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Review Article

Moonlighting Effects of Pyruvate Kinase M2 in Chronic Liver Diseases

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Abstract

Hepatic diseases have constituted a significant global problem for over two decades, numerous factors contribute to these diseases, and most eventually result in hepatocellular carcinoma. A particular pivotal factor responsible for hepatic diseases is the abnormal functioning of various metabolic processes. Pyruvate kinase is a crucial regulator of the glycolytic pathway, and overexpression of pyruvate kinase isoform M2 (PKM2) has been observed with various hepatic abnormalities due to genetic malfunctioning and other contributing factors. The present scenario for diagnosing and treating hepatic diseases includes surgery and immunosuppressant therapies. Kinase modulation may also be a potential therapeutic measure for rectifying hepatic diseases, and this can serve as a potential approach. This review summarizes the malfunctions and significance of PKM2 regulation and explores the potential of PKM2 as a target for treating hepatic abnormalities.

Introduction

Liver Diseases

The liver is a large, complex organ essential for maintaining overall body homeostasis. With the primary functionality of carbohydrate, protein, and fat metabolism, it is the site where metabolic waste products are detoxified via processes such as amino acid deamination, to produce urea. In concert with the spleen, spent red blood cells are degraded and their constituents are reclaimed. Bile synthesis and secretion, lipoprotein and plasma protein synthesis, and the production of clotting factors all take place in the liver. Additionally, blood glucose levels are stabilised via absorbing and storing glucose as glycogen (glycogenesis), breaking this down to glucose when needed (glycogenolysis), and the production of glucose from noncarbohydrate sources such as amino acids (gluconeogenesis).[1] Disruptions to normal liver functions by viral infections, alcohol abuse, metabolic disorders, and genetic predispositions can invariably lead to hepatic diseases.

Hepatic diseases are a significant global health problem, with various factors contributing to their prevalence. Chronic liver diseases (CLDs) refer to a group of diseases with varying degrees of intrahepatic inflammatory necrosis and/or fibrosis caused by various aetiologies and a minimum 6-month history. CLDs usually include cirrhosis, non-cirrhotic chronic liver diseases, chronic hepatitis (chronic hepatitis B and chronic hepatitis C), alcohol-associated liver disease, metabolic-associated fatty liver disease, autoimmune liver disease, genetic metabolic liver disease, and chronic drug-induced liver injury. Acute aggravation is defined as the emergence of new acute inflammatory necrosis in the liver as a result of several inducements (such as hepatitis virus mutation, overlap virus infection, bacterial infection, excessive alcohol intake, drugs, or immune damage), resulting in further aggravation of the original inflammation and/or fibrosis and leading to liver dysfunction, decompensation, or liver damage.[2] Liver diseases and their most serious complications, such as acute liver failure, cirrhosis, and liver cancer, are among the world's leading and fastest-

Keywords: Pyruvate Kinase M2; Hepatic abnormalities; Hepatocellular carcinoma; Hepatitis; Liver cirrhosis; Fatty liver disease.

Abbreviations: ADP, adenosine diphosphate; AKT, protein kinase B; anti-PD-1, anti-programmed cell death-1; ATP, adenosine triphosphate; Bcl-xL, B-cell lymphoma-extra-large; CK, cytokeratin; CLDs, chronic liver diseases; c-Met, c-mesenchymal epithelial transition factor; EGFR, epidermal growth factor receptor; ER, endoplasmic reticulum; ERK, extracellular signal-regulated kinase; FGFR, fibroblast growth factor receptor; FOXA3, forkhead box protein a3; GWAS, genome-wide association studies; HBV, hepatitis B virus; HCV, hepatitis C virus; HCC, hepatocellular carcinoma; Hep-1, Hepatocyte Parafn 1; HGF, hepatocyte growth factor; HDAC, histone deacetylase; HIF-1α, hypoxia-inducible factor -1α; JNK, c-Jun N-terminal kinase; LKB1, liver kinase B1; LHBS, large viral surface antigens; MAPK, mitogen-activated protein kinase; MEK, mitogen-activated extracellular signal-regulated kinase; NAFLD, non-alcoholic fatty liver disease; miRNA, micro RNA; MiR-122, MicroRNA-122; NASH, nonalcoholic steatohepatitis; PDGFR, platelet-derived growth factor receptor; pERK, phosphorylation extracellular regulated protein kinase; PEP, Phosphoenolpyruvate; PJS, Peutz-Jeghers syndrome; PKM2, pyruvate kinase M2; RAF, rapidly accelerated fibrosarcoma; STK11, Serine/threonine kinase 11; SUOX, sulfite oxidase; TACE, transarterial chemoembolization; TCA, tricarboxylic acid cycle; TRIM35, tripartite motif-containing protein 35; VEGFR, vascular endothelial growth factor receptor; ZFP91, zinc finger protein 91.

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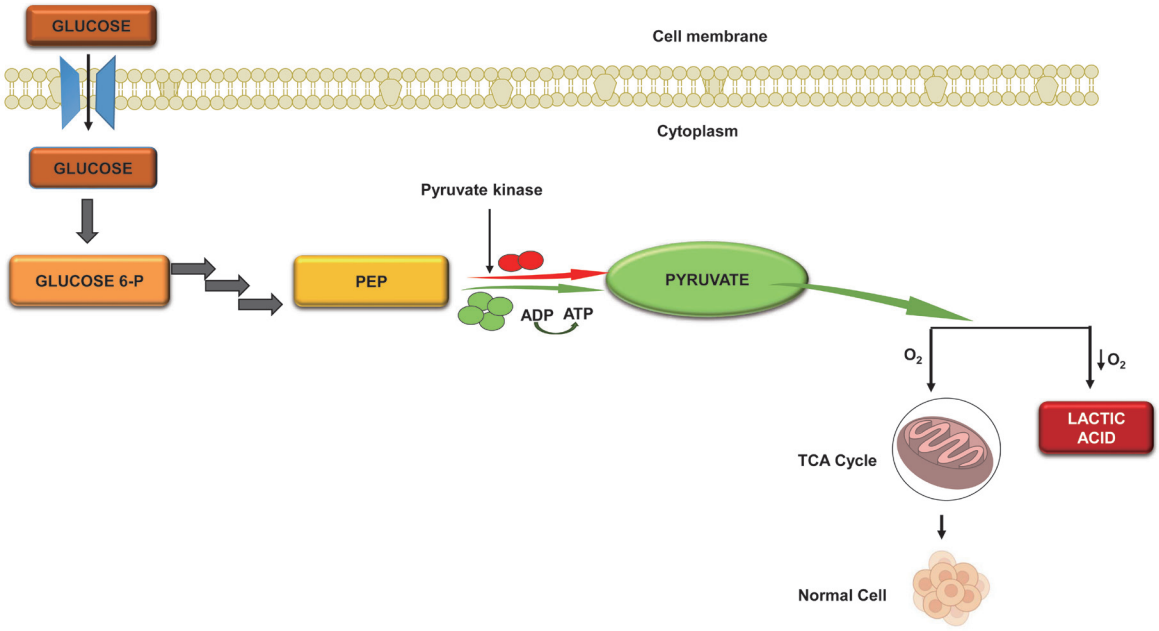

Fig. 1. Illustration depicting the role of pyruvate kinase in glycolysis of normal cells and cancerous cells. The terminal glycolytic step is catalyzed by the pyruvate kinase that involves the conversion of phosphoenolpyruvate to pyruvate. The pyruvate kinase M2 in its dimeric form (exclusively present in cancer cells) results in lactate production whereas its tetrameric form leads to the formation of pyruvate which enters the TCA cycle. ADP, adenosine diphosphate; ATP, adenosine triphosphate; PEP, Phosphoenolpyruvate; TCA, tricarboxylic acid cycle.

growing causes of death. It is estimated that CLDs (cirrhosis, viral hepatitis, and liver cancer) account for over 2 million deaths annually and are responsible for 4% of all deaths worldwide.[3] 1 out of 3 liver deaths are of females. It is the 11th foremost cause of death worldwide and the 15th leading cause of disability-associated life-years.[4] However, there has been no significant development in the treatment of the aforementioned hepatic abnormalities, but various supportive treatments to reduce their incidence are readily available. In this review, we discuss various hepatic abnormalities and their potential therapeutic approaches.

Kinases involved in hepatic diseases

Kinases, a class of enzymes responsible for phosphorylating proteins and modulating signaling pathways, play an influential role in the pathogenesis of hepatic diseases. Several kinases are implicated in hepatic diseases and are crucial for cellular processes inclusive of liver function, metabolism, and inflammation. Some kinases associated with hepatic diseases are c-Jun N-terminal Kinase (JNK), Hepatic Kinase B or Protein Kinase B/Akt, AMP-activated Protein Kinase, Transforming Growth Factor-beta-Activated Kinase 1, Fibroblast Growth Factor Receptor (FGFR), Mitogen-Activated Protein Kinase (MAPK), Protein Kinase C, Extracellular Signal-Regulated Kinase (ERK), Phosphoinositide 3-Kinase, Glycogen Synthase Kinase-3, and Pyruvate kinase M2 (PKM2).[5]

Stress-activated protein kinases, MAPKs, are a type of serine/threonine kinase that can regulate cellular processes by transducing extracellular stimuli into intracellular responses. In the liver, MAPKs play a significant role in adaptable processes that regulate inflammation.[6] MAPK/ERK signaling has prognostic significance because increased expression of renin-angiotensin system effectors is strongly associated with a poor survival rate in hepatocellular carcinoma (HCC) patients.[7] Rapidly accelerated fibrosarcoma kinase (RAF), mitogen-activated extracellular signal-regulated kinase (MEK), and ERK mRNA were overexpressed in 33, 40, and 50% of HCC patients, respectively, and MEK1/2 phosphorylation was seven-fold higher in HCC tissues compared to adjacent benign tissues.[8]

Specific oncogenic kinase targets include v-RAF murine sarcoma viral oncogene homolog B1, epidermal growth factor receptor (EGFR), vascular endothelial growth factor receptor (VEGFR), human epidermal growth factor receptor 2, Kit, platelet-derived growth factor receptor (PDGFR), mammalian target of rapamycin, hepatocyte growth factor (HGF)/c-mesenchymal epithelial transition factor (c-Met), FGFR, and others. These proteins are linked to hallmarks of carcinogenesis such as maintaining proliferative signaling, inducing angiogenesis, anti-apoptotic mechanisms, and activating invasion and metastasis.[9] Intracellular pathways, with EGFR, PDGFR, VEGFR, HGF/c-Met, and FGFR, are all deregulated in HCC. The activation of these receptors initiates additional intracellular renin-angiotensin system /RAF/ERK/MEK protein kinase signaling cascades. In experimental models, activating these mediators can cause liver tumors. Knockdown experiments revealed that deactivating these kinases may have anticancer effects, demonstrating that pathway blockade is a credible target for controlling HCC.[10]

PKM2 is an enzyme that plays an important role in cellular metabolism. It is expressed specifically in proliferating cells, including cancer cells, and in certain tissues such as the liver. Although PKM2 is most commonly associated with cancer, new research suggests that it may also be involved in hepatic diseases. PKM2 has been linked to several processes that contribute to liver pathologies in the context of hepatic diseases.

PKM2 is overexpressed in the most common type of liver cancer, hepatocellular carcinoma. It promotes tumor growth and survival by increasing glucose metabolism and producing biosynthetic precursors required for rapid cell proliferation (Fig. 1). PKM2 also regulates the Warburg effect, which is characterized by an increase in metabolic rate.[11] PKM2 expression is barely detect-

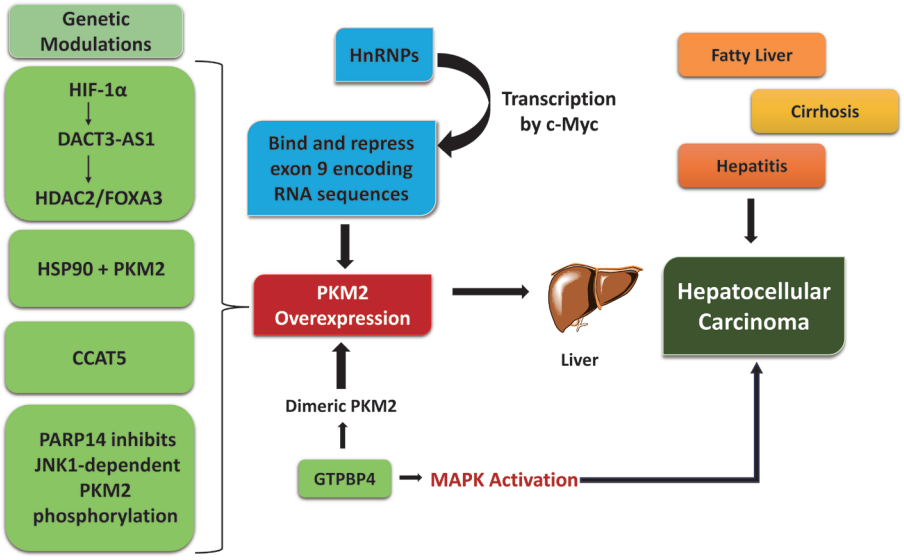

Fig. 2. Schematic representation provides insight into the intricate molecular factors contributing to liver diseases and genetic modulations of markers like HDAC2/FOXA3, HSP90, CCAT5, PARP14 along with GTPBP4 which eventually results in pyruvate kinase M2 overexpression, finally leading to alterations causing hepatic abnormalities. FOXA3, forkhead box protein a3; HDAC2, histone deacetylase 2; JNK, c-Jun N-terminal kinase; MAPK, mitogen-activated protein kinase; PKM2, pyruvate kinase M2.

able in healthy livers but is markedly upregulated in liver cancer. Interestingly, despite the fact that a switch from PKM1 to PKM2 is observed in many types of tumors, PKM2 is the dominant isoform of PKM in both normal livers and HCC.[12] The level of PKM2 in plasma ectosome gradually increases prior to tumor formation during N-nitroso diethylamine/carbon tetrachloride or streptozotocin/high-fat diet (N-nitrosodiethylamine/carbon tetrachloride - or streptozotocin/high fat diet) induced murine hepatocarcinogenesis. Furthermore, PKM2 is significantly more abundant in ectosomes from HCC patients than in healthy donors, indicating that PKM2 may function as an early diagnostic marker for HCC.[13] PKM2 is significantly upregulated in tumor tissues in HCC patients and is associated with a poor prognosis. Furthermore, PKM2 overexpression in HCC is associated with a high tumor, node, metastasis stage and level of vascular invasion. Patients who express PKM2 typically have an increased risk of postsurgical HCC recurrence.[14]

Non-alcoholic fatty liver disease (NAFLD) is a liver condition characterized by fat accumulation. PKM2 has been linked to the development and progression of NAFLD. It has the ability to influence lipid metabolism by controlling the expression of genes elaborated in fatty acid synthesis, oxidation, and storage. PKM2 activity changes may contribute to the abnormal lipid accumulation and hepatic steatosis seen in NAFLD.[15] Liver fibrosis is a wound-healing response to chronic liver injury characterized by an overabundance of extracellular matrix components. PKM2 has been linked to hepatic stellate cell activation, which contributes significantly to liver fibrosis. PKM2 stimulates the proliferation and activation of hepatic stellate cells, increasing the production of collagen and other fibrotic proteins.[16]

Correlation between various liver diseases and PKM2

Genetic regulation of hepatocellular carcinoma by PKM gene

As PKM2 is pivotal in the metastasizing mechanism of carcinogenic cells (termed the Warburg effect), studies have shown that HCC is linked with the PKM gene by numerous mechanisms (Fig. 2). A common feature of carcinogenic cells is the malfunction of biotransformation, for example, their ability to cause alterations in metabolic processes like glycolysis. In 2012, Wang *et al.* studied the genetic cross-walk of HCC alongside the oncogenic pathway protein kinase B (AKT) activation and lowering of the sprout 2 (*spry2*) gene. They reported that AKT-induced HCC development increased extensively through the overexpression of *Spry2Y55F*. This overexpression gave rise to increased cell proliferation, increasing glycolysis, and resulting in significantly increased frequency of PKM2 and MAPK pathway activity.[17]

Overexpression of PKM2 in HCC patients and its role in the enhancement of cell proliferation and ultimate progression of HCC occurs through various critical pathways including PRMT6-ERK-PKM2 regulatory axis, circMAT2B/miR-338-3p/PKM2 axis, and PARP14-JNK1-PKM2 regulatory axis.[18,19] There are certain oncogenic factors like heat shock protein 90 that bring about Thr-328 phosphorylation, or c-Myc, which drives the expression of MNX1-AS1 to consequently induce the upregulation of PKM2.[20,21]

Cellular metabolism is regulated by MicroRNA-122(MiR-122), and is abundantly expressed in normally functioning cells, however, metabolic alterations that occur in HCC result in the reduction of MiR-122. Studies reveal that genes demonstrating the interaction of MiR-122 at 3′UTR areas are *PK, ALDOA, GNPDA1, PFKFB2*, and *AKR1B10*, among which *PK* gene has maximum anticorrelation with MiR-122. In HCC cells, expression of PKM2 is comparably higher in the metastasizing state. Overexpression of MiR-122, therefore, is indicative of reduced lactate production, inhibited cell proliferation and increased chemosensitivity.[22] Additionally, MiR-122-5p has been investigated for its assistance in the function of lncRNA-SOX2OT, and modulating the metabolism and metastasis of HCC cells. lncRNA-SOX2OT is a PKM2 regulator and fosters PKM2-facilitated glucose metabolism. As such, PKM2 inhibition hinders lncRNA-SOX2OT in promoting the metastasis of HCC.[23]

When PKM2 expressions in HCC patients were studied by immunohistochemistry analysis, overexpression of PKM2 was ob-

served throughout, and was seemingly associated with the worse clinicopathologic characteristics in the patients. PKM2 overexpression was also correlated with endoplasmic reticulum (ER) stress. ER stress downregulates the expression of MiR-188-5p in the HCC cells, its target gene hnRNPA2B1, when downregulated, decreases PKM2 expression and enhances apoptosis.[24]

Wang *et al.* suggest lncRNA DACT3-AS1 is associated with the progression of HCC through the upregulation of PKM2, and this upregulation is brought about by the histone deacetylase 2/forkhead box protein a3 (HDAC2/FOXA3) pathway.[25] It promotes interaction with HDAC and FOXA3 and elicits the removal of an acetyl group from FOXA3, lowering FOXA3 protein levels.[25] Another study by Zhang *et al*. suggests HDAC8 carries out the deacetylation of K62 residue of PKM2, which subsequently alters its regulation. This process is activated by hypoxia-inducible factor -1α, which transcriptionally activates DACT3 antisense RNA 1 (DACT3-AS1) expression under hypoxic conditions.[18,25]

Activation of the transcription of hypoxia-inducible factor-1α (HIF-1α) by STAT3 phosphorylation, at tyrosine705, is a potential mechanism for the proliferation of HCC cells. Further studies demonstrated that up-regulation of HIF-1α and Bcl-xL (B-cell lymphoma-extra-large) by PKM2 enhances cell proliferation in HCC.[26]

Guanosine triphosphate binding protein 4, one of the pivotal regulators of MAPK and cell cycle progression, encourages HCC progression by PKM2-regulated glucose metabolism.[27]

A study by Chen *et al.* identified E3 ligase zinc finger protein 91 (ZFP91) to have a suppressing effect on the reprogramming of metabolic processes in HCC and cell propagation and metastasis through *in vitro* and *in vivo* studies.[28] According to this report, Lys48-linked ubiquitination of the oncoprotein hnRNP A1 at lysine 8 by ZFP91, and inhibiting hnRNP A1-dependent PKM splicing by proteasomal degradation results in greater production of PKM1 isoform than PKM2, leading to a suppressing effect on hepatocellular carcinogenesis.[28]

Tripartite motif-containing protein 35 (TRIM35) was identified as a novel tumor suppressor, particularly in HCC. It interacts with PKM2 and inhibits the phosphorylation of tyrosine residue 105 (Y105), which impedes glycolysis and suppresses cell proliferation.[29,30]

Genetic regulation of hepatitis by PKM gene

HCC is a highly aggressive malignancy, its onset is related to hepatitis virus infection, alcoholism, and other metabolic disorders.[31] A recent study by Wu *et al*. screening the interactions of large viral surface antigens (LHBS) with the host factors set by affinity purification screen illustrated the role of aerobic glycolysis played in supporting the hepatitis B virus.[32] PKM2 oligomerization in hepatocytes was affected by viral LHBS, increasing the lactate production in the cells.[32]

Chronic hepatitis B is a major risk factor for the development and progression of HCC. Hence the pharmacological targets that are involved in the HCC progression were investigated, including Hep-1 (Hepatocyte Parafn 1), CK18 (cytokeratin-18), CK19 (Cytokeratin 19), SUOX (sulfite oxidase), pERK (phosphorylation extracellular regulated protein kinasesTRIM35 (tripartite motif containing 35), and PKM2.[33]

Hepatitis C infections occur when the hepatitis C virus (HCV) core protein reduces the activity of (PPAR)-α/γ in hepatocytes.[34] This core protein surrounds the lipid vesicle membrane of the liver and causes lipid deposition in the cells via the activation of sterol regulatory-element-binding protein-1c.[35] In the glycolytic pathway, HCV down-regulates glucose transporter 2, resulting in less intracellular glucose transport. HCV also up-regulates the genes for phosphoenolpyruvate carboxykinase and glucose 6-phosphatase, which are pivotal enzymes for hepatic gluconeogenesis.[36] Studies carried out by Wu *et al.* reported on the specific interaction of PKM2 isoforms through the hepatitis C virus NS5B. The group studied both virus-encoded proteins and cellular factors involved in the pathogenesis and replication of HCV, ascertaining the interactions of NS5B with PKM2. They also showed that shRNA downregulated the expression of PKM2 which subsequently inhibited the replication of HCV in 9B replicon HCV cell lines.[37]

By binding to and down regulating HIF-1α activity, PKM2 is also a potential mediator and therapeutic target for regulating sterile inflammation of the liver, alcoholic, and non-alcoholic steatohepatitis (NASH).[38,39]

Genetic regulation of Liver cirrhosis by PKM gene

Hepatitis B and NASH are both related to liver cirrhosis. One of the most serious implications of NASH is the subsequent development of cirrhosis and HCC, which can also occur in patients with no history of alcohol consumption.[40] Lee *et al.* proposed increased gene expression of various glycolytic enzymes like hexokinase 2, aldolase A, and PKM2 as an indication for precancerous cirrhotic livers, which is predominantly associated with the development of HCC.[41] In liver cirrhosis, hepatocytes develop chronic inflammation, fibrosis, scarring, and hepatocellular regeneration. This leads to the accumulation of clusters of cells with genetic mutations causally associated with liver malignancy and HCC. The implication of PKM2 in both cirrhotic and non-cirrhotic liver disease has been extensively studied and over-expression of PKM2 correlates to the development of HCC. This observation suggests that PKM2 is a potential early stage biomarker for HCC.[42] PKM2 in peripheral blood is also considered a crucial marker of hepatitis B-related cirrhosis, where increased concentrations of PKM2 cause an increase in the rate of liver cirrhosis.[40]

Genetic regulation of fatty liver disease by PKM gene

PKM2 overexpression is an indication of fatty liver disease, NAFLD, one of the most common reasons for the development of chronic liver diseases. Numerous genetic risk factors are associated with this disease as determined by genome-wide association studies (GWAS). A study highlights the genes PNPLA3 and TM6SF2 as correlating with steatosis and HCC. This connection then purports NAFLD as a primary or early risk factor for HCC as end stage chronic liver disease.[43] PKM2-governed progression of fatty liver disease is the result of changes in metabolic processes linked to miR-122-5p downregulation.[44] In steatosis, this imbalance causes lipid and mitochondrial ROS accumulation in hepatocytes.[45] Additionally, because PKM2 controls the metabolic skewing of Th17 cells, and cell-specific PKM2 deletion dramatically reduces NAFLD and hepatic inflammatory disease, PKM2 was considered to be a potential new target for the diagnosis and treatment of NAFLD.[15,46]

Therapeutics available for hepatic diseases

Hepatic treatment approaches may vary depending on the specific liver condition. Several therapies are highly accessible, and surgical procedures for treating severe liver illnesses and extending patient survival have increased markedly in recent years. All chronic viral hepatitis types have a common pathophysiology and clinical course. Lamivudine, tenofovir-disoproxil, adefovir-dipivoxil, telbivudine

and entecavir are available drugs used to treat HBV orally.[47] For NASH, a category of pharmaceuticals known as farnesoid X receptor agonists is being studied to assess their suitability for treatment. In clinical trials, these medications, which target bile acid metabolism, have demonstrated promise in lowering liver fat and inflammation. Additionally, antifibrotic medications, such as obeticholic acid and cenicriviroc, are being evaluated for their capacity to lessen liver fibrosis in NASH patients.[48] Amino acids can be used successfully to treat liver disease since they are connected to a variety of biological processes. These advantages include using aspartate to treat fatty liver disease caused by cholesterol consumption and glycine to treat alcohol-induced liver damage. Recent studies have employed a variety of amino acids, including peptides and branched-chain amino acids, to treat various liver conditions.[49] New pharmacological treatments that prevent hepatic steatosis, the development of NASH, and even more serious liver disease are clearly needed to address unmet medical needs.[50] Hepatitis B therapy's current objectives are to lower the risk of cirrhosis progression, treat extra-hepatic side effects, slow the growth of hepatocellular cancer, and stop ongoing transmission. Reduction of HBV-DNA typically happens when using pegylated interferon alpha or nucleos(t)ide analogs, with the viral load being undetectable in a significant number of treated patients. The normalization of liver enzymes and a decreased risk of cirrhosis and liver cancer are all associated with undetectable serum HBV-DNA, which also stops the transmission.[51]

Available treatment and modalities

Although healthcare professionals may attempt to treat liver injury directly, treatment frequently entails managing problems and giving the liver time to heal. Specific consequences of decompensated cirrhosis, such as ascites, variceal hemorrhage, and hepatic encephalopathy, have a wide range of proven therapies.[52] Some liver complications can be treated with lifestyle changes, such as limiting alcohol consumption or weight loss, typically as part of a wider medical program that includes careful monitoring of liver function. Other liver complications may be treated with medication or may require surgery. Additional methods, such as the use of immunosuppressants, have been investigated, but these studies have insufficient output to support its use in clinical practice. Bile acid approaches and therapy remain the mainstays of primary biliary cholangitis treatment.[48] Along with medication to treat cholesterol or insulin resistance for liver disease, weight loss is the primary objective of treatment. It has been shown that bariatric surgery works in the case of overweight patients. Even though no drug treatment has been authorized, recent research on thiazolidinediones has shown improvements in both liver enzymes and histology. Statins are hepatoprotective in various liver diseases, although these studies are not many. Histologic research has not supported the initial enthusiasm for ursodeoxycholic acid. There is no agreed-upon definition of hepatoprotective pharmaceuticals, which are medications that can accelerate liver detoxification, promote liver cell regeneration, an+d/or improve liver function. It is loosely classified as detoxifying drugs (like NAC and GSH), anti-inflammatory pharmaceuticals (like Glycyrrhizic acid preparation), hepatocyte membrane protectors (like PPC), and antioxidant drugs (like Bicyclol and silymarin) based on the various mechanisms of action.[53]

Is kinase modulation an option?

Serine/threonine kinase 11 (STK11, Par-4 in C. elegans), also known as liver kinase B1 (LKB1), was initially discovered in its mutant form with loss of function in Peutz-Jeghers syndrome (PJS), a rare and predominantly inherited autosomal disorder. Germline-inactivating mutations of LKB1 are linked to the pathophysiology of PJS, which is marked by a number of benign gastrointestinal polyps and metastatic cancers.[54] Jun N-terminal kinase (JNK), activated in the fibrotic liver of both human and mouse models in myofibroblasts, is essential for HSC activation and liver fibrosis progression.[55]

The MAPK pathway, as a regulator of hepatic metabolism, also plays an important role in driving liver metabolic control mechanisms.[56]

PKM2 modulation: a fruitful way to depreciate hepatic disease?

The Warburg effect, a metabolic change in cancer cells that encourages tumor growth and survival, applies to PKM2. Preclinical studies inhibiting PKM2 activation decreased the proliferation of HCC cells, triggered apoptosis, and inhibited tumor growth. As such, PKM2 may be a predictor of HCC and a potential therapeutic target for immune checkpoint inhibitors. PKM2 regulation has also been investigated as a method to make HCC cells more susceptible to chemotherapy or other targeted treatments.[11]

PKM2 modulation effects on the different hepatic ailments

Propagation, migration, and incursion of HCC cells in vitro, along with the development of tumors in vivo, were all decreased by PKM2 knockdown. Surprisingly, PKM2 demonstrated a significant connection with immune inhibitory cytokine production and lymphocyte infiltration in HCC. A study showed that covalently modified PKM2 reduces lipid build-up, inflammation, and fibrosis in the liver. It was also noted that livers from patients with NAFLD and NASH, particularly their hepatic macrophages, had high expression of PKM2.[57]

Future of therapeutics to curb hepatic disorders

Non-alcoholic fatty liver diseases

The current standard treatment protocol for non-alcoholic fatty liver disease is lifestyle management, including decreased calorie intake and a low-fat diet.[58] For obese patients, bariatric surgery has been proven helpful. Although no FDA-approved drug has come to the market for NAFLD, certain potential therapies like vitamin E, pioglitazone and liraglutide have shown promising results against NAFLD in randomized clinical trials.[59,60] Due to the failure of a number of drugs against NAFLD in clinical trials, many pharmaceutical companies are exploring combination therapies to treat NAFLD. Therefore, the future of NAFLD treatment may well be with a combination of different classes of drugs.[61]

Hepatitis B and C

Antivirals are the main therapy for treating HBV. There are several therapeutics available targeting specific stages of the HBV lifecycle. However, treatment with current antivirals is not very effective and relapses after the discontinuation of nucleos(t)ide analogs-based antivirals are a chance occurrence.[62] Future treatments should be based on a combination of current antivirals with new anti-HBV agents. The nucleoside analogue could be given with HBV entry inhibitors or some antivirals with immunomodulatory vaccines.

In HCV, treatment with antivirals has achieved a cure rate close to 100%. Despite this, the high cost of treatment, poor diagnosis, and chances of re-infection are still challenges to be met, creating a need for the development of a vaccine against HCV. Developing an effective vaccination against HCV has been hampered by the virus's genetic diversity and a dearth of relevant animal models.[63]

Hepatocellular carcinoma

HCC is the third leading cause of cancer-related mortality, with only a 3% five-year survival rate. Liver resection and liver transplantation are the two most common surgical treatment strategies to limit HCC. Non-surgical treatments include transarterial radioembolization, or transarterial chemoembolization (TACE). TACE refers to the hepatic artery's catheterization followed by chemotherapy administration. Drug-eluting bead TACE is a novel combination method for delivering embolising particles that have been loaded with a chemotherapeutic drug. The comparatively slower release of chemotherapeutic medication causes patients undergoing drug-eluting bead TACE to experience fewer side effects than those treated with TACE.[64]

For late stage HCC, systemic therapies are the first choice of treatment. Molecular-targeted therapies against various tyrosine kinases have been developed. Sorafenib, a tyrosine kinase inhibitor was the first drug approved for the treatment of HCC.[65] Following this, a number of tyrosine kinases became commercially available. Various immune checkpoint inhibitors and anti-programmed cell death-1 (anti-PD-1) antibodies have also been approved for the treatment of HCC.[66] Future treatment options may arise from combining a variety of such approaches. Recently, the combination of atezolizumab (targeting PD-L1) and bevacizumab (targeting VEGF) proved beneficial in the treatment of HCC.[67]

Micro RNAs (miRNAs) based therapy could also be an alternative approach as a future therapy for liver diseases. Both acute hepatitis and NASH mice models benefited from miR-223 3p treatment.[68] Liver fibrosis was improved in long-term CCl_4-treated animals due to miR-221-3p suppression.[69] Multiple microRNAs have been shown to target ATP-binding cassette transporters that cause resistance in HCC.[70] This indicates that miRNA-based therapy could be helpful in overcoming resistance in HCC. However, miRNA-based therapy is still at an early stage with numerous shortcomings like difficulty in drug delivery.

Conclusion

Given the rising incidences of hepatic abnormalities, the present review gives a basic introduction to liver disease followed by a discussion about enzymes involved in hepatic disorders. The role of various kinases involved in the pathophysiology of hepatic diseases was discussed with special emphasis on PKM2. The PKM gene is intricately linked to the genetic regulation of HCC, hepatitis, NAFLD, and liver cirrhosis. In HCC, PKM2 is overexpressed, resulting in enhanced proliferation of tumorigenic cells. Expression of PKM2 was also affected in the presence of hepatitis viral proteins. Overexpression of PKM2 acts as a biomarker for HCC which is the end stage for most hepatic disorders. Current therapies available for liver diseases were also discussed, highlighting PKM2 as a potential therapeutic target. Future treatment strategy is likely to garner the most success through combination therapies. A synergistic effect could be achieved by targeting the disease through a multi-target approach. PKM2 could be recognized as one such target and the development of novel therapeutic modalities against PKM2.

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Conflict of interest

All authors have approved the final version of the manuscript. The authors declare no conflict of interests.

Author contributions

AMS conceptualized and designed the manuscript. MJ had done the data curation and was engaged in compilation and preparation of the manuscript. SS wrote the therapeutics available for hepatic diseases. VK and SMK wrote the manuscript and helped with figure preparation.

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