for NAFLD [9]. Non-invasive diagnostic methods for NAFLD include imaging techniques, such as liver ultrasound, transient elastography (FibroScan; Echosens, Paris, France), computed tomography (CT), and magnetic resonance imaging (MRI). Additionally, several diagnostic panels and models, such as the fatty liver index (FLI), enhanced liver fibrosis (ELF) score, NAFLD fibrosis score (NFS), and fibrosis-4 (FIB-4) index are widely used to assess liver fibrosis [10].

Despite the variety of non-invasive methods available, discrepancies in their diagnostic accuracy have been reported. Given these limitations, this study aims to compare the accuracy of non-invasive methods, including the FLI, ELF, NFS, FibroScan, and MRI liver fat measurements, against liver biopsy results in obese patients undergoing bariatric surgery. The goal is to identify the most reliable non-invasive tool for both diagnosis and follow-up, reducing reliance on liver biopsy in this high-risk population.

MATERIALS AND METHODS

1. Patient selection

This is a single-center study that retrospectively analyzed prospectively collected data. Among the patients who underwent laparoscopic sleeve gastrectomy (LSG) from March 2018 to March 2023 at Gachon University Gil Medical Center in Korea due to morbid obesity, only those who underwent liver biopsy during the LSG were included in this study. All surgeries

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during the study period were performed by one experienced bariatric surgeon (Seong Min Kim). This study protocol was approved by Institutional Review Board of Gachon University Gil Medical Center (GCIRB2023-197). Patients without results from preoperative non-invasive diagnostic methods (preoperative steatosis and fibrosis scores, FibroScan, or MRI not performed) were excluded from the study.

2. Data collection

Data were collected from the hospital electronic chart on the patient's baseline characteristics, surgical history, and pathology results of the liver biopsy performed during surgery. In addition, data were also collected on body mass index (BMI), complete blood count, electrolytes, and liver function test results before and 6 months after surgery.

3. Definition of NASH and liver fibrosis

The presence of hepatocyte ballooning degeneration in association with steatosis is the key histological feature that distinguishes NASH from simple steatosis. The 'NAFLD activity score' is the most widely used histological grading and staging system for NAFLD. For a more accurate pathologic diagnosis of NASH [11], referring to the paper published by Bedossa and FLIP Pathology Consortium [12], NASH was diagnosed in this study using the 'fatty liver inhibition of progression' (FLIP) definition (presence of steatosis, hepatocellular dilatation, and hepatic lobe inflammation with at least 1 point in each category) based on the SAF (steatosis, activity, fibrosis) score. Fibrosis was diagnosed according to fibrosis grade (≥F1). Patients were categorized according to the presence of NASH and liver cirrhosis, and the utility of non-invasive methods to diagnose NASH and liver cirrhosis was analyzed.

4. Non-invasive methods for diagnosis of NASH and liver fibrosis

Non-invasive methods to diagnose NASH included preoperative FLI (score calculated by putting BMI, waist circumference, triglycerides, and gamma-glutamyl transferase values into a formula) [13], FibroScan-controlled attenuation parameter (CAP), MRI-proton density fat fraction (MRI-PDFF), and magnetic resonance spectroscopy (MRS)-PDFF values, which were compared with liver biopsy pathology results to determine whether NASH was diagnosed.

Non-invasive methods to diagnose liver fibrosis include ELF (calculated as the value of hyaluronic acid, procollagen III amino-terminal peptide, and tissue inhibitor of matrix metalloproteinase 1) [14], NFS (calculated by age, BMI, diabetes diagnosis or impaired fasting glucose, aspartate aminotransferase [AST]/alanine aminotransferase [ALT] ratio, platelet count, and albumin levels into a formula) [15], the FIB-4 index (calculated AST, ALT, platelet count, and age into a formula) [16], FibroScan-liver stiffness measurement (LSM), and magnetic resonance elastography (MRE).

5. Statistical analysis

The collected clinical data were analyzed using IBM SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). For comparison of patient groups, χ^2 test or Fisher's exact test was used for categorical variables, and Student's t-test was used for continuous variables. Results are presented as mean ± standard deviation for continuous variables and frequency (%) for categorical variables, with results defined as statistically significant if the P value is less than 0.05 with a 95% confidence interval. To assess the correlation between histological findings (steatosis grade and fibrosis stage) and various non-invasive diagnostic methods, Spearman's rank correlation coefficient was calculated. Correlation strength was interpreted as follows: negligible (<0.2), weak (0.2–0.4), moderate (0.4–0.6), strong (0.6–0.8), and very strong

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(>0.8). Receiver operating characteristic curve (ROC) analysis was performed to evaluate the utility and accuracy of noninvasive tests as alternatives to liver biopsy.

RESULTS

1. Patients selection

A total of 799 patients underwent bariatric surgery at our institution during the study period. Of these, patients who did not undergo intraoperative liver biopsy were excluded (n=702). Among the remaining 77 patients who underwent liver biopsy, an additional 3 patients without preoperative abdominal MRI scans and 6 patients without sufficient data for steatosis and fibrosis score calculation were excluded. Sixty-eight patients with intraoperative liver biopsy pathology results who also had results of all preoperative parameters required for the analysis of this study were finally included in the study.

2. Liver biopsy results

Pathologically, simple fatty liver (Steatosis) was diagnosed in 92.7% of obese patients undergoing LSG (**Table 1**). When patients were divided according to the FLIP definition, NASH was diagnosed in 44 patients (64.7%), and 24 patients did not have NASH. On liver biopsy results, 49 (72.0%) patients had liver fibrosis of F1 or greater and 19 patients had no liver fibrosis (**Fig. 1**, **Table 1**).

3. Patients baseline characteristics

As shown in **Table 2**, patients were predominantly female (83.3%), with a mean age and BMI of 33.15 years and 37 kg/m^2. The BMI of patients with NASH or liver fibrosis was significantly higher than that of patients without NASH or liver fibrosis (NASH: 33.60±5.73 vs. 39.36±5.13 [P=0.000]; liver fibrosis: 34.46±5.51 vs. 38.43±5.84 [P=0.013]). Patients with NASH had

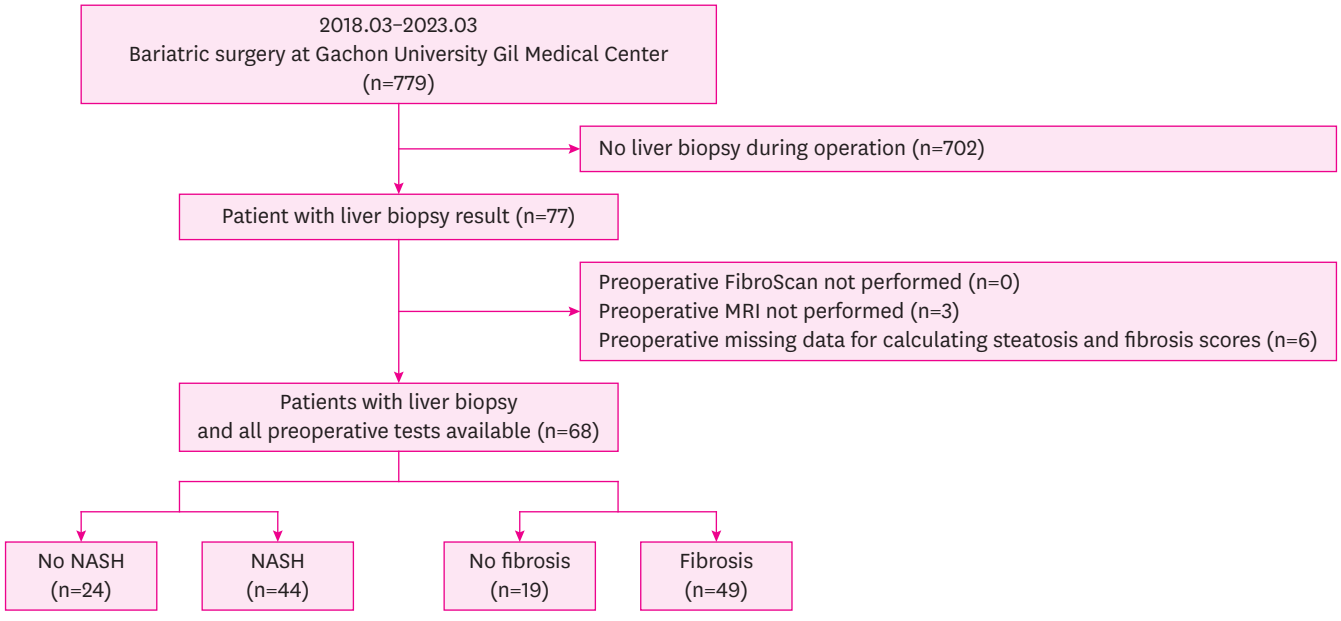

Fig. 1. Study flow diagram.
MRI = magnetic resonance imaging, NASH = non-alcoholic steatohepatitis.

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Table 1. Liver biopsy result

Variables	All valid tests available (n=68)	No NASH (n=24)	NASH (n=44)	P value (NASH)	No fibrosis (n=19)	Fibrosis (n=49)	P value (Fibrosis)
Steatosis grade				0.000[a]			0.009[a]
0 (<5%)	5 (7.4)	5 (20.8)	0		2 (10.5)	3 (6.1)	
1 (5–33%)	31 (45.6)	16 (66.7)	15 (34.1)		14 (73.7)	17 (34.7)	
2 (34–66%)	29 (42.6)	3 (12.5)	26 (59.1)		3 (15.8)	26 (53.1)	
3 (>66%)	3 (4.4)	0	3 (6.8)		0	3 (6.1)	
Lobular inflammation				0.000[a]			0.000[a]
0	20 (29.4)	20 (83.3)	0		17 (89.5)	3 (6.1)	
1	33 (48.5)	4 (16.7)	29 (65.9)		2 (10.5)	31 (63.3)	
2	12 (17.6)	0	12 (27.3)		0	12 (24.5)	
3	3 (4.4)	0	3 (6.8)		0	3 (6.1)	
Ballooning grade				0.000[a]			0.000[a]
0	24 (35.3)	24 (100.0)	0		19 (100.0)	5 (10.2)	
1	39 (57.4)	0	39 (88.6)		0	39 (79.6)	
2	5 (7.4)	0	5 (11.4)		0	5 (10.2)	
NAS score				0.000[a]			0.000[a]
0	4 (5.9)	4 (16.7)	0		2 (10.5)	2 (4.1)	
1	14 (20.6)	14 (58.3)	0		12 (63.2)	2 (4.1)	
2	6 (8.8)	6 (25.0)	0		5 (26.3)	1 (2.0)	
3	13 (19.1)	0	13 (29.5)		0	13 (26.5)	
4	16 (23.5)	0	16 (36.4)		0	16 (32.7)	
5	8 (11.8)	0	8 (18.2)		0	8 (16.3)	
6	5 (7.4)	0	5 (11.4)		0	5 (10.2)	
7	2 (2.9)	0	2 (4.5)		0	2 (4.1)	
8	0	0	0		0	0	
Fibrosis stage				0.000[a]			0.000[a]
F0	19 (27.9)	19 (79.2)	0		19 (100)	0	
F1	38 (55.9)	4 (16.7)	34 (77.3)		0	38 (77.6)	
F2	5 (7.4)	1 (4.2)	4 (9.1)		0	5 (10.2)	
F3	6 (8.8)	0	6 (13.6)		0	6 (12.2)	
F4	0	0	0		0	0	

Data presented as number (%).
NASH = non-alcoholic steatohepatitis, NAS score = non-alcoholic fatty liver disease activity score.
[a]P values refer to results of Fishe's exact test.

significantly higher levels of AST, AST, and GGT on liver function tests compared to patients without NASH (47.79±91.14 vs. 90.09±69.18 [P=0.035], 30.75±31.72 vs. 63.09±52.99 [P=0.002], 37.54±35.17 vs. 66.20±39.28 [P=0.004]). Similarly, patients with liver fibrosis had higher levels of ALT, AST, and GGT compared to patients without liver fibrosis, but this was not statistically significant. HbA1c was significantly higher in patients with NASH or liver fibrosis (NASH: 5.65±1.02 vs. 6.80±1.85 [P=0.002]; liver fibrosis: 5.74±1.12 vs. 6.64±1.81 [P=0.047]).

4. Correlation between steatosis grade/fibrosis stage and different diagnosis methods

Fig. 2A shows the correlation between histological steatosis grade and non-invasive diagnostic methods. MRI-PDFF (Spearman's ρ=0.713, P<0.001) and MRS-PDFF (ρ=0.708, P<0.001) demonstrated strong correlations with steatosis grade. In contrast, FibroScan-CAP (ρ=0.517, P<0.001) and FLI (ρ=0.527, P<0.001) showed moderate correlations. **Fig. 2B** shows the correlation between histological liver fibrosis stage and non-invasive diagnostic methods. MRE had the highest correlation with fibrosis stage (Spearman's ρ=0.455, P<0.001) followed by FibroScan-LSM (ρ=0.404, P=0.001). However, both demonstrated only moderate correlations. ELF score (ρ=0.304, P=0.012) and NFS (ρ=0.318, P=0.008) demonstrated weak correlations, while FIB-4 index showed a negligible and non-significant correlation (ρ=0.173, P=0.157).

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Table 2. Patient characteristics

Variables (normal range)	All valid tests available (n=68)	No NASH (n=24)	NASH (n=44)	P value (NASH)	No fibrosis (n=19)	Fibrosis (n=49)	P value (Fibrosis)
Sex				0.734[a]			1.000[a]
Male	11 (16.2)	3 (12.%)	8 (18.2)		3 (15.8)	8 (16.3)	
Female	57 (83.8)	21 (87.5)	36 (81.8)		16 (84.2)	41 (83.7)	
Age (years)	33.15±8.63	35.50±8.38	31.86±8.59	0.097[b]	35.58±8.93	32.20±8.42	0.149[b]
BMI (kg/m^2)	37.33±5.99	33.60±5.73	39.36±5.13	0.000[b]	34.46±5.51	38.43±5.84	0.013[b]
WC (cm)	110.54±13.82	103.60±14.07	114.32±12.25	0.002[b]	105.50±13.24	112.49±13.67	0.061[b]
Liver function test							
Protein (6.0–8.3 g/dL)	7.39±0.40	7.30±0.33	7.44±86.15	0.153[b]	7.26±0.33	7.44±0.41	0.090[b]
Albumin (3.4–5.4 g/dL)	4.63±0.29	4.55±0.22	4.68±0.32	0.081[b]	4.54±0.25	4.66±0.30	0.126[b]
Bilirubin (0.2–1.3 mol/L)	0.72±0.29	0.64±0.22	0.76±0.32	0.131[b]	0.67±0.22	0.73±0.32	0.482[b]
ALT (<40 U/IL)	75.16±79.61	47.79±91.14	90.09±69.18	0.035[b]	53.37±101.75	83.61±68.58	0.161[b]
AST (<40 U/IL)	51.68±48.89	30.75±31.72	63.09±52.99	0.002[b]	33.05±35.04	58.90±51.82	0.050[b]
GGT (<30 U/IL)	56.09±40.06	37.54±35.17	66.20±39.28	0.004[b]	34.42±21.14	64.49±42.60	0.005[b]
ALP (<130 U/IL)	76.94±20.12	71.63±23.90	79.84±17.34	0.108[b]	74.21±23.71	78.00±18.71	0.490[b]
LDH (140–280 U/IL)	345.49±130.95	350.04±119.07	343.00±138.27	0.834[b]	353.89±126.14	342.22±133.91	0.744[b]
PT (11–13.5 seconds)	11.39±0.71	11.21±0.77	11.48±0.67	0.128[b]	11.18±0.72	11.47±0.70	0.135[b]
Indicators of cardiovascular health and diabetes							
Total cholesterol (<200 mg/L)	207.44±37.25	196.46±41.38	213.43±33.79	0.072[b]	191.89±42.99	213.47±33.33	0.031[b]
Triglycerides (<150 mg/L)	165.62±100.26	145.75±145.36	176.45±63.39	0.333[b]	130.79±91.04	179.12±101.27	0.074[b]
HbA1c (<5.7%)	6.39±1.69	5.65±1.02	6.80±1.85	0.002[b]	5.74±1.12	6.64±1.81	0.047[b]
HOMA-IR	8.34±10.30	7.36±15.12	8.87±6.49	0.566[b]	7.48±16.48	8.67±6.76	0.673[b]

Data presented as mean ± standard deviation, or number (%).
NASH = non-alcoholic steatohepatitis, BMI = body mass index, WC = waist circumference, ALT = alanine transaminase, AST = aspartate transferase, GGT = gamma-glutamyl transpeptidase, ALP = alkaline phosphatase, LDH = lactate dehydrogenase, PT = prothrombin time, HOMA-IR = Homeostatic Model Assessment of Insulin Resistance.
[a]P values refer to results of Fisher's exact test. [b]P values refer to results of Student's t-test.

5. Quality of different noninvasive NASH/liver fibrosis diagnostic methods

The diagnostic values for NASH and liver fibrosis according to each diagnostic method are shown in **Table 3**. For NASH, the values for each NASH diagnostic method were all statistically significantly higher in patients with NASH compared to patients without NASH. However, for liver fibrosis, there was no difference in values for each diagnostic method between patients with and without liver fibrosis, except for MRE values.

As shown in **Fig. 3A**, all non-invasive methods had good quality (overall model quality >0.5) for diagnosing NASH. In particular, MRI-PDFF had the highest quality (0.74) compared to the other methods with a diagnostic accuracy of 80.88%. For liver fibrosis (**Fig. 3B**), all non-invasive diagnostic methods did not have high quality values (barely above or below 0.5). However, FibroScan-LSM had a slightly higher quality (0.56) than the other diagnostic methods (ELF score, NFS, FIB-4, and MRE) with a diagnostic accuracy of 76.47%.

DISCUSSION

Morbid obesity is a major risk factor for NAFLD progression, with liver fibrosis commonly observed in this population. While liver biopsy remains the gold standard for NAFLD diagnosis, repeated biopsies are impractical due to their invasive nature and sampling variability. Thus, identifying accurate non-invasive diagnostic methods is crucial for clinical assessment. In this study, various non-invasive tools were evaluated to determine the most effective method for diagnosing and monitoring NAFLD in morbidly obese patients.

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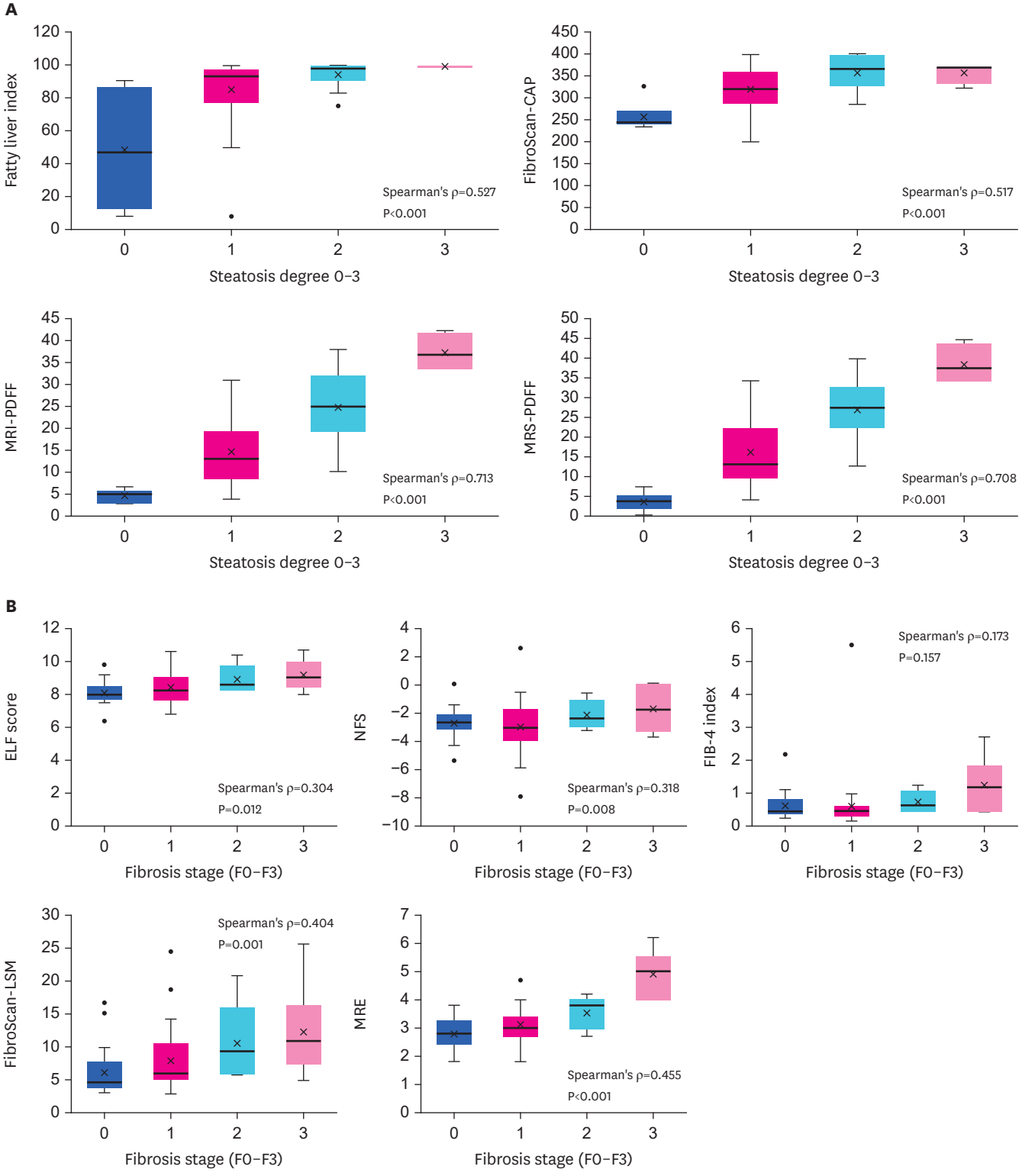

Fig. 2. Correlation between steatosis grade/liver fibrosis grade and different diagnosis methods (A) steatosis grade, (B) liver fibrosis grade.
FibroScan-CAP = FibroScan-controlled attenuation parameter, MRI-PDFF = magnetic resonance imaging-proton density fat fraction, MRS-PDFF = magnetic resonance spectroscopy-proton density fat fraction, ELF score = enhanced liver fibrosis score, NFS = non-alcoholic fatty liver disease fibrosis score, FIB-4 index = fibrosis-4 index, FibroScan-LSM = FibroScan-liver stiffness measurement, MRE = magnetic resonance elastography.

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Table 3. Quality of different noninvasive NASH/liver fibrosis diagnostic methods

Variables (normal range)	All valid tests available (n=68)	No NASH (n=24)	NASH (n=44)	P value (NASH)	No fibrosis (n=19)	Fibrosis (n=49)	P value (Fibrosis)
Diagnosis of NASH							
Fatty liver index	85.87±21.19	70.74±28.94	94.13±7.37	0.001[b]	74.61±26.54	90.24±17.13	0.025[b]
FibroScan-CAP (dB/m)	330.35±50.82	297.75±52.80	348.14±40.20	0.000[b]	308.05±53.79	339.00±47.40	0.023[b]
MRI-PDFF (%)	19.25±10.16	11.73±7.57	23.36±9.03	0.000[b]	12.48±7.74	21.88±9.83	0.000[b]
MRS-PDFF (%)	20.68±11.16	12.45±8.85	25.17±9.69	0.000[b]	13.58±9.17	23.43±10.71	0.001[b]
Diagnosis of liver fibrosis							
ELF score	8.45±0.89	8.25±0.71	8.56±0.96	0.130[b]	8.13±0.72	8.58±0.92	0.062[b]
NFS	−2.73±1.57	−2.75±1.07	−2.72±1.80	0.932[b]	−2.75±1.13	−2.72±1.73	0.940[b]
FIB-4	0.68±0.73	0.62±0.41	0.72±0.87	0.606[b]	0.64±0.45	0.70±0.82	0.740[b]
FibroScan-LSM (kPa)	8.00±4.94	6.05±3.57	9.07±5.28	0.015[b]	6.24±3.90	8.68±5.16	0.067[b]
MRE	3.22±0.85	2.78±0.54	3.46±0.89	0.000[b]	2.82±0.56	3.38±0.90	0.013[b]

Data presented as mean ± standard deviation.
NASH = non-alcoholic steatohepatitis, FibroScan-CAP = FibroScan-controlled attenuation parameter, MRI-PDFF = magnetic resonance imaging-proton density fat fraction, MRS-PDFF = magnetic resonance spectroscopy-proton density fat fraction, ELF score = enhanced liver fibrosis score, NFS = non-alcoholic fatty liver disease fibrosis score, FIB-4 index = fibrosis-4 index, FibroScan-LSM = FibroScan-liver stiffness measurement, MRE = magnetic resonance elastography.
[a]P values refer to results of Fisher's exact test. [b]P values refer to results of Student's t-test.

According to the literature, 80–90% of obese patients have comorbid NAFLD, including simple fatty liver. In Korea, the indications for bariatric surgery are BMI >35, BMI >30 with comorbidities such as diabetes, hypertension, sleep apnea, and fatty liver, and BMI >27.5 with poorly controlled type 2 diabetes. Although most patients undergoing bariatric surgery are assumed to have NAFLD; however, direct confirmation via intraoperative biopsy remains limited. In this study, liver biopsy confirmed steatosis in 92.6% of patients, NASH in 64.7%, and liver fibrosis in 72.0%, consistent with previous findings [5,6]. The high prevalence of NASH and fibrosis highlights the need for early detection and intervention.

According to the results of this study, MRI-PDFF (area under ROC curve [AUC] value of 0.83 with a cut-off value of 14.7) and MRS-PDFF (AUC value of 0.84 with a cut-off value of 13.9) demonstrated the highest accuracy in diagnosing NASH, demonstrating strong concordance with histopathological findings. Previous studies have also reported MRI-PDFF as the most reliable method for quantitatively assessing liver fat content, and the findings of this study further support this conclusion [17-20]. MRS-PDFF, in particular, mitigates sampling bias associated with liver biopsy by enabling precise regional fat quantification. Unlike liver biopsy, which is subject to variability depending on the sampling site, MRS-PDFF provides a more consistent evaluation of liver fat distribution [21]. Therefore, it serves as a valuable non-invasive tool to complement the limitations of liver biopsy in NAFLD assessment.

MRI-based techniques allow for quantitative assessment and facilitate repeated measurements, making them highly applicable in both clinical and research settings. However, their high cost and limited accessibility pose significant barriers to widespread clinical adoption. Notably, our study demonstrated that alternative non-invasive diagnostic tools, including FibroScan, also exhibited substantial diagnostic utility (quality value above 0.5), providing more accessible and cost-effective options for routine clinical practice.

Liver fibrosis is a condition that is difficult to reverse once it progresses, making early identification and intervention crucial, particularly for patients with early-stage fibrosis (F1 stage) through non-invasive methods. In the case of liver fibrosis, the quality value of all non-invasive diagnostic methods was not high, around 0.5, making it difficult to fully replace liver biopsy. However, FibroScan or MRE can be used as non-invasive diagnostic

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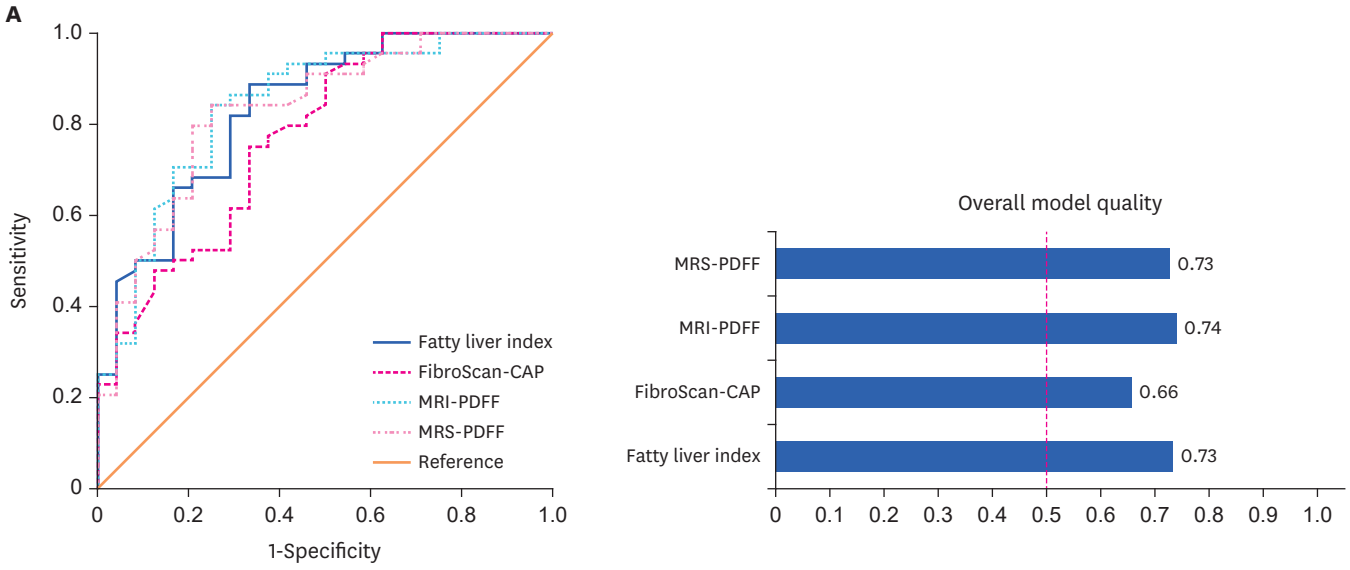
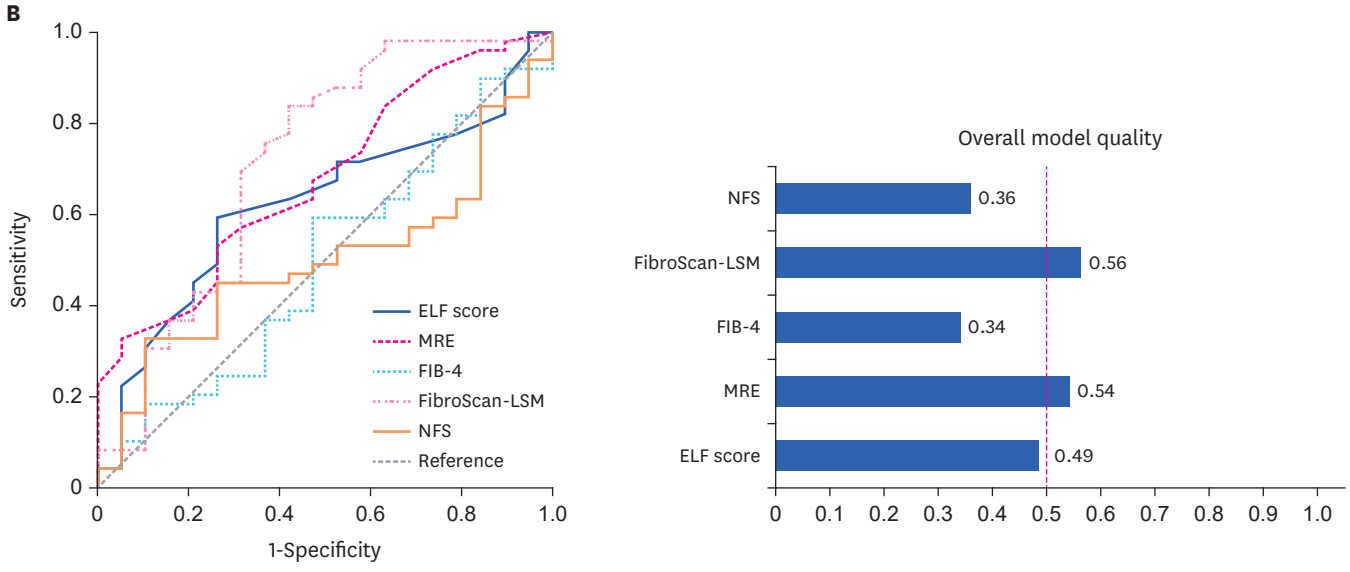


Diagnosis methods for NASH	AUROC (95% CI)	Cut-off (Youden' J)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy
Fatty liver index	0.833	86.13	88.64	66.67	82.98	76.19	80.88
FibroScan-CAP (dB/m)	0.774	319.00	75.00	66.67	80.49	59.26	72.06
MRI-PDFF (%)	0.830	14.70	84.09	75.00	86.05	72.00	80.88
MRS-PDFF	0.840	13.90	84.09	75.00	86.05	72.00	80.88



Diagnosis methods for liver fibrosis	AUROC (95% CI)	Cut-off (Youden' J)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	Accuracy
ELF score	0.625	8.25	59.18	73.68	85.29	41.18	63.24
NFS	0.501	−1.88	32.65	89.47	88.89	34.00	48.26
FIB-4	0.494	0.46	57.14	52.63	75.68	32.26	55.88
FibroScan-LSM (kPa)	0.714	4.85	83.67	57.89	83.67	57.90	76.47
MRE	0.677	3.55	32.65	94.74	94.12	35.29	50.00

Fig. 3. Quality of different noninvasive NASH/liver fibrosis diagnostic methods. (A) NASH, (B) liver fibrosis.
FibroScan-CAP = FibroScan-controlled attenuation parameter, MRI-PDFF = magnetic resonance imaging-proton density fat fraction, MRS-PDFF = magnetic resonance spectroscopy-proton density fat fraction, NASH = non-alcoholic steatohepatitis, AUROC = area under receiver operating characteristic curve, CI = confidence interval, PPV = positive predictive value, NPV = negative predictive value, ELF score = enhanced liver fibrosis score, MRE = magnetic resonance elastography, FIB-4 index = fibrosis-4 index, FibroScan-LSM = FibroScan-liver stiffness measurement, NFS = non-alcoholic fatty liver disease fibrosis score.

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tools for liver fibrosis rather than relying on scoring systems. FibroScan-LSM demonstrated the highest performance among non-invasive tools in ROC analysis, though its absolute diagnostic accuracy was still suboptimal, aligning with previous studies [22,23]. Notably, the accuracy of FibroScan-LSM decreases in patients with high BMI, as excessive adipose tissue interferes with shear wave propagation [24].

In our study, MRE showed a slightly higher correlation with histological fibrosis stage (ρ=0.455) compared to FibroScan-LSM (ρ=0.404), suggesting that MRE may be more appropriate for tracking disease severity and progression across different fibrosis stages. In contrast, FibroScan-LSM demonstrated better diagnostic performance in ROC analysis, indicating its relative strength in distinguishing the presence or absence of fibrosis. These complementary findings suggest that the choice of non-invasive modality should be tailored to the clinical objective—FibroScan-LSM for diagnostic screening, and MRE for longitudinal monitoring of disease severity.

Recently, MRE has been extensively studied as a diagnostic tool for NAFLD and liver fibrosis [25]. Theoretically, MRE is considered one of the most accurate methods for quantitatively assessing liver fibrosis stages. However, in this study, MRE did not yield significant results, indicating potential limitations in its applicability to morbidly obese patients and highlighting the need for further research.

A major strength of this study is the direct comparison of non-invasive diagnostic methods for NAFLD with liver biopsy in morbidly obese patients in Korea, allowing for an assessment of their diagnostic accuracy for NASH and liver fibrosis. Given the limited research on this topic in the Korean population, these findings provide valuable insights and highlight promising alternatives to liver biopsy; however, several limitations should be considered.

First, the retrospective nature of this study, based on prospectively collected data from a single center, limits generalizability. Future multicenter prospective studies are warranted to validate these results. Second, CT imaging, despite its utility in evaluating liver fibrosis and steatosis, was excluded due to its inability to provide automated liver fat quantification. Incorporating CT-based methodologies in future research may enhance diagnostic precision. Third, non-invasive methods for liver fibrosis demonstrated only moderate diagnostic accuracy, likely due to the broad classification of fibrosis stages (F1–F4) rather than a stratified analysis. Given that early-stage fibrosis (F1) remains reversible, optimizing non-invasive detection strategies for F1 fibrosis could be crucial in preventing progression to cirrhosis.

Lastly, a terminology-related limitation should be acknowledged. During the course of this study, the diagnostic framework for NAFLD was revised, and the term metabolic dysfunction-associated steatotic liver disease (MASLD) was proposed to better reflect the underlying metabolic abnormalities. However, this study was designed and conducted prior to the formal adoption of MASLD criteria, and all patients were diagnosed according to the then-current NAFLD definitions. While the transition to MASLD is ongoing, it has not yet been universally implemented in clinical settings or diagnostic coding. Therefore, we used the term NAFLD throughout this study to ensure consistency with the original diagnostic framework. Future studies incorporating the MASLD criteria will be necessary to evaluate whether the same non-invasive diagnostic tools perform similarly under the new definition and to confirm the reproducibility of our findings.

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CONCLUSION

In conclusion, MRI-PDFF and MRS-PDFF showed the highest accuracy for diagnosing NASH. For liver fibrosis, FibroScan-LSM demonstrated better diagnostic performance in ROC analysis, whereas MRE showed a slightly stronger correlation with histological fibrosis stage. However, evaluating fibrosis in morbidly obese patients remains challenging, emphasizing the need for better early detection strategies. While advanced imaging techniques such as MRI-PDFF, MRS-PDFF, and MRE have improved NAFLD diagnosis, their high cost limits widespread clinical use. This study provides valuable data on the diagnostic accuracy of various non-invasive tools, which can serve as a reference for clinicians to ensure that NAFLD is properly assessed and monitored in patients undergoing bariatric metabolic surgery, preventing it from being overlooked in routine care.

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