Review Article

Update on Pparγ and Nonalcoholic Fatty Liver Disease

Gene P. Ables

Animal Science Laboratory, Orentreich Foundation for the Advancement of Science, 855 Route 301, Cold Spring, NY 10516, USA

Correspondence should be addressed to Gene P. Ables, gables@orentreich.org

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1. Introduction

Hepatic steatosis without excessive alcohol intake, called nonalcoholic fatty liver disease (NAFLD), is commonly associated with obesity and insulin resistance [1, 2]. NAFLD affects the general population and its incidence is linked with the epidemics of obesity and type 2 diabetes [3]. The metabolic pathways leading to hepatic steatosis include enhanced nonesterified fatty acid release from the adipose tissue, increased de novo lipogenesis, decreased β-oxidation and reduced VLDL export [4, 5]. Steatosis in the liver is characterized by a large intracytoplasmic fat droplet or well-defined droplets displacing the nucleus to the cell periphery [6]. The accumulation of hepatic lipids could be due to elevated peripheral fatty acids, de novo lipogenesis and defective apolipoprotein biosynthesis [7, 8]. The progression of hepatic steatosis often leads to liver inflammation or steatohepatitis and, if unchecked, will worsen liver fibrosis and cirrhosis [9]. Several mouse models are used to elucidate the mechanisms of fatty liver disease [10, 11]. The bulk of studies on NAFLD have been through the administration of high fat diets or methionine-choline-deficient diets and the use of genetically leptin-deficient (ob/ob) or leptin-receptor-deficient (db/db) mouse models [12]. These models exhibit insulin resistance which is one sequela of NAFLD [13].

Increased insulin secretion has been directly implicated in the development of fatty liver disease [14]. The therapy used for insulin resistance frequently include the administration of TZDs which are agonists for the nuclear receptor peroxisome proliferator activated receptor gamma (Pparγ) [15]. However, studies have demonstrated that TZDs have also exhibited deleterious side effects that warrant their withdrawal from the market [16]. Of interest, selective Pparγ modulators (SPPARMs) that do not have the undesirable effects of TZDs have been recently identified [17, 18]. Since NAFLD often leads to insulin resistance, this paper focuses on the relationship between Pparγ and NAFLD.

2. Ppar-gamma (Pparγ)

Pparγ is a member of the nuclear receptor superfamily of ligand-activated transcription factors [19] highly expressed in adipocytes [20, 21] and plays a role in improving glucose homeostasis and adipocyte differentiation [22]. It increases insulin sensitivity by upregulating the glucose transporter 4 (Glut4) [23]. Pparγ also enhances the transcription factors adipocyte determination and differentiation-dependent factor 1 (Add1) and sterol regulatory element binding protein 1 (Srebp1) which results in the expression of lipogenic genes such as fatty acid synthase (Fas) [24]. Pparγ is expressed as
2 major isoforms, γ1 and γ2, generated from the same gene by alternate promoter usage and RNA splicing [25]. Both isoforms could stimulate adipogenesis when introduced to fibroblasts [26]. Adipocytes treated with the Pparα ligand, TZD, stimulate expression of uncoupling protein 2 (Ucp2) and therefore increase energy expenditure [27]. Another mechanism of action by TZDs in the adipose tissue is to upregulate the expression of AMP-activated protein kinase (Ampk) which increases fatty acid oxidation while decreasing lipogenesis via downregulation of Srebpl-1c and carbohydrate response element binding protein (Chrebp) [28]. The upregulation of hepatic Pparγ is frequently observed in mice fed a high fat diet [29]. In addition, liver specific deletion of Pparγ in mice established its role as a prosteatotic factor in the development of NAFLD [30]. Of importance is that Pparγ activation by TZDs promotes efflux of free fatty acids from the liver and muscle while increasing fat mass which consequently improves insulin sensitivity [31]. Therefore, whether the upregulation of Pparγ causes steatosis or vice versa remains unclear.

3. The Effect of Pparγ Variants in the Development of NAFLD

Variants in the Pparγ gene found in human genotyping studies have been reported to affect hepatic steatosis. A Japanese cohort was first reported to have a polymorphism in the peroxisome proliferator receptor activator gamma coactivator 1 alpha (Pparγc1a) gene [32]. The polymorphism in the T allele of rs2290602 was found in patients with nonalcoholic steatosis which was further confirmed by quantitative real time PCR [32]. In addition, single nucleotide polymorphisms (SNPs) in the C161T genotype in the Pparγ gene found in human genotyping following administration of rosiglitazone due to stimulation of fatty acid oxidation in the liver [47]. In addition, the Long Evans rats, which exhibit moderate obesity and gene expression patterns in the livers of Ppara-KO mice [40]. Therefore, they propose that excess Pparγ activity can lead to the development of adipogenic hepatic steatosis [40]. In addition, hepatic adenoviral overexpression of Pparγ2 in lean mice increased liver triglyceride content and induced hypertension [41]. This occurrence was reported to involve the target of Pparγ, fat specific protein 27 (Fsp27) [42] and its actions on the afferent vagal signals in the liver [41]. In a liver specific Pparγ deletion study, Gavrilova et al. reported that the A/ZIP/F-1 mouse model, which develops severe lipoatrophic diabetes, exhibited attenuation of hepatic steatosis but compromised triglyceride clearance [43]. The same group also showed that the liver Pparγ is essential for the effects of a Pparγ agonist, rosiglitazone, to improve glucose metabolism [43]. Moran-Salvador et al. reported that hepatocyte specific deletion of Pparγ in mice protected high fat diet fed mice from accumulation of lipids and, therefore, further implicated its role in the development of hepatic steatosis [30]. They also showed that the Pparγ in Kupffer cells might not be involved in the development of hepatic steatosis [30]. In addition, a mouse model of dyslipidemia showed that hepatic Pparγ2 upregulation induced hepatic de novo lipogenesis [44]. Zhang et al. fed a western-type diet to mice that express the human apolipoprotein B and lack the brown adipose tissue (apoB/BATless) [44]. These mice are obese, insulin resistant and have hepatic steatosis [44]. They showed that hepatic Pparγ2 expression is increased due to elevated rates of lipogenesis via the upregulation of de novo lipogenic genesfas and acetyl-CoA carboxylase (Acc) [44]. Taken together, these studies strongly implicate Pparγ in the development of hepatic steatosis.

4. The Role of Pparγ in the Development of Hepatic Steatosis

The mode of action of Pparγ in liver was suggested to promote insulin sensitivity but with concomitant development of fatty liver. High-fat diet fed mice develop hepatic steatosis and have increased Pparγ expression [39]. This could be due to the suppression cAMP response element binding protein (Creb) levels, the upstream regulator of Pparγ, in high fat diet fed mice [39]. In hepatic overexpression studies, Yu et al. showed that Pparγ1 leads to adipogenic hepatic steatosis [40]. This group employed the Ppara deleted (Ppara-KO) mouse model and then injected the mice with adenovirus overexpressing Pparγ1 [40]. They showed that hepatic overexpression of Pparγ1 induced adipocyte specific
insulin resistance, were given rosiglitazone and subsequently ameliorated hepatic steatosis which could be modulated by SirTuin 6 (Sirt6) and its target genes Pparγc1α, forkhead box protein O1 (Foxo1), liver kinase B1 (Lkb1) and 5′ adenosine monophosphate-activated protein kinase (Ampk) [48]. In vitro experiments, confirmed the function of Sirt6 by using the free fatty acid stimulated mouse hepatocyte cell line, AML 12, which also showed the protection from hepatic steatosis following rosiglitazone treatment [48]. Similarly, Sprague-Dawley rats that were given high sucrose and high fat diet showed amelioration of hepatic steatosis following treatment with rosiglitazone [49]. The decrease in liver triglycerides in these rats could be due to the effect the Ppar γ agonist in increasing serum adiponectin and the upregulation of fatty acid oxidation genes, carnitine palmitoyltransferase 1 (Cpt1) and acyl coenzyme A oxidase (Aco) [49]. Furthermore, dietary metionine restriction (MR) in F344 rats upregulated hepatic Ppar γ expression, improved insulin sensitivity, and increased fatty acid oxidation [50–52]. Overall, these sets of data suggest that Ppar γ ameliorated hepatic steatosis due to increased fatty acid oxidation.

6. The Development of Selective Ppar γ Modulators (SPPARMS)

Although Ppar γ agonists have direct actions to improve insulin sensitivity, this line of treatment also has undesirable side effects. For example, rosiglitazone was reported to reduce bone mass in mice [53]. In addition, mice that are obese and diabetic develop hepatic steatosis following treatment with TZDs [54]. More recently, a meta-analysis of type 2 diabetes patients showed that pioglitazone is associated with increased risk for urinary bladder cancer [55]. The development of SPPARMS could potentially reduce these negative effects. Modifications in the Ppar γ ligands showed direct effects on insulin sensitivity but not on adipogenesis [56, 57]. The ligand FMOC-L-Leucine, a chemically distinct ligand for Ppar γ, was reported to improve insulin sensitivity but did not affect hepatic lipid metabolism in db/db mice [58]. Telmisartan, an angiotensin receptor blocker that acts as a Ppar γ ligand, enhanced insulin sensitivity and decreased body fat in high fat diet fed mice [59]. A synthetic Ppar γ ligand, nTZDpa, ameliorated fasting hyperglycemia and hyperinsulinemia and caused decrease in weight gain and adipose tissue size in high fat diet fed mice [60]. In addition, results using a gene expression-based screening identified N-acetylfarnesyleysteine (AFC) as a full and partial agonist of Ppar γ [61]. The compound upregulated Ppar γ agonist target genes adipose differentiation-related protein (Adrp), angiopoietin-related protein 4 (Angptl4) and adipog, but was only a partial agonist of adipocyte fatty acid binding protein 2 (ap2) [61]. The AFC also improved glucose homeostasis and reduced adipose tissue inflammation and expansion in diet-induced obese mice [61]. Furthermore, a synthetic Ppar γ antagonist, SR-202, decreased expression of Ppar γ target genes and promoted insulin sensitivity in diet-induced obese mice as well as in ob/ob mice [62]. Moreover, a partial Ppar γ agonist, INT131, was designed to mitigate insulin sensitivity while minimizing the side effects of thiazolidinediones [63]. It was reported that INT131 reduced fasting plasma glucose in humans and also increased insulin sensitivity in db/db and diet induced obesity in mice [64, 65]. Taken together, recent data on the use of SPPARMS maintain the effects of Ppar γ as an insulin sensitizing agent but with decreased risks for undesirable effects.

7. Conclusion

With all these data surrounding the effect of Ppar γ on the development of NAFLD and improvements in insulin sensitivity in several models, it is still not conclusive as to whether the nuclear receptor is beneficial or detrimental. Therefore, further investigations are necessary to elucidate the effect of specific conformational and structural differences between the nuclear receptor and its ligands. The advent of the development of SPPARMS points to the direction of specifically eliciting the desirable effects of Ppar γ activation.

Conflict of Interests

The author reports no conflict of interests.

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References


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