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Original Article

Radiology Section

Diagnostic Performance of 2D ROI Sampling and 3D Volumetric Methods in Liver Attenuation Assessment using Non Contrast CT: A Retrospective Observational Study

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ABSTRACT

Introduction: Fatty liver disease, or hepatic steatosis, is a highly prevalent condition that can be non-invasively diagnosed using Computed Tomography (CT) attenuation values. However, the optimal method for attenuation measurement remains uncertain.

Aim: To compare the performance of three CT-based techniques-Two dimensional (2D) sampling, Three dimensional (3D) sampling, and whole-liver segmentation-using non-contrast scans.

Materials and Methods: The present retrospective analysis of 230 patients (121 normal, 109 with fatty liver) was conducted in the Radiology Department at Madha Medical College & Research Institute, Chennai, Tamil Nadu, India. The study included patients who underwent both Ultrasonography (USG) and CT between January 2023 and December 2023. Fatty liver diagnosis was confirmed using both ultrasound and non-contrast CT attenuation values {<50 Hounsfield Units (HU)}. Liver attenuation was measured using 2D Region of Interest (ROI) sampling, 3D volumetric sampling, and fully automated whole-liver segmentation. Agreement was assessed using correlation analysis, Analysis of Variance (ANOVA) with post-hoc comparisons, and interobserver agreement statistics (Intraclass Correlation Coefficient (ICC), Kappa).

Results: The mean age of the study population was 51.1±11.7 years. All three methods showed strong correlation, with 2D sampling demonstrating near-perfect agreement with whole-liver segmentation (Pearson's R=0.98). Mean attenuation values declined consistently from normal to mild and moderate-severe steatosis across all methods (p<0.001). Pairwise comparisons revealed only minimal differences, with whole-liver segmentation recording slightly lower values but without significant clinical advantage (2D vs. 3D: 0.85 HU, p=0.006; 2D vs. segmentation: 2.48 HU, p<0.001; 3D vs. segmentation: 1.63 HU, p<0.001). Interobserver agreement was excellent (ICC=0.989, κ=0.97-1.00), confirming high measurement reproducibility.

Conclusion: 2D sampling emerges as the clinically optimal method for liver fat quantification, offering high correlation with whole-liver metrics, excellent reproducibility, and operational efficiency. In the absence of advanced automation, it provides a practical and reliable tool for routine clinical assessment of hepatic steatosis.

Keywords: Computed tomography, Fatty liver, Hepatic steatosis, Radiology, Region of Interest, Volumetric analysis

INTRODUCTION

Non-Alcoholic Fatty Liver Disease (NAFLD) is the most prevalent chronic liver disease worldwide and a significant public health concern due to its rising incidence and strong association with metabolic syndrome, obesity, and cardiovascular disease [1]. The increasing burden of NAFLD highlights the need for accurate, cost-effective, and affordable diagnostic methods. Although liver biopsy remains the gold standard, its invasive nature limits its routine use, making imaging modalities the mainstay of non-invasive evaluation [1].

CT is one of the most commonly used non-invasive imaging modalities for hepatic fat quantification. CT-based assessment of liver attenuation in HU serves as a reliable marker of hepatic fat content, with lower attenuation values indicating higher fat deposition [2]. Traditional methods of measuring liver attenuation include 2D ROI sampling, in which a few representative hepatic regions are selected for HU measurement. Although simple and widely used in clinical practice, concerns persist regarding its ability to capture heterogeneous fat distribution within the liver [3].

Advances in imaging technology have enabled 3D sampling and whole-liver segmentation techniques, providing a more comprehensive volumetric analysis of hepatic attenuation. These approaches assess larger portions of liver parenchyma, thereby reducing sampling error and potentially improving diagnostic accuracy. However, they require greater computational resources and specialised software, raising questions about their practicality for routine use [4,5].

Segmentation plays a crucial role in accurate quantification of hepatic steatosis. Traditional 2D ROI sampling captures only small areas and may overlook regional variations in fat deposition. In contrast, 3D volumetric sampling and whole-liver segmentation address this limitation by assessing attenuation across larger or entire liver volumes. Whole-liver segmentation offers an objective and comprehensive assessment, reducing sampling bias and providing precise measurements that may be particularly valuable for disease monitoring and integration into Artificial Intelligence (AI)-driven diagnostic workflows [6,7].

The purpose of the present study is to compare the accuracy of 2D sampling, 3D sampling, and whole-liver segmentation in assessing liver attenuation for the diagnosis of fatty liver disease using non-contrast scans. Intravenous contrast administration alters hepatic attenuation values and may obscure or confound fat quantification; therefore, non-contrast scans provide the most reliable and reproducible measure of parenchymal attenuation [2]. By evaluating these techniques in a cohort of patients with confirmed hepatic steatosis or normal liver status, the present study aimed to determine whether advanced segmentation methods offer a significant advantage over traditional 2D sampling, or if 2D sampling remains the most efficient and clinically relevant approach.

MATERIALS AND METHODS

The present retrospective observational study was conducted in the Radiology Department at Madha Medical College and Research Institute, Chennai, Tamil Nadu, India. The study included patients who underwent both USG and CT between January 2023 and December 2023. The study was conducted after approval from the Institutional Ethics Committee (IEC) (MMCRI/IEC/2024/005). The sample size of 230 patients-109 with fatty liver disease and 121 with normal liver attenuation-was determined based on the availability of retrospective data.

Inclusion criteria

- Patients who underwent abdominal CT imaging for any indication.
- Availability of ultrasound confirmation of fatty liver for patients in the steatosis group with normal Liver Function Test (LFT).
- CT attenuation values confirming fatty liver (<50 HU) [8].

Exclusion criteria

- Patients with known liver diseases other than hepatic steatosis (e.g., cirrhosis, hepatitis, malignancy).
- History of prior liver surgery or hepatic interventions.
- Poor-quality CT images due to motion artifacts or inadequate contrast enhancement.

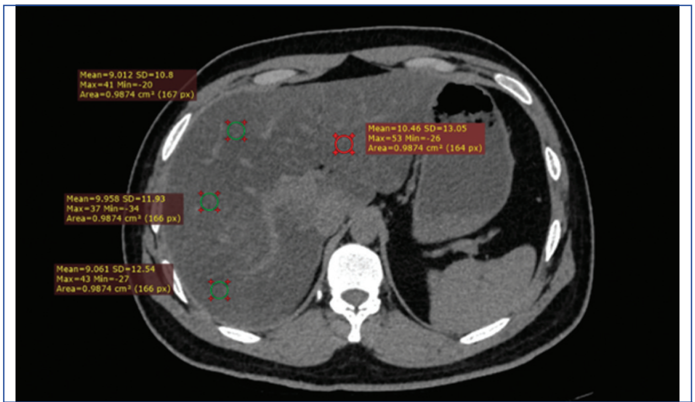
Hepatic steatosis on non-contrast CT was categorised as follows:

- Normal liver: >50 HU
- Mild fatty liver: 40-50 HU
- Moderate-to-severe fatty liver: <40 HU [8]

Study Procedure

CT attenuation values were measured using three different techniques:

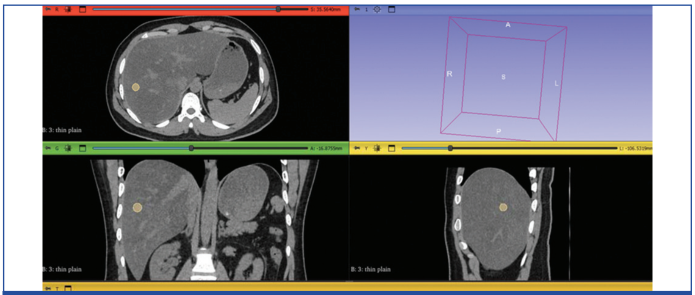
1. **2D Sampling:** Five ROIs of 1 cm² were placed in representative areas of the liver parenchyma-segments V, VI, VII, VIII, and the left lobe-avoiding vessels and bile ducts. The average attenuation value was calculated [Table/Fig-1].



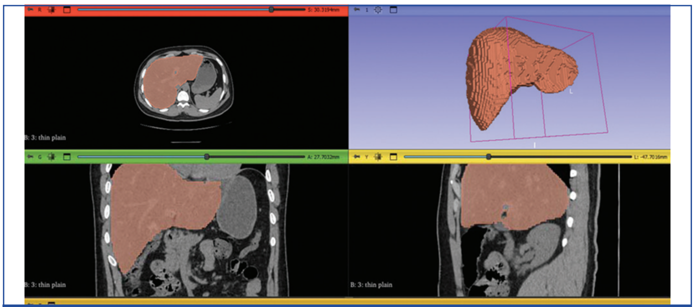
[Table/Fig-1]: 2D sampling of Liver.

2. **3D Sampling:** A 3D volumetric assessment using a 1 cm³ Volume of Interest (VOI) was performed in the same segments using 3D Slicer [Table/Fig-2].
3. **Whole-Liver Segmentation:** A fully automated algorithm (Total Segmentator) in 3D Slicer was used to segment the entire liver and calculate the mean attenuation value [Table/Fig-3] [9].

The present study analysed hepatic attenuation across all three methods-2D ROI sampling, 3D VOI sampling, and full-liver segmentation-among patients with non-contrast scans. Patients were categorised into three groups based on hepatic attenuation values:



[Table/Fig-2]: 3D sampling of Liver



[Table/Fig-3]: Whole-liver segmentation.

- Normal: ≥50 HU (n=121)
- Mild steatosis: 40-50 HU (n=72)
- Moderate-to-severe steatosis: <40 HU (n=37)

STATISTICAL ANALYSIS

Descriptive statistics were used to summarise patient demographics and attenuation values. Normality was assessed using the Shapiro-Wilk test. Pearson correlation coefficients were calculated to evaluate the relationships between the three methods. Group comparisons were performed using ANOVA with post-hoc Tukey tests to differentiate between normal liver (attenuation 40–50 HU), mild fatty liver (<40 HU), and moderate-to-severe fatty liver. A p-value <0.05 was considered statistically significant. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 27 (IBM Corp., Armonk, NY).

RESULTS

Mean age, male-to-female ratio, Body Mass Index (BMI), and comorbidities are summarised in [Table/Fig-4].

Characteristics	Total (N=230)	Normal (n=121)	Fatty Liver (n=109)
Age (years), mean±SD	51.1±11.7	50.5±11.0	51.8±12.5
Sex (M/F)	140 (60.9%) / 90 (39.1%)	71 (58.7%) / 50 (41.3%)	69 (63.3%) / 40 (36.7%)
BMI (kg/m²), mean±SD	27.0±4.9	24.1±3.5	30.3±4.2
Diabetes	61 (26.5%)	15 (12.4%)	46 (42.2%)
Hypertension	86 (37.4%)	36 (29.8%)	50 (45.9%)
Dyslipidemia	83 (36.1%)	24 (19.8%)	59 (54.1%)
Smoking	55 (23.9%)	23 (19.0%)	32 (29.4%)

[Table/Fig-4]: Sociodemographic and baseline characteristics of study participants.

A progressive decline in liver attenuation was consistently observed across all sampling methods with increasing severity of steatosis [Table/Fig-5]. This decline was statistically significant, as demonstrated by repeated-measures ANOVA (F=47.4, p<0.001).

Pairwise comparisons demonstrated statistically significant differences between all three methods [Table/Fig-6]. Excellent inter-observer agreement was demonstrated for attenuation measurements across all three methods (2D ROI sampling, 3D VOI sampling, and whole-liver segmentation) when interpreted independently by radiologists. Light's Kappa=0.985, Fleiss' Kappa=0.985, and ICC=0.989 indicated almost perfect agreement.

Category	2D Sampling (HU)	3D Sampling (HU)	Whole Liver Segmentation (HU)
Normal (≥50 HU)	57.8	57	52.9
Mild Steatosis (40-50 HU)	44.8	43.6	44.8
Moderate-to-Severe Steatosis (<40 HU)	33	31.3	32.2

[Table/Fig-5]: Mean attenuation values across: Normal, Mild steatosis & Moderate-to-severe steatosis.

Comparison	Mean Difference (HU)	p-value
2D vs 3D	0.85	0.006
2D vs Full Segmentation	2.48	<0.001
3D vs Full Segmentation	1.63	<0.001

[Table/Fig-6]: Post-hoc comparison on non-contrast scans.

Category-wise analysis showed perfect agreement for the Normal liver group (κ=1.00), and excellent agreement for Mild steatosis (κ=0.983) and Moderate-to-Severe steatosis (κ=0.971). The overall simple agreement of 98.5% underscores the consistency and reliability of radiologists' interpretations across all sampling techniques. Pearson correlation analysis demonstrated near-perfect agreement between 2D sampling and whole-liver segmentation (R=0.98), with slightly lower but still excellent correlation between 3D sampling and whole-liver segmentation (R=0.96). Correlation between 2D and 3D sampling was similarly strong (R=0.97).

DISCUSSION

The present study comprehensively compared 2D ROI sampling, 3D volumetric sampling, and whole-liver segmentation for quantifying hepatic steatosis on non-contrast CT. All three approaches yielded highly correlated attenuation values with similar diagnostic performance. Although whole-liver segmentation demonstrated slightly greater sensitivity for detecting subtle fat infiltration, 2D sampling performed nearly equivalently, offering a more resource-efficient and clinically practical solution.

The findings of the present study align with those of Park J et al., who reported strong intra-observer correlation between single-slice ROI measurements and volumetric liver fat quantification on CT, suggesting that simple ROI-based approaches reliably reflect whole-organ fat content [10]. They also noted that liver attenuation on unenhanced CT is consistently higher than splenic attenuation, reinforcing the use of the liver-spleen attenuation difference. While this reinforces the utility of non-contrast CT, their study focused on liver-spleen relationships rather than intrahepatic variability across sampling strategies. In contrast, the present work demonstrates that systematically performed 2D sampling achieves results comparable to those obtained with more advanced 3D and whole-liver segmentation methods.

Similarly, studies by Kodama Y et al., and Lee JH et al., have demonstrated that non-contrast CT attenuation thresholds serve as robust markers of hepatic steatosis, with performance comparable to sophisticated volumetric or automated segmentation methods [11,12] Research by Kim MN et al., has further suggested that although whole-liver analysis may reduce measurement variability, its incremental diagnostic advantage is minimal relative to the significantly greater computational effort required [13].

A recent state-of-the-art review by Hu N et al., highlighted AI-driven segmentation as an emerging direction for hepatic steatosis quantification [14]. While this represents an important advancement, our findings nuance this perspective by demonstrating that although whole-liver segmentation can capture subtle variations, its incremental benefit over 2D sampling is small. This makes the present work particularly relevant in routine or resource-limited clinical settings, where 2D ROI measurements remain sufficiently accurate for detection and grading of fatty liver [14].

Although AI-based 3D and volumetric analyses hold promise-particularly for research applications and longitudinal monitoring-2D approaches continue to be clinically viable for screening and diagnosis [15]. Another emerging area is the use of ultrasound-based fat quantification methods such as the Controlled Attenuation Parameter (CAP) and ultrasound attenuation imaging, which offer real-time, radiation-free assessment of hepatic steatosis and are well-suited for large-scale screening [16].

Limitation(s)

The findings of the present study has several limitations. First, its retrospective design precludes causal inference. Second, liver biopsy-the definitive gold standard-was not used for comparison. Potential variability arising from CT scanner calibration, patient positioning, and ROI placement may also influence attenuation measurements. Additionally, although inter-observer variability was not assessed, it remains an important factor for future investigation. Finally, while manual whole-liver segmentation was used to maintain consistency, it does not fully represent real-world AI-based automated segmentation workflows. Validation using clinically deployed AI-generated segmentations would be a valuable extension.

CONCLUSION(S)

The present study demonstrate that all three methods-2D ROI sampling, 3D volumetric sampling, and whole-liver segmentation-yield highly correlated liver attenuation values with no significant differences in diagnostic performance. These findings support the use of standardised 2D sampling as a reliable, efficient, and clinically practical method for identifying fatty liver on non-contrast CT. Ultimately, the results of the present study reinforce 2D attenuation measurement as a robust and accessible tool for early detection and risk stratification of hepatic steatosis, particularly in routine and resource-limited clinical settings.

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