

Early Regression of Hepatic Steatosis after Bariatric Surgery Assessed by Ultrasound Including Attenuation Imaging

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Early Regression of Hepatic Steatosis after Bariatric Surgery Assessed by Ultrasound Including Attenuation Imaging

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Abstract

Background:

Metabolic dysfunction-associated fatty liver disease (MAFLD) is associated with increased liver-related morbidity. Bariatric surgery provides substantial weight loss and metabolic improvement, yet data on ultrasound (US)-based monitoring remain limited. This study evaluated perioperative changes in hepatic steatosis using B-mode US and Attenuation Imaging (ATI), a quantitative US technique for fat quantification.

Methods:

In this prospective single-center study, patients undergoing bariatric surgery between February 2024 and July 2025 were included. B-mode and ATI were performed preoperatively and at 3 and/or 6 months postoperatively; the earliest follow-up was defined as early follow-up. Steatosis was graded using B-mode (0–3) and ATI (aS0–aS3). Body mass index (BMI) and liver size were recorded. Statistical analysis was conducted using JMP 18.2.

Results:

89 patients were included (mean age 42.8 years; 28% men). At baseline, B-mode and ATI were strongly correlated ($\tau_c = 0.73$, $p < 0.001$). At early follow-up, BMI decreased in all patients ($p < 0.001$). Grading of hepatic steatosis improved in 56.2 % of patients by B-mode ($p < 0.001$) and in 68.5 % by ATI ($p < 0.001$), while absolute ATI values decreased in 94.4 %. Liver size decreased in 94.4 %. In patients with both follow-up visits, largest reductions in ATI and liver size were observed at 3 months. Changes in B-mode and ATI grading were strongly correlated ($\tau_c = 0.65$, $p < 0.001$).

Conclusions:

Regression of hepatic steatosis occurs early after bariatric surgery. ATI enhances B-mode by providing quantitative assessment and enabling more precise longitudinal monitoring.

Key Words:

ultrasound, Attenuation Imaging, quantification, hepatic steatosis, bariatric surgery, MAFLD, BMI

Background

Metabolic dysfunction-associated steatotic liver disease (MAFLD) is an increasing global health concern, affecting 25–30 % of the general population and up to 70–90 % of severely obese individuals [18]. While this increase may not have immediate clinical significance, patients with MAFLD are at risk of developing metabolic dysfunction-associated steatohepatitis (MASH) and associated complications [1].

Hepatic steatosis is more dynamic than fibrosis, responding to weight changes induced by diet, exercise, pharmacotherapy, or bariatric surgery [8]. The primary treatment of MAFLD is lifestyle modification and weight loss. Vilar-Gomez et al. demonstrated that weight loss ≥ 10 % was associated with significant resolution of MASH in 90 % and regression of fibrosis in 45 % of patients [26]. Bariatric surgery is recommended for patients with BMI ≥ 40 kg/m² or ≥ 35 kg/m² with comorbidities and induces substantial and sustained weight loss [22].

A biopsy-controlled meta-analysis demonstrated that bariatric surgery can lead to complete resolution of MAFLD and lower MAFLD activity scores; however, follow-up examinations were performed relatively late (median 15 months) [19]. A systematic review of liver biochemistry following bariatric surgery also reported significant reductions in hepatic steatosis and inflammation, although the effect on fibrosis remains controversial [4].

Liver biopsy and magnetic resonance imaging (MRI) allow accurate quantification of hepatic steatosis but are limited by invasiveness, cost, and restricted availability. Conventional B-mode ultrasound (US) is widely used for semiquantitative assessment of hepatic fat, graded from 0 (absent) to 3 (severe) [12]. A meta-analysis demonstrated diagnostic accuracy comparable to CT or MRI for moderate-to-severe hepatic steatosis when histology was used as the reference standard [14]. However, B-mode US is less sensitive for mild steatosis and is associated with significant interobserver variability [14].

Recently, quantitative US methods have emerged as promising noninvasive biomarkers for hepatic steatosis [9]. One such technique, attenuation imaging (ATI), measures US beam attenuation and calculates an attenuation coefficient (AC) as a surrogate marker for liver fat. Steatotic tissue attenuates US beams more strongly than normal liver tissue, resulting in higher AC values. Previous studies have demonstrated good-to-excellent intra- and interobserver agreement, with intraclass correlation coefficients exceeding 0.80 [8].

Published data in patients with MAFLD are particularly promising [3]. The diagnostic performance of ATI has been shown to be comparable to that of the controlled attenuation parameter (CAP), while

offering advantages in terms of convenience and feasibility, especially in obese patients, because ATI is integrated into conventional B-mode US systems [17]. Furthermore, ATI performs better than CAP for all steatosis grades (S1–S3) when MRI proton density fat fraction (MRI-PDFF) is used as the reference standard [7]. ATI also correlates strongly with MRI findings and histology [10,27]. Recently, the World Federation for Ultrasound in Medicine and Biology (WFUMB) published updated guidance on US-based liver fat quantification [8].

Recent studies have shown that quantitative assessment using ATI identifies more patients with hepatic steatosis than qualitative B-mode US, particularly in patients with mild steatosis [23]. To improve diagnostic consistency, a standardized ATI grading system has recently been proposed. In a meta-analysis including 1,374 patients with MRI or biopsy as reference standards, ATI values correlated significantly with steatosis grades [15]. Based on these findings, ATI grading was defined as follows: aS0 ($ATI \leq 0.66$), aS1 ($0.66 < ATI \leq 0.73$), aS2 ($0.73 < ATI \leq 0.81$), and aS3 ($ATI \geq 0.81$) [15].

To our knowledge, there are currently no data on early postoperative changes in hepatic steatosis assessed by B-mode US and ATI in patients undergoing bariatric surgery. Given that US is noninvasive, rapid, cost-effective, and widely available, its role in longitudinal postoperative monitoring warrants further investigation.

The primary objective of this study was to assess whether significant postoperative weight loss results in detectable reductions in hepatic steatosis at early follow-up. The secondary objective was to evaluate the additional value of ATI for longitudinal liver fat assessment in this patient population.

Methods

Ethical approval

The study was approved by the Ethics Committee of the University of Tübingen (approval number 042/2024BO2), and all participants provided written informed consent.

Study design

This prospective single-center study included 89 patients undergoing first-time bariatric surgery between February 2024 and July 2025. Inclusion criteria were age >18 years, ability to provide consent, and comprehension of German language. Exclusion criteria were chronic liver disease, insufficient compliance, or participation in other studies.

Data collection

Baseline examination, including B-mode US and ATI, was performed preoperatively. Follow-up examinations were scheduled at 3 and/or 6 months postoperatively. For overall analysis, the earliest available follow-up was defined as early follow-up. Demographic and anthropometric data, including age, sex, BMI, liver size, and median AC, were recorded at each examination.

US imaging and ATI measurements

US examinations were performed by DEGUM-certified gastroenterologists using an Aplio i800 system (Canon Medical Systems) equipped with a 1–8 MHz convex abdominal transducer (i8CX1), according to current WFUMB recommendations [8]. Hepatic steatosis was graded using B-mode US according to a widely used four-point scale [6]: score 0 indicated normal hepatic echogenicity; score 1 indicated mildly increased echogenicity with preserved visualization of the diaphragm and portal vein borders; score 2 indicated moderate echogenicity with impaired visualization of periportal structures; and score 3 indicated marked echogenicity with poor visualization of periportal structures and the posterior right hepatic lobe.

ATI measurements were obtained through the right intercostal space using a 3-cm region of interest positioned subcapsularly in homogeneous liver tissue, with an attenuation fit correlation coefficient (R^2) > 0.80. Measurements were performed in real time using a color-coded overlay on the B-mode image, as shown in figure 1. AC values (dB/cm/MHz) were calculated while accounting for beam profile, gain settings, time gain compensation, and signal compounding. Hepatic steatosis was additionally

categorized using the ATI four-scale classification proposed by Hobeika et al. [15], with cutoff values of 0.66, 0.73, and 0.81 dB/cm/MHz.

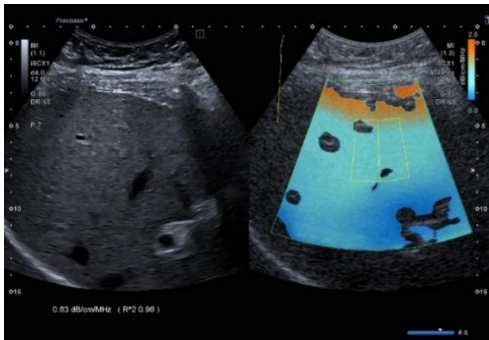


Figure 1: Measurement of hepatic steatosis using Attenuation Imaging (ATI)

Statistical Analysis

Continuous data on BMI, liver size, and ATI values were measured at baseline and at follow-up (3 and/or 6 months postoperatively), and are presented using box and whisker plots. B-mode US as well as ATI were classified on a four-graded ordinal scale. Changes from baseline for repeated measurements were examined using the two-sided paired t-test or by ANOVA. For all tests, the level of statistical significance was predetermined at $p \leq 0.05$. Kendall's tau coefficient was used as measure of ordinal association with a correction for the number of ties (Tau-b) and an additional adjustment for table size (Stuart-Kendall Tau-c), and the strength of the observed relationship was assessed. Data analysis was performed using JMP 18.2 statistical software (JMP Statistical Discovery LLC, Cary, NC, USA).

Results

Baseline characteristics

Table 1 summarizes the demographic and clinical characteristics of the patients at baseline. All included individuals were classified as having class III obesity, with a mean BMI value of 49.4 kg/m² ($\pm$ 7.3). The median age was 42.8 years, and 71.9 % (64/89) were women.

Regarding ATI measurement, the median AC was 0.74 dB/cm/MHz. As expected, the majority of patients (88.8 %, 79/89) exhibited signs of hepatic steatosis on baseline B-mode US. Among these 50.6 % (45/89) were classified as S1, 29.2 % (26/89) as S2, and 9.0 % (8/89) as S3.

According to the four-scale classification of Hobeika et al. 78.7 % (70/89) showed signs of hepatic steatosis in ATI. Of these, 34.8 % (31/89) were classified as aS1, 21.3 % (19/89) as aS2, and 22.5 % (20/89) as aS3.

Number (n)	89
Male/Female	25/64
Mean age (range)	42.8 yrs (19–73)
Mean BMI (SD)	49.4 kg/m ² (7.3)
Grade of steatosis based on B-Mode	
S0	10 (11.2 %)
S1	45 (50.6 %)
S2	26 (29.2%)
S3	8 (9.0 %)
Mean ATI absolute value (range)	0.74 dB/cm/MHz (0.58–0.96)
Grade of steatosis based on ATI	
aS0	19 (21.3 %)
aS1	31 (34.8 %)
aS2	19 (21.3 %)
aS3	20 (22.5 %)
Mean Liver Size (range)	17 cm (11,5–23)

Table 1: Demographic and clinical patient characteristics at baseline

Changes at follow-up

Follow-up US examinations were performed at 3 months in 73.0 % (65/89) of patients and at 6 months in 53.9 % (48/89). Among the cohort, 26.9 % (24/89) attended both follow-up visits, 48.3 % (43/89) only the 3-month follow-up, and 24.7 % (22/89) only the 6-month follow-up.

Body mass index (BMI)

Following bariatric surgery, all patients demonstrated a significant reduction in BMI during early follow-up, as shown in Figure 2. The mean preoperative BMI was $49.4 \pm 7.3 \text{ kg/m}^2$, which decreased to $40.4 \pm 6.7 \text{ kg/m}^2$ at early follow-up ($p < 0.001$).

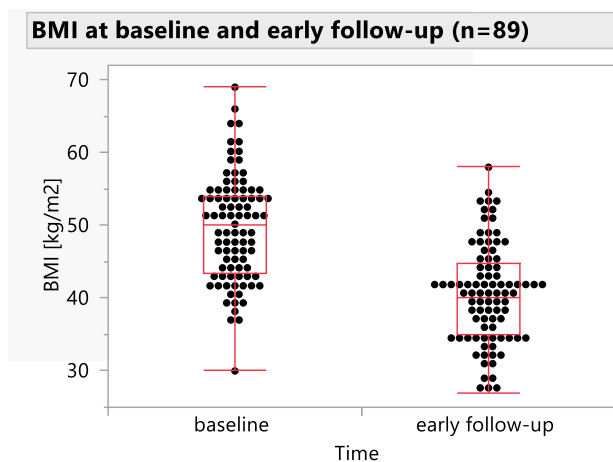


Figure 2: BMI-scores at baseline and early follow-up, showing a significant reduction ($p < 0.001$)

As shown in figure 3, among patients who attended both follow-up visits, the decrease in BMI was more pronounced during the first 3-months. At 3 months, the mean BMI was 40.9 kg/m^2 , corresponding to a reduction of 7.8 kg/m^2 from baseline. At 6 months, the mean BMI further decreased to 37.4 kg/m^2 , representing an additional reduction of 3.5 kg/m^2 .

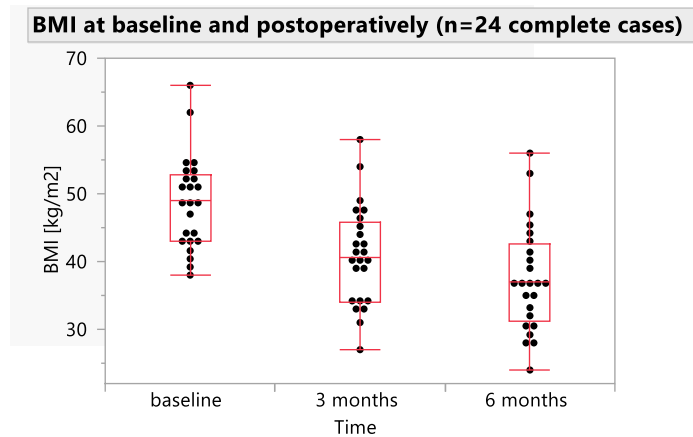


Figure 3: Changes in BMI scores from baseline to 3 and 6 months after bariatric surgery

Attenuation Imaging (ATI)

As shown in Figure 4, analysis of the absolute ATI values revealed a significant decrease at early follow-up compared to baseline ($p < 0.001$). The mean preoperative ATI value was 0.73 dB/cm/MHz (range: 0.58–0.96), which decreased to 0.60 dB/cm/MHz (range: 0.35–0.92), corresponding to a mean reduction of 0.14 dB/cm/MHz. Overall, 94.4 % of patients exhibited a decrease in ATI values. In the subgroup of patients with only a 6-month follow-up (22/89), 100 % showed a reduction in absolute ATI values.

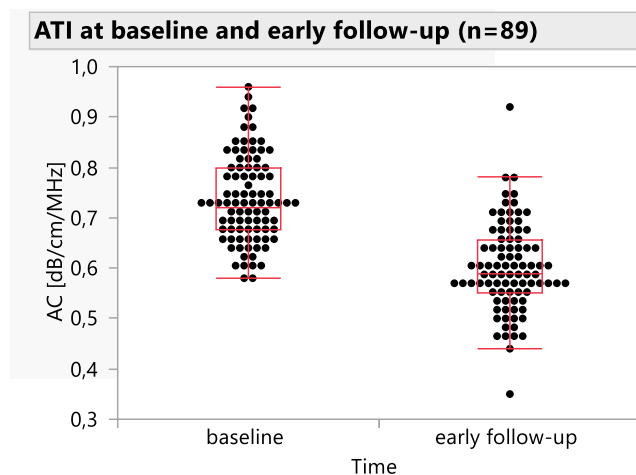


Figure 4: AC values at baseline and early follow-up with significant reduction ($p < 0.001$)

As illustrated in Figure 5, among the 24 patients attending both follow-up visits, the reduction in ATI values was more pronounced at 3 months. At this time point, the mean ATI value was 0.61 dB/cm/MHz, corresponding to a decrease of 0.15 dB/cm/MHz from baseline. At 6 months postoperatively, the mean ATI value further decreased to 0.57 dB/cm/MHz, representing an additional reduction of 0.035 dB/cm/MHz.

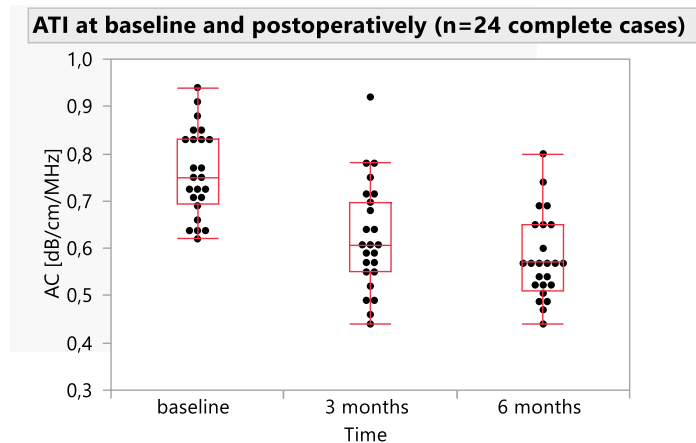


Figure 5: Changes in AC values from baseline to 3 and 6 months after bariatric surgery

Liver size

Analysis of liver size demonstrated a significant decrease during early follow-up, as shown in Figure 6. The mean preoperative liver size was 17.4 cm (range: 11.5–23.0 cm), which decreased significantly at early follow-up ($p < 0.001$) to a mean of 14.8 cm (range: 10.5 – 20.0 cm), corresponding to an average decrease of 2.5 cm compared to baseline.

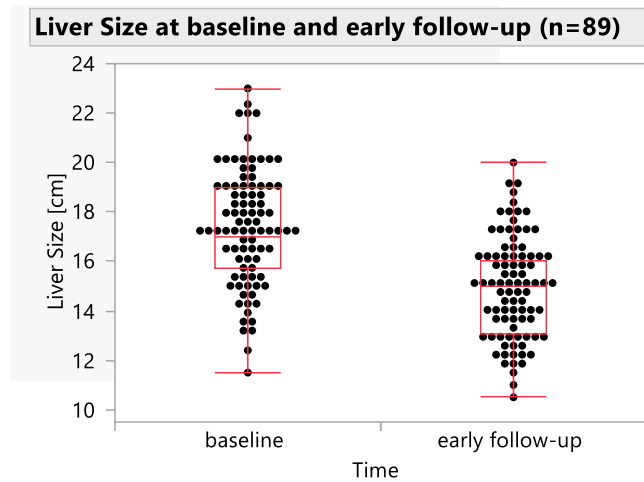


Figure 6: Liver size at baseline and early follow-up, demonstrating a significant reduction ($p < 0.001$)

As demonstrated in Figure 7, among the patients who attended both follow-up visits, liver size decreased more markedly during the first 3 months. At 3 months, the mean liver size was 15.7 cm, corresponding to a reduction of 2.1 cm from the baseline value of 17.8 cm. At 6 months postoperatively, liver size further decreased to 14.3 cm, representing an additional reduction of 1.4 cm.

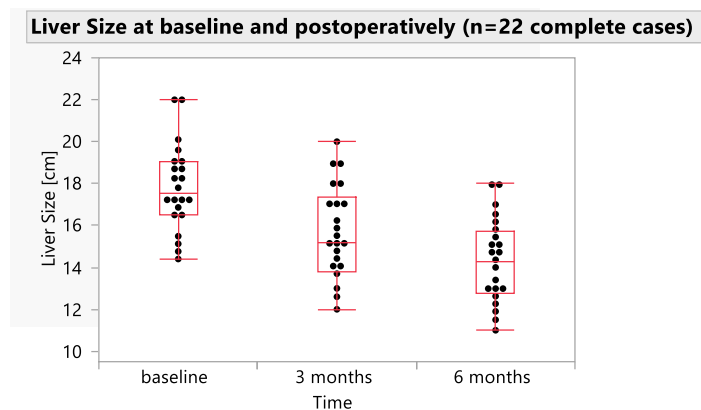


Figure 7: Changes in liver size from baseline to 3 and 6 months after bariatric surgery

Relationship between US and ATI

At baseline, the relationship between US and ATI grading of hepatic steatosis showed a strong and statistically significant positive correlation assessed by Kendall's Tau correlation analysis ($\tau_b=0.73$; 95 % CI 0.66–0.81; $p < 0.001$), as shown in Table 2.

		Grading ATI0				Total
		aS0	aS1	aS2	aS3	
Grading Sono 0	absent	9	1	0	0	10
	mild	10	26	8	1	45
	moderate	0	4	11	11	26
	severe	0	0	0	8	8
Total		19	31	19	20	89

Table 2: Association between B-mode US and ATI grading demonstrating a significant correlation ($p < 0.001$)

Changes in steatosis grading from baseline to early follow-up were also strongly positively associated between B-mode US grading and ATI grading ($\tau_c=0.65$; 95 % CI 0.54–0.76; $p < 0.001$), as shown in table 3.

		Grading ATI Delta Early-0					Total
		-3	-2	-1	0	1	
Grading Sono Delta Early-0	-2	5	2	0	0	0	7
	-1	5	14	22	2	0	43
	0	0	2	11	25	1	39
Total		10	18	33	27	1	89

Table 3: Association of changes in hepatic steatosis from baseline to early follow-up between B-mode US and ATI grading

As illustrated in Figure 8, a reduction in steatosis grading from baseline to early follow-up was more frequently detected using ATI (68.5 %) than B-mode US (56.2 %). According to the four-level grading

system proposed by Hobeika et al., hepatic steatosis improved in 68.5 % of patients based on ATI grading. Among patients without improvement, 19 had already been classified as aS0 at baseline. Among patients classified as $\geq$ aS1, a reduction was observed in all but six patients. In the subgroup with only a 6-month follow-up, 72.7 % (16/22) showed a reduction in ATI grading.

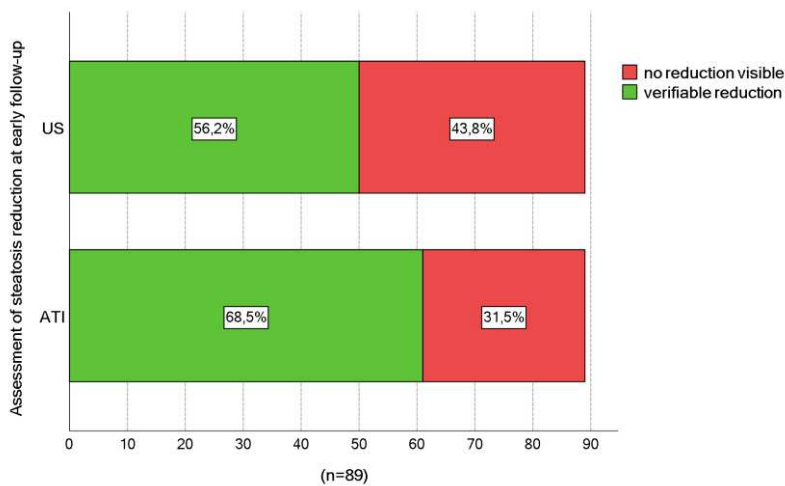


Figure 8: Proportion of patients with steatosis reduction at early follow-up in B-mode US and ATI grading

When absolute ATI values were considered, a decrease was observed in 94.4 %. In the subgroup with a 6-month follow-up only, a reduction in ATI values was observed in 100 % of patients.

Discussion

Noninvasive and cost-effective diagnostic methods for hepatic steatosis are essential to address the increasing global burden of steatotic liver disease and its associated risk of progression to MASH and liver-related morbidity. Bariatric surgery has been shown to induce substantial regression or even complete resolution of MAFLD [4,19].

Rapid changes in hepatic fat content are best evaluated using short-term follow-up intervals. However, repeated assessment using liver biopsy or MRI is limited by invasiveness, high cost, and restricted feasibility in routine clinical practice [8]. A meta-analysis demonstrated that B-mode US provides diagnostic accuracy comparable to CT or MRI for detecting moderate-to-severe hepatic steatosis when histology serves as the reference standard [14].

More recently, ATI has emerged as a promising noninvasive quantitative US marker for liver fat assessment in MAFLD [3], particularly in longitudinal follow-up studies with moderate to severe steatosis [16]. Moreover, ATI appears to outperform CAP in differentiating steatosis grades when MRI-PDFF is used as the reference standard [7].

In the present study, perioperative B-mode US combined with ATI demonstrated significant postoperative changes in 89 patients undergoing bariatric surgery. Both B-mode US findings and ATI values decreased significantly during early follow-up, in parallel with BMI reduction. These findings are consistent with previous studies reporting histological regression of MAFLD following bariatric surgery [4,19]. However, in line with previous studies [25], BMI was not significantly associated with ATI values, likely due to the limited variability in BMI within our cohort.

When absolute ATI values were analyzed, a reduction was observed in 94.4 % of patients, suggesting that ATI is highly sensitive to early postoperative changes in hepatic fat content following substantial weight loss.

According to the grading system proposed by Hobeika et al. [15], hepatic steatosis grade improved in 68.5 % of patients based on ATI, whereas only 56.2 % showed improvement on B-mode US. These findings suggest that ATI may be more sensitive to subtle longitudinal changes in hepatic fat content than conventional B-mode US.

Using the Hobeika classification, hepatic steatosis was detected at baseline in 78.7 % of patients by ATI compared with 88.7 % using B-mode US. This differs from previous studies reporting higher detection rates with ATI than with B-mode US [23]. One possible explanation is the relatively high cutoff (> 0.66)

used to define aS1 steatosis. Previous studies have used lower thresholds, such as > 0.64 [2]. Applying this lower threshold would have classified 90.0 % of our cohort as having hepatic steatosis.

In parallel with BMI reduction, which was most pronounced within the first 3 months after surgery, ATI values also decreased more markedly during this interval than between 3 and 6 months. This supports the notion that hepatic fat reduction can be reliably detected by ATI at early postoperative time points. This observation is consistent with previous reports demonstrating that liver fat content can change within months [8].

Notably, all patients in the subgroup with only 6-month follow-up demonstrated reduced ATI values. This further suggests that ATI is highly sensitive to quantitative changes in hepatic steatosis even over relatively short time intervals, and that follow-up US at 6 months may reveal more pronounced changes than earlier assessments.

The correlation between B-mode US and ATI grading was strong both at baseline and during follow-up. Nevertheless, ATI detected steatosis regression more frequently, indicating that ATI provides clinically relevant complementary information to conventional B-mode US - particularly in follow-up examinations - by enabling the detection of more subtle changes over time.

The quantitative nature of ATI represents a major advantage over semiquantitative B-mode US because it provides objective measurements that are less dependent on examiner subjectivity. ATI may therefore reduce the inter- and intraobserver variability associated with visual steatosis grading. Interobserver agreement was not assessed in this study because previous investigations have already demonstrated excellent reproducibility [5].

Another notable finding was the rapid and significant postoperative reduction in liver size observed on B-mode US, which has not yet been systematically investigated in the literature. However, reductions in liver volume after bariatric surgery have previously been described using MRI and CT [21,24]. Similar to ATI, the greatest reduction occurred within the first 3 months, with a smaller additional reduction between 3 and 6 months.

A limitation of this study is the absence of histological or MRI-based reference standards. However, routine MRI follow-up is impractical because of cost and limited availability, whereas liver biopsy is invasive and samples only a small portion of hepatic tissue. Consequently, biopsy is neither feasible nor ethically justified for serial liver fat quantification in large MAFLD cohorts [8].

Strengths of this study include its prospective design, longitudinal assessment, and examinations performed by highly experienced sonographers.

Conclusions

Early regression of hepatic steatosis following significant weight loss can be reliably assessed by US, as evidenced by improvements in B-mode findings, ATI values, and liver size. ATI provides quantitative, examiner-independent assessment, allowing detection of subtle changes. This technique may enhance longitudinal monitoring of MAFLD, with potential clinical value for risk stratification and treatment follow-up, though further validation in larger cohorts is needed.

Declarations

- **Ethics approval and consent to participate:** Ethics approval was obtained from the appropriate ethics committee, and informed consent to participate was obtained from all participants.
- **Consent for publication:** Informed consent for publication was obtained from all authors included in the study.
- **Availability of data and materials:** The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request

No funding was received for this study.

The authors declare no competing interests

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