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Original Research Article

Cost-Effective Imaging Strategies for Liver Cancer Diagnosis: A Retrospective Comparative Study of Ultrasound, CT, and MRI

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Abstract:

Background: Early and accurate diagnosis of hepatocellular carcinoma (HCC) is essential for timely treatment. However, selection of the initial imaging modality impacts cost, diagnostic accuracy, and time to confirmation.

Methods: A retrospective comparative study was conducted in the Department of Radiodiagnosis, Karpagam Hospital, Coimbatore, over a period of three years. A total of 200 patients evaluated for suspected focal liver lesions were included. Data on demographic variables, liver disease status, tumor characteristics, imaging findings, diagnostic pathways, time to diagnosis, and direct medical costs were collected. Ultrasound (US), contrast-enhanced CT, and contrast-enhanced MRI were compared for diagnostic accuracy and cost-effectiveness.

Results: MRI demonstrated the highest diagnostic accuracy (Sensitivity 90%, Specificity 92%), followed by CT (Sensitivity 85%, Specificity 90%) and US (Sensitivity 68%, Specificity 80%). While US was the least expensive test per scan, it frequently required confirmatory CT or MRI, increasing overall diagnostic pathway time. CT provided a more balanced profile, with moderate cost and good diagnostic agreement. MRI minimized follow-up imaging but represented the highest upfront cost.

Conclusion: US remains the most economical first-line modality; however, CT appears to provide a practical balance between diagnostic performance and resource utilization in this cohort. MRI is most accurate but should be reserved for indeterminate or high-risk lesions. These findings should be interpreted in the context of study limitations, including retrospective design and selection bias.

Introduction

Hepatocellular carcinoma (HCC) is the most common type of primary liver cancer and is usually seen in individuals with long-standing liver disease. Conditions such as chronic hepatitis B and C infection, alcohol-related cirrhosis, and the increasing incidence of fatty liver disease have contributed to the rising number of HCC cases in India. Detecting HCC at an early stage is important because patients have better chances for curative treatment when the tumor is small and localized. However, early lesions are often subtle, and clinical symptoms may be absent, making imaging central to the diagnostic process.

Ultrasound is often the first imaging test used in patients with suspected liver disease because it is simple to perform, widely available, and inexpensive. It is also commonly used in surveillance programs for high-risk patients. However, the accuracy of ultrasound can vary from case to case. Small nodules or lesions located deep within a cirrhotic liver may not be clearly visualized, and results may depend on the skill of the person performing the scan. When ultrasound findings are unclear, further imaging is usually needed to confirm or rule out malignancy.

Contrast-enhanced CT is frequently used as a follow-up tool because it provides consistent image quality and clearly shows the typical vascular pattern seen in many HCC lesions. CT is also useful for assessing the extent of disease and planning treatment. MRI, on the other hand, offers even better soft-tissue contrast and can help in situations where CT findings are not definitive. MRI is often preferred for small lesions or when detailed tissue characterization is required. However, both CT and MRI are more expensive than ultrasound, and MRI may not be easily accessible in all clinical settings.

Considering differences in cost, accuracy, and availability, hospitals must make practical decisions regarding which imaging test should be used first and when to escalate to more advanced modalities. Delays in diagnosis may allow disease progression, while excessive testing increases financial burden. For these reasons, it is important to evaluate the actual performance and cost implications of ultrasound, CT, and MRI in the real clinical setting. The present study compares these three imaging approaches among patients investigated for suspected liver cancer in our institution, with the goal of identifying a diagnostic pathway that is both clinically effective and cost-efficient.

Methods

Study Design and Setting: This was a retrospective comparative study conducted in the Department of Radiodiagnosis, Karpagam Hospital, Coimbatore, Tamil Nadu, India, over a period of three years. The study was approved by the Institutional Ethics Committee and conducted in accordance with institutional guidelines. Patient records were accessed retrospectively, and the requirement for individual informed consent was waived given the observational nature of the study.

Patient Selection: A total of 200 consecutive adult patients (aged 18 years or above) who underwent imaging evaluation for suspected focal liver lesions during the study period were included. All included patients had a final confirmed diagnosis available through either histopathological examination or clinical follow-up. Patients were excluded if they had incomplete clinical or imaging data, a prior history of treated liver malignancy, or imaging studies of non-diagnostic quality. The choice of imaging modality was not standardized and was determined by the treating clinician based on clinical presentation, availability, and prior imaging findings; this is acknowledged as a potential source of selection bias.

Reference Standard: The final diagnosis was established using a composite reference standard. Histopathological confirmation (via biopsy or surgical resection) was used as the preferred standard wherever available. In patients who did not undergo tissue sampling, the diagnosis was established by multidisciplinary team (MDT) consensus incorporating clinical, laboratory, and imaging findings, with a minimum follow-up period sufficient to confirm or exclude malignancy. This approach reflects real-world institutional practice but introduces heterogeneity in the reference standard, which is acknowledged as a limitation of the study.

Imaging Technique: All imaging examinations were performed using standardized institutional protocols. Ultrasound examinations were conducted using convex transducers on multiple platforms available in the department, including a 3.5–5 MHz convex transducer on the Voluson P8 (GE Healthcare, Chicago, IL, USA), a 1.0–5.0 MHz convex transducer on the Voluson E6 (GE Healthcare, Chicago, IL, USA), and a 2–6 MHz transducer on the Affiniti 50 (Philips Healthcare, Andover, MA, USA). Examinations were performed by qualified radiologists or trained sonographers and assessed for the presence, size, echogenicity, and vascularity of focal liver lesions. Contrast-enhanced computed tomography (CT) was performed using a SOMATOM Scope 32-slice CT scanner (Siemens Healthineers, Erlangen, Germany) following a standard triphasic liver protocol, including pre-contrast, arterial, portal venous, and delayed phases where applicable. Magnetic resonance imaging (MRI) was performed on a 1.5 Tesla Ingenia Prodiva system (Philips Healthcare, Best, The Netherlands) using multiphasic liver sequences, including T1-weighted in- and out-of-phase imaging, T2-weighted imaging, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced sequences. Imaging findings were interpreted by radiologists as part of routine clinical reporting; images were not re-read independently for the purposes of this study, and blinding to clinical information was not performed, which is acknowledged as a potential source of observer bias.

Data Collection and Outcome Measures: Data on demographic variables, underlying liver disease, tumor characteristics, imaging findings, diagnostic pathways, time to final diagnosis, and direct imaging costs were collected from electronic medical records. The primary outcome measures were diagnostic sensitivity, specificity, and overall accuracy of each imaging modality. Time to diagnosis was defined as the interval from initial imaging to final confirmed diagnosis, extracted from clinical records. Cost data were limited to direct imaging costs obtained from institutional billing records; indirect costs and formal cost-effectiveness metrics were not calculated.

Statistical Analysis: Sensitivity, specificity, and overall diagnostic accuracy were calculated for each modality based on the reference standard. Due to the non-uniform distribution of imaging modalities across the study population, formal statistical comparison between modalities was not performed; results are therefore reported descriptively. Continuous variables are expressed as mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate. Categorical variables are presented as frequencies and percentages. All analyses were performed using standard statistical software. A p-value of less than 0.05 was considered statistically significant where applicable.

Results

A total of 200 patients who underwent imaging for suspected liver malignancy during the study period were included. The mean age of the study population was 59 ± 10 years, and 70% were male. Cirrhosis was present in approximately two-thirds of the cases. The prevalence of confirmed HCC was 55%. Each patient had at least one imaging modality performed, and a proportion underwent more than one test depending on initial findings or diagnostic uncertainty. Time to diagnosis was assessed as the duration between initial imaging and final confirmed diagnosis, based on patient records

Diagnostic Performance: The diagnostic performance of the three imaging modalities is summarized in Table 1. MRI demonstrated the highest diagnostic accuracy, with a sensitivity of 90%, specificity of 92%, and overall accuracy of 91%, based on 48 patients who underwent MRI evaluation. CT also showed strong diagnostic performance, with a sensitivity of 85%, specificity of 90%, and overall accuracy of 89% among 174 patients. In comparison, ultrasound showed lower diagnostic performance, with a sensitivity of 68%, specificity of 80%, and overall accuracy of 74% in 182 patients. Overall, cross-sectional imaging modalities (CT and MRI) demonstrated higher diagnostic reliability compared to ultrasound for detecting liver malignancy. Representative imaging findings are shown in Figure 1–3

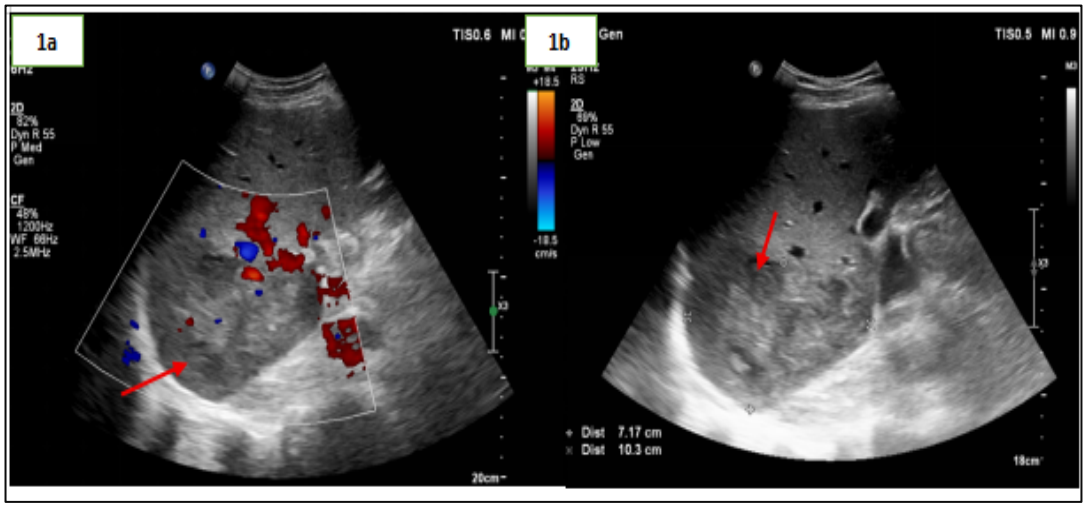

Figure 1a and 1b. Ultrasound abdomen of a 45-year-old male patient with known hepatitis B infection showing a well-defined lobulated hypoechoic space-occupying lesion in segment VII and VI of the right lobe of the liver (red arrows), measuring 10.3 × 7.1 cm with internal vascularity. The lesion extends up to the liver capsule, suggestive of a neoplastic etiology

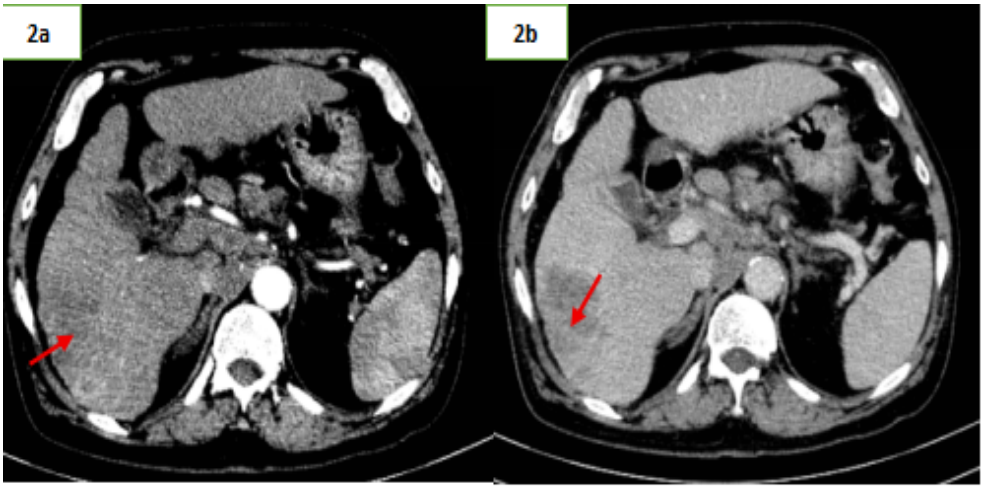

Figure 2a and 2b. Contrast-enhanced CT (CECT) abdomen of a 50-year-old male with history of chronic alcohol use, evaluated for suspected liver lesion. Triphasic CT demonstrates a well-defined lobulated and encapsulated arterial phase–enhancing lesion with washout in the portal venous phase and delayed capsular enhancement in segment VI of the liver (red arrows), measuring 5 × 4 cm, characteristic of hepatocellular carcinoma.

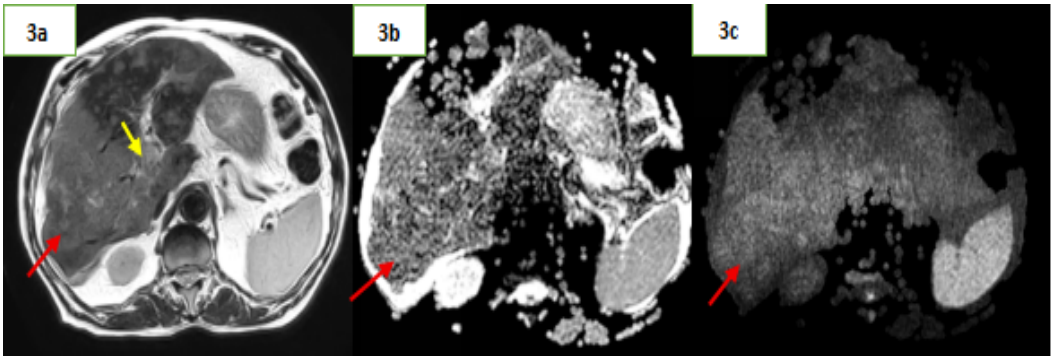

Figure 3a, 3b and 3c - Non contrast MRI upper abdomen in a patient with acute kidney injury– There is a ill-defined T2 heterointense infiltrative space occupying lesion (red arrow) noted in segment VI of liver with corresponding diffusion restriction and associated tumor thrombus (yellow arrow) in the portal vein – likely infiltrative hepatocellular carcinoma

Table 1: Diagnostic Performance

Modality	Sensitivity	Specificity	Overall Accuracy	No. of Patients Scanned
Ultrasound	68%	80%	**74%**	182
CT	85%	90%	**89%**	174
MRI	90%	92%	**91%**	48

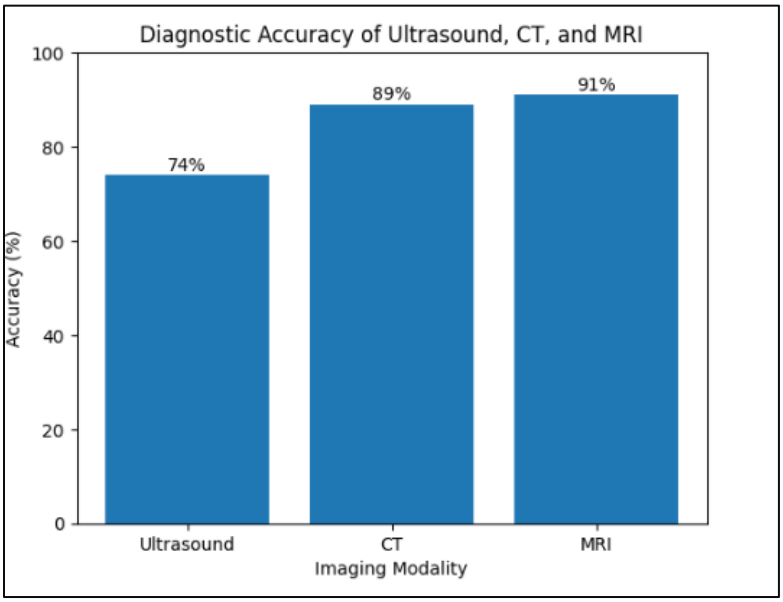

Figure 1: Diagnostic Accuracy of Each Imaging Modality

Cost and Time to Diagnosis: The median diagnostic pathway cost was lowest when ultrasound was used as the first test. However, the need for repeat or confirmatory imaging increased the overall time-to-diagnosis. CT provided a balance of cost and accuracy, with shorter diagnostic timelines. MRI offered the fastest confirmation when used early but had the highest cost per patient. Of the total study population, 182 patients underwent ultrasound, 174 underwent contrast-enhanced CT, and 48 underwent MRI. Ultrasound remained the most frequently performed initial investigation, while CT and MRI were primarily used for further lesion characterization

Table 2: Cost and Time to Diagnosis

Imaging Modality	No. of Scans	Cost per Scan (INR)
Ultrasound	182	800
CT	174	5,000
MRI	48	8,000

Discussion

In this study, the three commonly used imaging modalities—Ultrasound, CT, and MRI—were compared based on their diagnostic performance and practical implications in patients evaluated for suspected liver malignancy. The results

demonstrated clear differences in accuracy, the need for additional testing, and the overall time taken to reach a definitive diagnosis. These findings help guide appropriate sequencing of imaging tests in routine practice rather than relying on a single-modality approach.

Ultrasound was frequently used as the first investigation because it is easily accessible and routinely performed. However, in several cases, the initial ultrasound result was inconclusive. This led to additional imaging in a considerable proportion of patients. The lower accuracy observed with ultrasound in this study was mainly due to difficulty in confidently identifying small or poorly defined lesions. This pattern aligns with everyday clinical experience where ultrasound often guides the decision to proceed with more definitive imaging rather than providing a final diagnosis by itself.

CT performed better than ultrasound across all diagnostic performance parameters in this study. The majority of cases in which CT was used provided sufficient information to establish the presence or absence of malignancy. CT also reduced the number of diagnostic steps required, resulting in a shorter time to confirmation. This is an important practical advantage, as delays in diagnosis can affect treatment decisions and clinical outcomes. However, CT was not without limitations. A small number of lesions, especially very small nodules or lesions without classic enhancement features, required further clarification using MRI.

MRI offered the highest diagnostic accuracy in the present study. In most of the patients who underwent MRI, additional testing was not necessary. This suggests that MRI may be particularly valuable when the clinical concern for malignancy is strong or when lesions appear uncertain on other imaging modalities. However, MRI's cost and limited access in some settings restrict routine first-line use. For this reason, MRI may be best reserved for cases where the diagnosis remains unclear after initial imaging or where precise lesion characterization is required for treatment planning.

The evaluation of time to diagnosis showed that starting with ultrasound generally led to a longer diagnostic course because of the need for subsequent imaging. Pathways beginning with CT led to quicker confirmation, and MRI-based pathways appeared to result in shorter diagnostic intervals; however, this observation is descriptive and should be interpreted with caution, as formal statistical comparison was not performed. When choosing imaging strategy, this timeline consideration may be as important as cost or accuracy.

Cost analysis demonstrated that while ultrasound is the lowest-cost starting point, the total cost increases when repeat imaging becomes necessary. CT provided a more cost-efficient balance by offering higher accuracy at a moderate cost and reducing the number of follow-up tests. MRI, despite the highest per-test cost, avoided repeated investigations; however, its upfront expense may limit routine use. It should be noted that the cost analysis in this study was limited to direct imaging costs and did not include formal cost-effectiveness modeling; therefore, conclusions regarding cost-effectiveness should be interpreted as descriptive rather than definitive.

Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, its retrospective design introduces potential selection bias, as the choice of imaging modality was guided by clinical factors rather than a standardized protocol. Second, not all patients underwent all three imaging modalities, limiting direct cross-modality comparison on equivalent populations. Third, the reference standard was heterogeneous, as not all diagnoses were confirmed by histopathology; a proportion relied on multidisciplinary consensus with follow-up, which may introduce verification bias. Fourth, the smaller number of MRI examinations (n=48) reduces the statistical precision of MRI performance estimates, and strong conclusions regarding MRI superiority should be interpreted cautiously. Fifth, the cost analysis was limited to direct imaging costs without formal cost-effectiveness modeling. These limitations highlight the need for prospective studies with standardized imaging protocols and formal economic evaluation.

Taken together, the findings support a structured, step-wise imaging approach. Ultrasound may continue to serve as the initial scan, particularly in surveillance or low-suspicion cases. When a lesion is detected or suspicion remains, CT provides a reliable and timely second-level assessment. MRI should be used when lesion characterization remains uncertain or when higher diagnostic confidence is required for management planning. This tiered approach is both clinically practical and economically rational in routine hospital settings.

Conclusion

In this retrospective comparative study, the diagnostic performance and practical use of ultrasound, CT, and MRI were evaluated in patients investigated for suspected liver malignancy. Ultrasound was frequently used as the initial modality due to accessibility, but often required additional imaging because of lower diagnostic confidence. CT demonstrated higher accuracy and reduced the need for further evaluation, providing a more efficient diagnostic pathway in most patients. MRI yielded the highest diagnostic accuracy and least need for supplementary imaging, particularly

in cases where lesion characterization was clinically important. However, higher cost and more limited availability may constrain its routine first-line use. Overall, a stepwise imaging strategy is supported, beginning with ultrasound in appropriate cases and proceeding to CT or MRI based on initial findings and clinical suspicion. Such an approach balances diagnostic certainty, cost, and timeliness of care in the evaluation of suspected hepatocellular carcinoma.

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