International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

A Comprehensive Review of Liver Diseases: Classification, Diagnosis, Risk Factors, and Emerging Artificial Intelligence-Based Prediction Approaches

Anshita Prabhakar[1], Ashish Kumar Tiwari[2]
[1,2] Dept. of Computer Science and Technology, SAM Global University, Bhopal, India
[1]anshitaprabhakar@gmail.com, [2]aashish.tiwari7898@gmail.com

ABSTRACT
Diseases of the liver present a considerable challenge for world health due to their increasing incidence, complicated mechanisms, and great impact on mortality. The liver has several important functions such as metabolism, detoxification, secretion of bile, and regulation of biochemical processes and any abnormalities, both functional and structural, can result in serious health consequences. The present review article is a detailed review of the liver diseases including fatty liver disease, hepatitis, alcoholic liver diseases, fibroses, cirrhosis, autoimmune disorders, liver failure, and hepatocellular carcinoma. The article describes the causes of liver diseases, their symptoms, process of diagnosis, and underlying mechanisms of diseases development. Different diagnostic methods such as biochemical tests, imaging methods, and biopsy as well as problems connected with the diagnosis of the early stages of the diseases are examined. Advanced developments in machine learning and deep learning in liver disease prediction, classification, and decision support system also discussed. The issue of obtaining and working with complicated medical datasets as well as a high precision during diagnostics is also discussed. Problems of obtaining and analysing the data as well as the staying in line with privacy regulations and the medical community acceptance are also analysed.

Keywords: Liver Diseases; Hepatitis; Liver Failure; Artificial Intelligence; Machine Learning; Deep Learning

INTRODUCTION

The rapid Liver diseases have emerged as a significant global healthcare concern due to their increasing prevalence, complex progression patterns, and high contribution to morbidity and mortality worldwide. The liver is one of the most vital organs in the human body [1], responsible for performing several essential biological functions, including metabolism of nutrients, detoxification of harmful substances, regulation of blood composition, synthesis of plasma proteins, bile production, and immune system regulation. Any abnormality affecting liver structure or function can lead to a wide range of disorders, including fatty liver disease, viral hepatitis, alcoholic liver disease, liver fibrosis, cirrhosis, liver failure, and hepatocellular carcinoma. According to global health reports, millions of individuals are affected by chronic liver disorders every year, creating a substantial burden on healthcare systems due to long-term treatment requirements, reduced quality of life, and increased mortality rates [2-[3]]. The rising incidence of metabolic disorders, unhealthy lifestyles, excessive alcohol consumption, viral infections, and genetic factors has further accelerated the occurrence of liver-related complications across different populations.

Early detection and accurate diagnosis play a crucial role in preventing the progression of liver diseases and improving patient outcomes. Many liver disorders remain asymptomatic during their initial stages, allowing gradual deterioration of liver tissues before clinical symptoms become visible. Timely identification of liver abnormalities enables healthcare professionals to initiate appropriate treatment strategies, modify risk factors, and prevent irreversible damage such as advanced fibrosis, cirrhosis, and liver failure. Conventional diagnostic approaches, including biochemical blood tests, imaging techniques such as ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI), along with liver biopsy, are widely used for disease assessment. These methods provide valuable information regarding liver functionality, structural changes, and pathological conditions [4]. However, accurate diagnosis often requires expert interpretation, extensive clinical experience, and integration of multiple diagnostic parameters, which may introduce variability and delay in decision-making.

Despite significant advancements in medical diagnosis, conventional liver disease assessment methods face several challenges. Laboratory-based tests generally evaluate specific biomarkers and may not always provide comprehensive information regarding disease severity or progression. Imaging-based techniques depend heavily on image quality, equipment availability, and the expertise of radiologists for accurate interpretation. Liver biopsy, considered a reference diagnostic method for evaluating fibrosis and tissue damage, is invasive, expensive, and associated with patient discomfort and sampling errors [5]. Additionally, traditional approaches may have limitations in handling large-scale healthcare datasets containing complex relationships among clinical parameters, genetic information, and imaging features. These challenges highlight the need for advanced computational approaches capable of supporting clinicians with faster, more accurate, and reliable diagnostic solutions.

Artificial intelligence (AI) has recently gained considerable attention in healthcare due to its ability to analyse complex medical data, recognize hidden patterns, and improve clinical decision-making. AI-based approaches, including machine learning (ML) and deep learning (DL), have demonstrated promising capabilities in disease prediction, classification, risk assessment, and personalized treatment planning. Machine learning algorithms such as support vector machines [6], decision trees, random forests, and ensemble models can identify important clinical features associated with liver disorders, while deep learning techniques, including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and transformer-based architectures, provide advanced solutions for analysing medical images and sequential health records.

In liver disease management, AI models have been applied for early diagnosis, severity prediction, classification of different liver conditions, and analysis of radiological images. These intelligent systems can integrate diverse data sources, including laboratory parameters, electronic health records, medical imaging, and patient history, to generate accurate

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predictions and assist healthcare professionals in clinical decision-making [7]. Furthermore, emerging concepts such as explainable artificial intelligence (XAI) aim to improve transparency by providing understandable reasons behind model predictions, thereby increasing trust and acceptance among medical practitioners. This figure 1 illustrates the anatomical structure of the human liver and highlights its major functions, including metabolism, detoxification, bile production, nutrient storage, and protein synthesis.

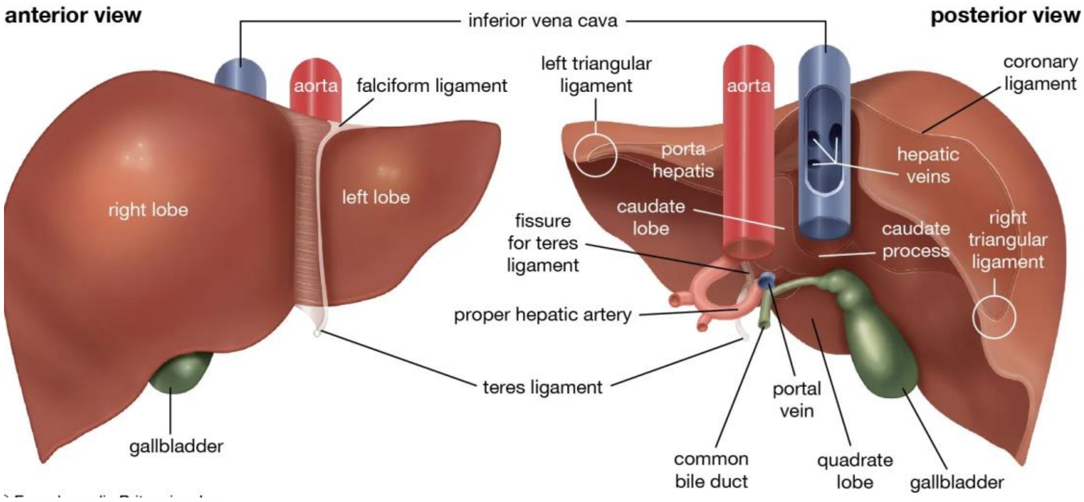

Figure 1: Human Liver: Structure and Functions [7]

Although AI-based healthcare systems offer significant advantages, challenges related to data privacy, model interpretability, availability of high-quality datasets, computational requirements, and clinical validation remain important research concerns. Addressing these limitations is essential for successful real-world deployment of AI-driven liver disease prediction systems. Therefore, this review focuses on the current landscape of liver diseases, conventional diagnostic approaches, and recent advancements in artificial intelligence-based techniques, highlighting their potential to transform early detection, accurate diagnosis, and effective management of liver-related disorders.

FUNDAMENTALS AND CLASSIFICATION OF LIVER DISEASES

The liver is the largest internal glandular organ in the human body and plays a central role in maintaining overall physiological balance. Located in the upper-right region of the abdominal cavity, the liver consists of specialized structural units called hepatic lobules, which contain hepatocytes responsible for performing essential metabolic activities. The liver receives blood through the hepatic artery and portal vein, enabling efficient processing of nutrients, oxygen, and biochemical substances [8]. It performs numerous vital functions, including carbohydrate, protein, and lipid metabolism, detoxification of drugs and harmful chemicals, synthesis of plasma proteins and clotting factors, regulation of cholesterol levels, storage of vitamins and minerals, immune system regulation, and production of bile required for digestion. Due to its multifunctional role, any structural damage or functional impairment of the liver can significantly affect multiple body systems and result in progressive liver disorders.

Liver diseases represent a broad group of disorders characterized by inflammation, degeneration, abnormal accumulation of substances, fibrosis, or malignant transformation of liver tissues. These diseases can be classified based on their causes, progression patterns, and clinical manifestations. Fatty liver disease, including non-alcoholic fatty liver disease (NAFLD) and non-alcoholic steatohepatitis (NASH) [9], is one of the most common liver disorders caused by excessive accumulation of fat within hepatocytes. While simple fatty liver may remain harmless, continuous inflammation can lead to fibrosis, cirrhosis, and liver failure. Major risk factors include obesity, diabetes, metabolic syndrome, unhealthy dietary habits, and physical inactivity.

Viral hepatitis is another significant category of liver disease caused by hepatitis viruses, including hepatitis A, B, C, D, and E. These infections induce liver inflammation and may result in acute or chronic liver damage. Among these, hepatitis B and C are major contributors to chronic liver disease, fibrosis, cirrhosis, and hepatocellular carcinoma due to their long-term effects on liver cells. Transmission routes, immune response, and viral persistence influence disease severity and progression.

Alcoholic liver disease (ALD) develops due to prolonged and excessive alcohol consumption, which causes oxidative stress, inflammation, and hepatocyte injury [10]. The disease typically progresses through stages of alcoholic fatty liver, alcoholic hepatitis, and advanced cirrhosis. Genetic susceptibility, nutritional deficiencies, and duration of alcohol exposure influence the severity of liver damage.

Liver fibrosis and cirrhosis represent progressive stages of chronic liver injury. Continuous inflammation activates hepatic stellate cells, leading to excessive deposition of extracellular matrix proteins and scar tissue formation. Fibrosis reduces normal liver architecture, while cirrhosis represents an advanced irreversible stage associated with impaired liver function, portal hypertension, and increased risk of liver cancer [11].

Autoimmune liver disorders, such as autoimmune hepatitis and primary biliary cholangitis, occur when the immune system mistakenly attacks liver cells or bile ducts. These conditions cause chronic inflammation and gradual deterioration of liver function. In advanced stages, untreated autoimmune disorders may progress to fibrosis and cirrhosis.

Liver failure occurs when the liver loses its ability to perform essential functions and can be classified as acute or chronic liver failure. Acute liver failure develops rapidly due to factors such as drug toxicity or viral infections, whereas chronic liver failure usually results from long-term liver diseases [12]. Liver cancer, particularly hepatocellular carcinoma, is a severe complication commonly associated with chronic hepatitis infection, cirrhosis, and prolonged liver inflammation.

The progression of liver diseases is influenced by multiple biological and environmental factors, including genetic predisposition, viral infections, alcohol consumption, obesity, metabolic disorders, exposure to toxins, and lifestyle habits. Persistent liver injury initiates inflammatory responses, oxidative stress, hepatocyte death, and tissue remodelling, eventually leading to fibrosis, cirrhosis, and malignant transformation [13]. Understanding the classification, mechanisms, and risk factors associated with liver diseases is essential for

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developing effective diagnostic strategies, preventive measures, and advanced treatment approaches. . Table 1 summarizes recent research studies on MASLD, highlighting disease classification, risk factors, therapeutic approaches, clinical outcomes, mortality analysis, and emerging challenges in diagnosis and management.

Table 1: Literature Review on Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD)

Ref.	Study Focus	Methodology	Dataset	Key Findings	Limitations	Future Scope
[14]	Therapeutic management and clinical guidelines for MASLD	Comprehensive review of therapeutic strategies, lifestyle modifications, pharmacological interventions, and updated EASL–EASD–EASO guidelines.	Clinical guidelines and evidence-based literature analysis.	Identified weight reduction, metabolic risk management, and emerging pharmacological therapies as key strategies for MASLD treatment.	Limited long-term clinical evidence for newly developed drugs and personalized treatment approaches.	Development of precision medicine-based therapies and long-term clinical trials.
[15]	Association between MASLD and cancer progression	Review of epidemiological studies and clinical evidence exploring MASLD-related cancer risks.	Population studies and clinical outcome analysis.	Demonstrated that MASLD increases the risk of hepatocellular carcinoma and other malignancies through metabolic imbalance and chronic inflammation.	Molecular pathways connecting MASLD with cancer progression require further investigation.	Integration of molecular biomarkers for early cancer prediction in MASLD patients.
[16]	Comparison of MASLD and NAFLD clinical characteristics and mortality	Comparative clinical assessment of patient profiles, disease progression, and mortality patterns.	Clinical cohort analysis.	Found similar clinical profiles and mortality trends between MASLD and NAFLD populations,	Limited validation across different demographic and geographic populations.	Large-scale international studies for global validation of MASLD

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	outcomes			supporting the updated terminology.		classification.
[17]	Impact of MASLD nomenclature on clinical practice	Analysis of updated AASLD guidance and evaluation of diagnostic implications.	Clinical practice guideline review.	Highlighted that MASLD provides improved classification by incorporating metabolic dysfunction as a major disease factor.	Challenges in implementation, diagnosis standardization, and clinical awareness.	Development of standardized diagnostic protocols and automated screening tools.
[18]	Evolution of MASLD terminology and classification	Review of historical progression from NAFLD and MAFLD definitions to MASLD.	Terminology and clinical framework analysis.	Explained that MASLD better represents metabolic-associated liver dysfunction and improves disease understanding.	Acceptance and implementation of new terminology remain challenging worldwide.	Global consensus development and integration into healthcare systems.
[19]	MASLD criteria evaluation in lean patients	Comparative analysis of MASLD and MAFLD diagnostic criteria among lean individuals with fatty liver disease.	Patient subgroup evaluation and diagnostic criteria comparison.	Reported that MASLD criteria provide improved classification for lean patients compared with previous	Limited studies involving different ethnic groups and lean patient populations.	Development of improved diagnostic models for diverse patient categories.

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				approaches.		
[20]	Mortality risk associated with MASLD	Nationwide population-based cohort analysis evaluating mortality outcomes and associated factors.	Large-scale epidemiological cohort study.	Revealed increased mortality risk among MASLD patients, particularly those with advanced fibrosis and metabolic complications.	Limited evaluation of treatment impact on reducing mortality risk.	Predictive risk models for early mortality estimation and intervention planning.
[21]	Transition from NAFLD to MASLD terminology	Review of advantages and challenges associated with the updated nomenclature.	Clinical literature review and expert analysis.	Identified MASLD as a significant advancement toward metabolic-based liver disease classification.	Difficulties related to diagnosis criteria adaptation and healthcare implementation.	AI-assisted diagnostic systems using MASLD-specific clinical parameters.
[22]	Pharmacological treatment approaches for MASLD/MAFLD	Review of recent drug developments targeting metabolic dysfunction, inflammation, and fibrosis.	Pharmacological research and clinical trial analysis.	Identified potential therapeutic agents targeting fibrosis reduction and metabolic regulation.	Absence of widely approved medications and limited long-term efficacy evidence.	Development of safe, effective, and patient-specific therapeutic interventions.

CONVENTIONAL DIAGNOSTIC TECHNIQUES FOR LIVER DISEASE DETECTION

Conventional diagnostic approaches have played a fundamental role in the identification and clinical management of liver diseases by evaluating biochemical alterations, structural abnormalities, and tissue-level changes. These techniques remain widely used as primary assessment tools due to their clinical reliability and availability; however, their effectiveness in early-stage disease detection and continuous monitoring remains limited. [14] Current

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diagnostic practices generally include biochemical and laboratory investigations, medical imaging techniques, and histopathological examination through liver biopsy.

Biochemical and laboratory-based investigations are the most commonly applied initial screening methods for evaluating liver dysfunction. Several studies have reported the importance of liver function biomarkers, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), bilirubin, albumin, and gamma-glutamyl transferase (GGT), for identifying hepatocellular injury and impaired liver function. These parameters are extensively used for detecting conditions such as viral hepatitis, metabolic dysfunction-associated steatotic liver disease (MASLD) [15], and alcoholic liver disease. However, recent research indicates that biochemical markers alone are insufficient for accurate assessment of disease severity because enzyme levels may remain normal during early stages or fail to represent the extent of fibrosis and structural damage. Therefore, combination with imaging and clinical parameters is often required for improved diagnostic reliability.

Imaging-based diagnosis methods, including ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI), have become important non-invasive alternatives for liver disease evaluation. Ultrasound-based techniques are frequently used for initial screening of fatty liver, liver enlargement, and morphological abnormalities due to their low cost and accessibility. CT imaging provides enhanced anatomical visualization and is commonly applied for tumour detection, vascular assessment, and advanced liver disease evaluation. MRI-based techniques, particularly magnetic resonance elastography (MRE) [16], have demonstrated improved capability for quantifying liver fat accumulation and fibrosis without invasive procedures. Despite these advantages, imaging-based diagnosis is influenced by operator expertise, imaging quality, equipment availability, and variations in interpretation, which may affect diagnostic consistency across clinical environments.

Liver biopsy and histopathological examination remain the reference standard for evaluating liver fibrosis, inflammation, steatosis, and malignant transformation. Several clinical studies have highlighted that biopsy provides detailed information regarding cellular-level changes and disease staging, making it valuable for confirming diagnosis and assessing treatment response. However, its invasive nature, risk of complications, sampling variability, patient discomfort, and requirement for specialized pathological expertise limit its widespread application, particularly for large-scale screening and repeated monitoring.

Although conventional diagnostic techniques have significantly contributed to liver disease management, existing literature highlights several limitations, including delayed detection, dependency on expert interpretation, inability to efficiently process complex multidimensional health data, and limited predictive capability for future disease progression. These challenges have created the need for advanced computational approaches capable of integrating clinical, imaging, and molecular information [17]. Consequently, recent research has increasingly focused on artificial intelligence-based methods, including machine learning and deep learning models, to enhance early diagnosis, improve classification accuracy, and support personalized liver disease prediction.

MACHINE LEARNING AND DEEP LEARNING APPROACHES FOR LIVER DISEASE PREDICTION

The Machine learning (ML) and deep learning (DL) approaches have emerged as effective tools for liver disease prediction by enabling automated analysis of clinical parameters, laboratory investigations, and medical imaging data. According to recent review studies, ML-based classification techniques such as support vector machine (SVM), decision tree (DT), random forest (RF), k-nearest neighbor (KNN), logistic regression (LR), naïve Bayes (NB), and ensemble learning methods have been widely applied for detecting and classifying liver diseases including hepatitis, cirrhosis, hepatocellular carcinoma, and metabolic dysfunction-associated steatotic liver disease. These models utilize important clinical attributes such as bilirubin, albumin, alanine aminotransferase (ALT) [18], aspartate aminotransferase (AST), alkaline phosphatase (ALP), age, and other biochemical indicators to identify disease patterns. Ensemble models, particularly random forest and boosting-based techniques, have shown improved prediction performance due to their ability to combine multiple classifiers and reduce overfitting. However, traditional ML approaches rely on manually extracted features, which limits their effectiveness for complex and large-scale medical datasets. Deep learning models overcome these limitations by automatically learning representative features from raw clinical and imaging data. Convolutional neural networks (CNNs) have been extensively used for liver image analysis, including segmentation [19], tumor detection, fibrosis assessment, and classification of ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI) images. Furthermore, advanced architectures such as recurrent neural networks (RNN), long short-term memory (LSTM), autoencoders, and transformer-based models have been employed for analysing sequential clinical information and longitudinal patient records. Hybrid models, such as CNN-LSTM architectures, combine spatial feature extraction and temporal learning capabilities, providing improved predictive accuracy [20]. Feature extraction, selection, and optimization play a crucial role in enhancing AI-based liver disease prediction systems by eliminating irrelevant information and improving model efficiency. Various techniques, including principal component analysis (PCA), mutual information, correlation-based feature selection, recursive feature elimination (RFE), and evolutionary optimization algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), and grey wolf optimization (GWO), have been utilized to select significant biomarkers and optimize model parameters. Comparative analyses reported in review studies indicate that AI-based models generally achieve higher accuracy, sensitivity, and reliability than conventional statistical approaches. Machine learning methods demonstrate strong performance for structured clinical datasets, while deep learning techniques provide superior feature [21] learning capabilities for medical images and multimodal data. Despite significant progress, existing AI-based liver disease prediction models face challenges related to limited annotated datasets, data imbalance, computational complexity, and lack of interpretability. Therefore, recent research emphasizes the integration of explainable artificial intelligence (XAI), hybrid ML-DL frameworks, and multimodal learning approaches to develop accurate, transparent, and clinically applicable liver disease prediction systems [22].

CONCLUSION AND FUTURE WORK

The paper presents an extensive overview of techniques pertaining to deep and machine learning that are used in predicting liver diseases. This study emphasizes the significance of Artificial Intelligence techniques in enhancing the processes of early diagnosis of the condition, as well as disease categorization and medical decision-making through analysis of medical images and clinical information concerning patients. Several classifiers based on machine learning, deep learning, methods of feature selection, and optimization practices are also reviewed in order to determine their contributions to prediction performance improvement. Despite the fact that AI-powered models provide satisfactory results, the issue of availability of data, interpretability of models, complexity of computations, and medical verification will still remain severe. Therefore, future studies should be directed at the elaboration of hybrid AI frameworks integrating different forms of clinical information, as well as medical images featuring explainable AI methods. Also, great potential remains in the use of large healthcare datasets, as well as lightweight optimized AI models for real-time diagnosis.

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