Diabetes, Metabolic Syndrome and Obesity

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ORIGINAL RESEARCH

Glucagon-Like Peptide-2 as a Potential Biomarker for Nonalcoholic Fatty Liver Disease in Children with Obesity: Preliminary Assessment of Metabolic Associations and Underlying Mechanisms

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Objective: This study aimed to investigate the effects of glucagon-like peptide-2 (GLP-2) on insulin resistance and lipid metabolism, as well as potential mechanisms contributing to the development of non-alcoholic fatty liver disease (NAFLD) in children with obesity.

Methods: A cross-sectional study was conducted involving 107 children with obesity, aged between 5 and 15 years, including 55 with NAFLD and 52 without NAFLD. Anthropometric assessments and fasting blood samples were collected to evaluate GLP-2, plasma glucose, insulin (INS), lipids, leptin (LEP), and adiponectin (ADPN). Correlation and logistic regression analyses were performed to evaluate associations between GLP-2 and metabolic parameters.

Results: Children with NAFLD exhibited significantly higher levels of GLP-2, LEP, total cholesterol (TC), triglyceride (TG), low-density lipoprotein cholesterol (LDL-C), fasting blood glucose (FPG), INS, and the homeostasis model assessment of insulin resistance index (HOMA-IR) (all $p<0.05$), along with significantly lower levels of ADPN and high-density lipoprotein cholesterol (HDL-C) compared with those without NAFLD ($p<0.05$). GLP-2 concentrations correlated positively with TC ($r=0.42$), TG ($r=0.51$), LDL-C ($r=0.38$), FPG ($r=0.61$), INS ($r=0.58$), HOMA-IR ($r=0.61$), and LEP ($r=0.42$), and negatively with ADPN ($r=-0.53$; all $p<0.01$). In univariate analysis, GLP-2 was identified as a risk factor for NAFLD (odds ratio [OR]=1.225, 95% confidence interval [CI]: 1.001–1.499, $p<0.05$); however, the association was attenuated after adjustment for body mass index (OR=1.112, $p=0.102$). ADPN retained a protective association (OR=0.771, $p<0.05$).

Conclusion: GLP-2 may contribute to the pathophysiology of insulin resistance and dyslipidemia in pediatric NAFLD, potentially via modulation of adipokine activity. These findings suggest GLP-2 as a candidate biomarker and possible therapeutic target in this population.

Keywords: children, glucagon-like peptide-2, insulin resistance, lipid metabolism, non-alcoholic fatty liver disease, obesity

Introduction

Childhood and adolescent obesity has become a major global public health concern and is strongly associated with non-alcoholic fatty liver disease (NAFLD), the most prevalent chronic liver disorder in the pediatric population.[1,2] The global prevalence of NAFLD is estimated at 32.4%.[3] In the general pediatric and adolescent population, the prevalence is approximately 13%, whereas among children and adolescents with obesity, it can reach 47%.[4] Multiple risk factors for NAFLD have been identified, including overweight or obesity, diabetes mellitus, and insulin resistance (IR).[5] Abdominal obesity is recognized as a major risk factor for the development of NAFLD in pediatric populations.[6] The rising prevalence of NAFLD, particularly in younger populations, has contributed to increased liver-related morbidity and mortality, as well as substantial healthcare and economic challenges.[7–9] Consequently, early screening and intervention for pediatric NAFLD are of critical importance.

Received: 17 March 2025
Accepted: 9 September 2025
Published: 18 September 2025

Pediatric NAFLD is characterized by chronic hepatic steatosis in the absence of genetic or metabolic disorders, infectious diseases, use of steatogenic medications, ethanol consumption, or malnutrition.[10] The pathophysiology and progression of NAFLD are complex, involving hepatocellular injury, necrosis and fibrosis resulting from chronic inflammatory response of hepatocytes, oxidative stress, hepatic lipid accumulation, and mitochondrial dysfunction induced by factors such as obesity and IR.[11–13] Children with NAFLD frequently demonstrate a higher prevalence of both glucose and lipid metabolism abnormalities.[14,15]

Glucagon-like peptide-2 (GLP-2) is a gastrointestinal hormone primarily secreted by enteroendocrine L-cells in the intestines, with secretion stimulated mainly by the presence of nutrients, particularly fats and glucose.[16] GLP-2 has been implicated in delaying the onset of IR, maintaining hepatic lipid homeostasis, and exerting protective effects on lipid metabolism. In the liver, activation of GLP-2R can inhibit fatty acid synthase expression and reduce triglyceride deposition.[17] Conversely, GLP-2R-deficient mice exhibit impaired postprandial glucose tolerance and hepatic IR.[18] Elevated GLP-2 levels in children with obesity have also been associated with disturbances in carbohydrate metabolism.[19] Recent advances in the understanding of GLP-2 biology and pharmacology have generated significant interest in GLP-2 receptor (GLP-2R) as a potential therapeutic target for obesity.[20] However, despite evidence linking GLP-2 to energy balance regulation, its specific role in pediatric obesity and NAFLD remains unclear.[21]

This study aimed to investigate the relationship between GLP-2 and the pathophysiology of NAFLD in children with obesity, focusing on its associations with IR, lipid metabolism, and potential underlying mechanisms in this population.

Methods

Study Design and Sampling Method

A cross-sectional study was conducted involving children aged 5–15 years who received medical care at the Second Hospital of Jiaxing between June 2022 and June 2024. Recruitment was carried out through routine clinical care encounters and voluntary consultations sought by parents.

Exclusion criteria were as follows:

(1) Absence of physical measurements or liver imaging examinations;

(2) Normal body mass index (BMI) for age;

(3) Secondary obesity attributable to endocrine disorders, inherited metabolic diseases, or medication use;

(4) History of alcohol consumption;

(5) Other risk factors for fatty liver, including systemic diseases, inherited metabolic disorders, or drug/chemical-induced liver injury.

Diagnostic criteria for obesity were based on the 2022 *Expert Consensus on Diagnosis, Evaluation, and Management of Childhood Obesity in China*.[22] NAFLD diagnosis and imaging interpretation followed the *Expert Consensus on Diagnosis and Treatment of Nonalcoholic Fatty Liver Disease in Children* issued by the Pediatrics Branch of the Chinese Medical Association.[23] Diagnosis and differential diagnosis were performed by pediatric clinicians and required the following:

① No history of alcohol consumption; and

② Imaging diagnosis with at least two of the following three abdominal ultrasound findings indicative of diffuse fatty liver:

(a) Diffuse enhancement of near-field liver echo (bright liver), with echogenicity greater than that of the kidney;

(b) Poor visualization of intrahepatic ductal structures;

(c) Gradual attenuation of far-field liver echogenicity.

The presence of both criterion ① and any two features from (a)~(c) confirmed the diagnosis of NAFLD.

CT diagnostic criteria included generalized reduction in liver density, with a liver-to-spleen density ratio on computed tomography (CT) <1.0. Severity grading was as follows:

Severe: liver-to-spleen CT density ratio ≤0.5

Moderate: >0.5 and ≤0.7

Mild: >0.7 and <1.0

Participants were categorized into two groups according to liver imaging results obtained via three-dimensional ultrasound or CT: the simple obesity group (n=49) and the obesity with NAFLD group (n=55).

Ethical approval for the study was obtained from the Ethics Committee of the Second Hospital of Jiaxing. Written informed consent was obtained from all participants and their parents or legal guardians.

Anthropometric Measurements

All children with obesity underwent standardized physical examinations in the morning. Body weight and height were measured using a digital scale while participants stood barefoot in an erect posture. Waist circumference was measured at the midpoint between the lower rib margin and the iliac crest, and hip circumference was measured at the widest part of the hip region. BMI and waist-to-hip ratio (WHR) were calculated as follows:

BMI = weight (kg) / height^2 (m^2)

WHR = waist circumference (cm) / hip circumference (cm).

Laboratory Examination

Fasting venous blood samples (4 mL) were collected after an 8–12 hour overnight fast using ethylenediaminetetraacetic acid anticoagulant tubes. Plasma was separated by centrifugation and stored at −80 °C until analysis.

Biochemical parameters including triglycerides (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C), were measured using an automated biochemical analyzer. Fasting plasma glucose (FPG) and insulin (INS) concentrations were determined using standard laboratory techniques; INS was quantified by chemiluminescence assay.

Leptin (LEP), adiponectin (ADPN), and GLP-2 concentrations were measured using enzyme-linked immunosorbent assay kits (Elabscience Biotechnology Ltd., China) according to the manufacturer's instructions. IR was calculated using the homeostasis model assessment of insulin resistance (HOMA-IR) formula: HOMA-IR = (INS × FPG) / 22.5.

Statistical Analysis

Data distribution was assessed before analysis. Normally distributed variables are expressed as mean ± standard deviation (SD), and non-normally distributed variables as median (interquartile range, IQR). Non-normally distributed variables were natural log-transformed to approximate normality.

Between-group comparisons were performed using the independent samples *t*-test for normally distributed variables and the Mann–Whitney *U*-test for non-normally distributed variables. Spearman's rank correlation coefficient was used to assess associations between variables. Univariate logistic regression analysis was conducted to examine associations between serological markers and NAFLD, with odds ratios (ORs) and 95% confidence intervals (CIs) calculated.

All statistical analyses were performed using SPSS software, version 26.0 (SPSS Inc., Chicago, IL, USA). A two-tailed $p<0.05$ was considered statistically significant.

Results

Characteristics of the Study Population

This study included 107 children with obesity, comprising 79 males and 28 females. Among these, 55 children were diagnosed with NAFLD, including 42 males (76.36%) and 13 females (23.64%), with a mean age of 9.86 ± 1.86 years. The remaining 52 children had simple obesity only, including 37 males (71.15%) and 15 females (28.85%), with a mean age of 9.08 ± 2.07 years. The clinical characteristics and biochemical parameters of the study cohort are summarized in Table 1.

No statistically significant differences were observed between the NAFLD and simple obesity groups in sex distribution, age, BMI, or WHR ($p>0.05$). However, children with NAFLD had significantly higher levels of GLP-2, LEP, TC, TG, LDL-C, FPG, INS, and HOMA-IR compared with those with simple obesity ($p<0.05$). Conversely, ADPN and HDL-C concentrations were significantly lower in the NAFLD group ($p<0.05$). The distribution of GLP-2 concentrations between groups is shown in Figure 1A.

Table 1 Anthropometric and Laboratory Measurements of the Participants

Variables	NAFLD (n = 55)	Simple Obesity (n = 52)	*t* value/Z value	*p* Value
Age (y)	10.18±2.40	9.37±2.15	1.847	0.068
<10 y	20(36.36%)	26(50%)		
≥10 y	35(63.63%)	26(50%)		
Sex	42/13	37/15	0.375	0.54
Boys	42(76.36%)	37(71.15%)		
Girls	13(23.64%)	15(28.84%)		
BMI (kg/m^2)	26.64±4.17	25.29±3.21	1.892	0.061
WHR	0.91±0.03	0.90±0.04	1.774	0.079
TC (mmol/L)	4.54±0.89	4.08±0.83	2.758	0.007*
TG (mmol/L)	1.60±0.77	1.19±0.64	2.996	0.003*
HDL-C (mmol/L)	1.15±0.21	1.31±0.47	−2.284	0.028*
LDL-C (mmol/L)	2.80±0.82	2.42±0.75	2.487	0.014*
FPG (mmol/L)	5.12(4.92,5.45)	4.85(4.615,5.085)	3.277	0.001*
INS (μU/mL)	24.64±16.04	18.02±6.53	2.825	0.006*
HOMA-IR	5.89±4.91	3.95±1.53	2.723	0.008*
GLP-2 (ng/mL)	5.89(4.26,6.53)	4.33(3.63,5.53)	−2.515	0.012*
ADPN (μg/mL)	3.35(2.57,4.78)	4.43(3.40,6.57)	−2.799	0.005*
LEP (ng/mL)	10.45±3.76	8.90±3.07	2.343	0.021*

Note: Data are expressed as mean±SD, median (IQR), or number (%). *p<0.05 is considered statistically significant.
Abbreviations: BMI, body mass index; WHR, waist-to-hip ratios; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FPG, fasting plasma glucose; INS, insulin; HOMA-IR, homeostasis model assessment of insulin resistance; GLP-2, glucagon-like peptide-2; ADPN, adiponectin; LEP, leptin.

Subgroup analyses within the NAFLD group, stratified by age (<10 years vs ≥10 years) and sex (boys vs girls), revealed no statistically significant differences in GLP-2 concentrations (p>0.05) (Figure 1B and C).

Correlation Between GLP-2 and Biochemical Parameters

Spearman correlation analysis demonstrated significant associations between GLP-2 and multiple biochemical parameters. GLP-2 was positively correlated with TC, TG, FPG, INS, HOMA-IR, and LEP (p<0.05 for all). In contrast, GLP-2 was negatively correlated with LDL-C and ADPN (p<0.05 for both) (Figure 2).

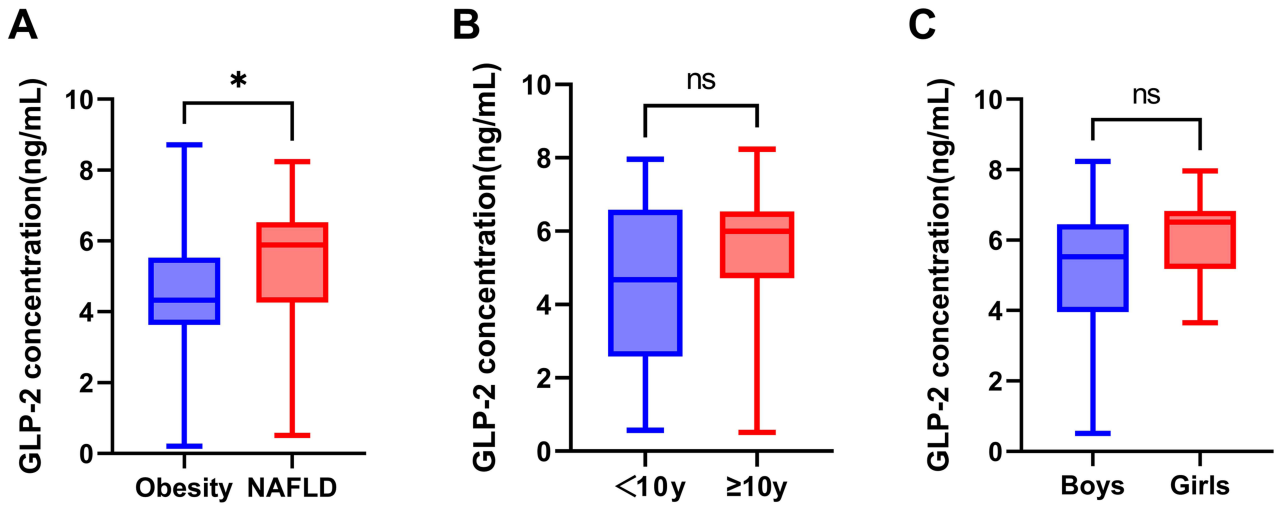

Figure 1 (**A**) Distribution of GLP-2 concentrations in children with obesity and NAFLD compared with those with simple obesity. (**B**) Distribution of GLP-2 concentrations in children with NAFLD stratified by age. (**C**) Distribution of GLP-2 concentrations in children with NAFLD stratified by sex. * p < 0.05; ns: not significant.

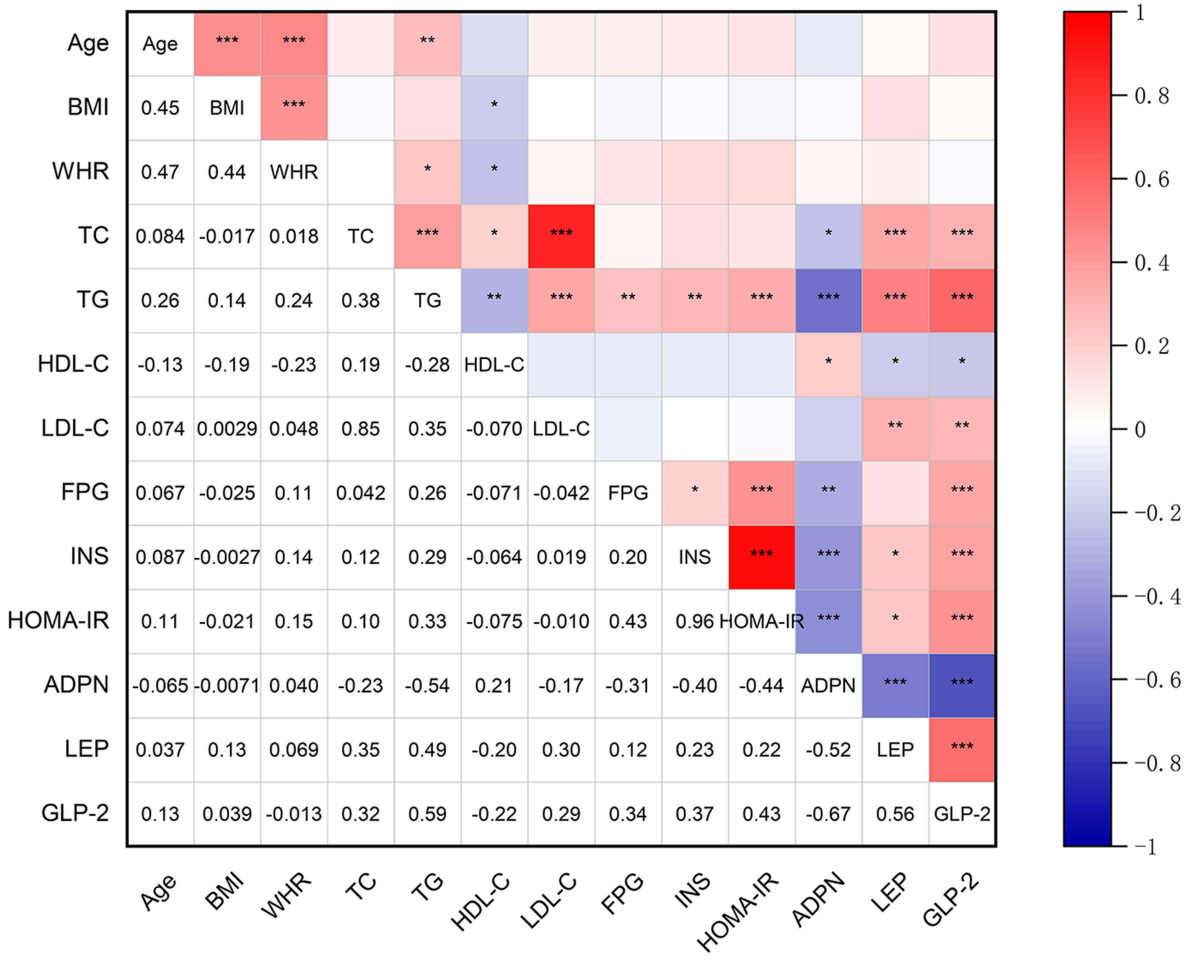

Figure 2 Correlation analysis between GLP-2 and metabolic parameters. Statistical analysis was performed using Spearman correlation method. *$p < 0.05$; ** < 0.01; ***$p < 0.001$.
Abbreviations: BMI, body mass index; WHR, waist-to-Hip ratio; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FPG, fasting plasma glucose; INS, insulin; HOMA-IR, homeostasis model assessment of insulin resistance; ADPN, adiponectin; LEP, leptin; GLP-2, glucagon-like peptide-2.

Univariate Linear Regression Analysis of GLP-2 and Biochemical Parameters

Univariate linear regression analysis was performed to examine associations between GLP-2 and various biochemical parameters. No significant association was found between GLP-2 and HDL-C ($p>0.05$), and HDL-C was not included in the regression model. Significant associations were identified between GLP-2 and TC, TG, LDL-C, FPG, INS, HOMA-IR, ADPN, and LEP ($p<0.05$) (Figure 3).

Specifically, GLP-2 exhibited positive correlations with TC, TG, LDL-C, FPG, INS, HOMA-IR, and LEP (Figure 3A–G), indicating that elevated levels of GLP-2 may contribute to the increase in these metabolic parameters. In contrast, GLP-2 exhibited negative correlation with ADPN levels (Figure 3H), indicating that higher GLP-2 concentrations may be associated with lower adiponectin levels.

Evaluation of Parameters Affecting NAFLD in Pediatric Obesity: Binary Logistic Regression Analysis

Binary logistic regression analysis was conducted to evaluate the associations of GLP-2, ADPN, and LEP with NAFLD risk (Table 2). GLP-2 was identified as a positive predictor of NAFLD, with each unit increase in GLP-2 associated with a 22.5% higher risk of NAFLD in children with obesity (OR = 1.225, 95% CI: 1.001–1.499,

https://doi.org/10.2147/DMSO.S528780

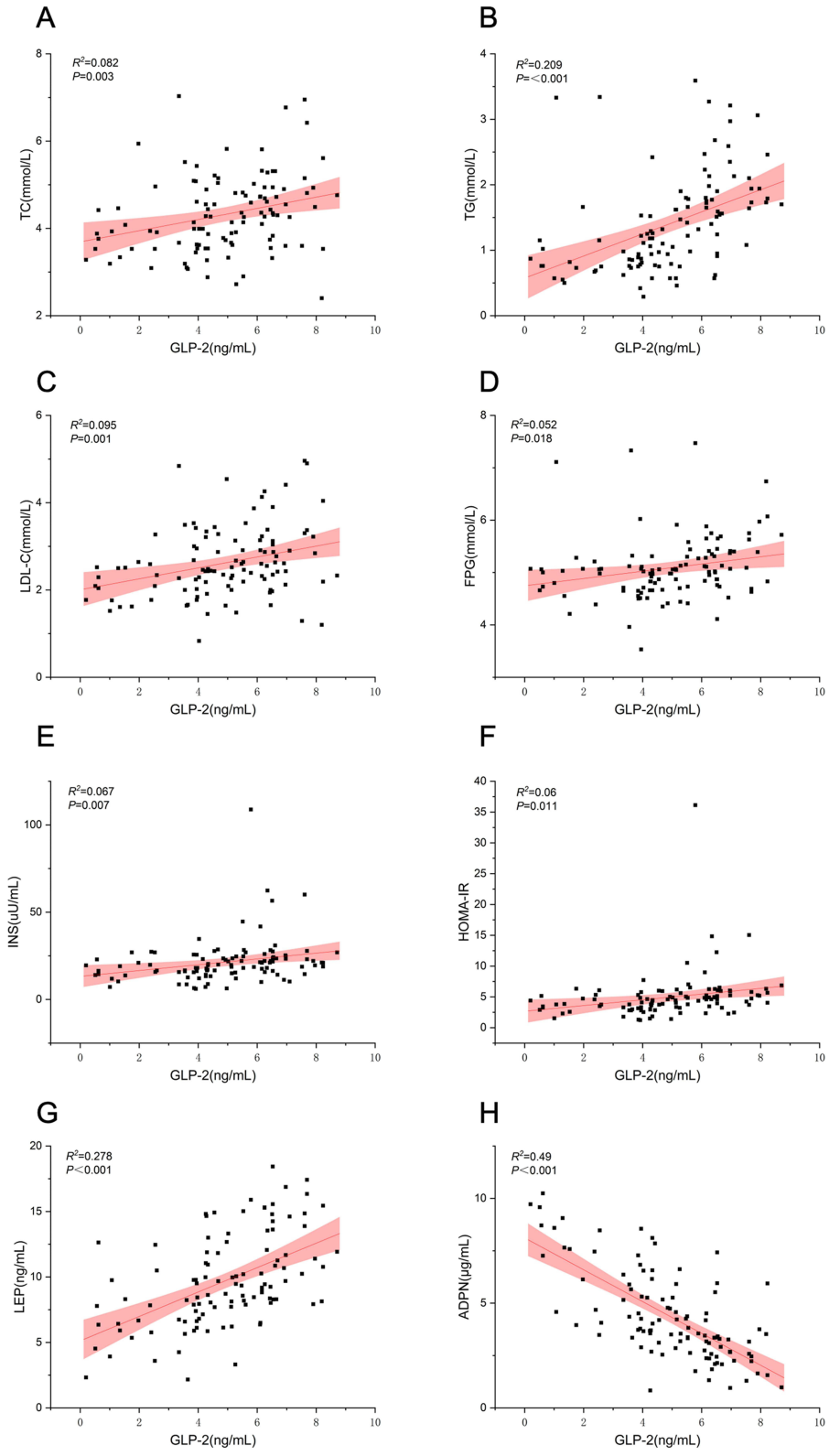

Figure 3 Correlations between GLP-2 and selected markers: (**A**) TC, (**B**) TG, (**C**) LDL-C, (**D**) FPG, (**E**) INS, (**F**) HOMA-IR, (**G**) LEP, (**H**) ADPN. Statistical analysis was performed using Spearman correlation analysis method.

Table 2 Evaluation of Parameters Affecting NAFLD in Children with Obesity via Logistic Regression Analysis

Variables	Univariate Logistic Regression Analysis					Multivariable Logistic Regression Analysis				
	B	S.E	OR	95% CI	*p* value	B	S.E	OR	95% CI	*p* value
BMI	0.099	0.054	1.105	0.993 ~ 1.228	0.066	0.108	0.056	1.114	0.998 ~ 1.244	0.055
GLP-2	0.203	0.103	1.225	1.001~1.499	0.048*					
ADPN	−0.247	0.099	0.781	0.644~0.948	0.012*	−0.260	0.102	0.771	0.631 ~ 0.942	0.011*
LEP	0.133	0.059	1.142	1.017~1.283	0.025*					

Note: *$p<0.05$ is considered statistically significant. For every 1-unit increase in GLP-2, the odds of NAFLD increased by 22.5%; for every 1-unit increase in ADPN, the odds of NAFLD decreased by 21.9%; for every 1-unit increase in LEP, the odds of NAFLD increased by 14.2%.
Abbreviations: BMI, body mass index; GLP-2, glucagon-like peptide-2; ADPN, adiponectin; LEP, leptin.

$p<0.05$). LEP was also a positive predictor, with each unit increase associated with a 14.2% higher risk (OR = 1.142, 95% CI: 1.017–1.283, $p<0.05$).

In contrast, ADPN was identified as a protective factor, with each unit increase associated with a 21.9% lower risk of NAFLD (OR = 0.781, 95% CI: 0.644–0.948, $p<0.05$) After adjusting for BMI as a covariate, multivariable logistic regression analysis showed that the protective effect of ADPN remained significant (OR = 0.771, 95% CI: 0.631–0.942, $p<0.05$), indicating that ADPN is an independent protective factor against NAFLD onset. In the adjusted model, BMI was not significantly associated with NAFLD (OR = 1.114, $p>0.05$), although a trend toward significance was observed ($p = 0.055$), suggesting a potential association that may warrant further investigation in larger or more diverse cohorts. GLP-2 and LEP were not retained in the final model, suggesting that their associations with NAFLD risk may be mediated by other metabolic factors.

Discussion

The increasing prevalence of childhood obesity has been accompanied by a rising incidence of metabolic NAFLD, now recognized as the primary etiology of chronic liver pathology in both children and adolescents.[2] The present study compared a range of metabolic indices between children with obesity and NAFLD and those with simple obesity. The findings showed that children with NAFLD had significantly higher levels of LEP, TC, TG, LDL-C, FPG, INS, and HOMA-IR compared with those with simple obesity ($p<0.05$). Conversely, the levels of ADPN and HDL-C were significantly lower ($p<0.05$), consistent with previous research findings.[24–26] These results further substantiate the established association between NAFLD onset and IR and lipid metabolism disorders in children, beyond the effects of obesity alone.

Prior studies have reported that GLP-2 levels are impaired in adults with obesity.[27] As obesity represents the central pathological basis of NAFLD, dysregulation of GLP-2 or its synergistic effects may contribute to hepatic injury. In the present study, children with obesity exhibited elevated GLP-2 concentrations, with serum GLP-2 positively associated with WHR and FPG. Given its established role in both IR and glucose homeostasis, GLP-2 may contribute to the pathophysiology of obesity.[19,28] However, to date, its relationship with NAFLD, IR, and lipid metabolism in pediatric obesity has not been reported. The current findings indicate that serum GLP-2 concentrations were significantly higher in children with NAFLD compared with those with simple obesity ($p<0.05$). Moreover, binary logistic regression analysis identified GLP-2 as a potential biomarker associated with NAFLD, suggesting a possible contribution to disease progression.

The present study demonstrated significant positive correlations between GLP-2 and multiple markers of lipid and glucose metabolism, including TC, TG, LDL-C, FPG, INS, and HOMA-IR. These associations were confirmed by univariate linear regression analysis, suggesting that GLP-2 may influence glucose and lipid metabolism, or alternatively, that dysregulation in these metabolic pathways may affect GLP-2 expression. Endogenous GLP-2 has been proposed as a potential protective factor against hepatic metabolic disorders, contributing to the amelioration of IR and the maintenance of hepatic lipid homeostasis.[29–31]

Several studies have reported the beneficial effects of GLP-2 on glucose metabolism.[32,33] In high-fat diet (HFD)-induced obesity models, GLP-2 has been shown to improve impaired glucose metabolism by modulating glucose-related parameters, including plasma glucose levels, glucose tolerance, and insulin sensitivity.[34,35] Within the central nervous system, GLP-2 has been implicated in glucose homeostasis and insulin sensitivity regulation. Notably, mice lacking GLP-2 receptors (*Glp2r*–/–) in pro-opiomelanocortin (POMC) neurons exhibit impaired glucose tolerance and hepatic IR.[36]

In addition to its role in glucose regulation, GLP-2 is involved in regulating lipid metabolism, influencing both postprandial lipid absorption and the release of lipids in the post-absorptive state.[37] This regulatory function is crucial for maintaining lipid homeostasis and energy balance within the body. Notably, GLP-2R inhibition in HFD-fed mice has been associated with significant dyslipidemia and exacerbation of hepatic steatosis.[38] Furthermore, GLP-2R expression in hepatic stellate cells further highlights its role in maintaining normal lipid homeostasis. Studies indicate that GLP-2R deficiency in *Glp2r*–/– mice results in increased hepatic lipid accumulation and impaired insulin sensitivity, further compromising glucose metabolism.[39]

In an NAFLD mouse model, administration of long-acting GLP-2R agonists effectively reduced body weight, liver weight, hepatic fat accumulation, inflammation, and hepatic fibrosis.[17] Collectively, these findings suggest that GLP-2 and its receptor may function as a protective factor in liver diseases and represent potential therapeutic targets or biomarkers for NAFLD.

Logistic regression results from the present study indicated that GLP-2, LEP, and ADPN were independently associated with NAFLD occurrence in pediatric obesity. To further examine the relationships among these factors, Spearman correlation analysis was conducted, demonstrating that serum GLP-2 levels were positively correlated with LEP and negatively correlated with ADPN. These associations were confirmed by linear regression analysis.

Previous studies have demonstrated that LEP and ADPN, as adipokines, contribute to IR through multiple mechanisms, thereby exacerbating the onset and progression of NAFLD.[5,40,41] The current findings highlight the need for further investigation into the underlying mechanisms linking GLP-2 with metabolic parameters in children with obesity and NAFLD. Given that GLP-2 can enhance insulin sensitivity, potential physiological interactions between GLP-2 and adipokines may collectively influence NAFLD development. Although there are no existing reports directly addressing this relationship, the specific mechanisms remain to be elucidated. Future research will focus on further clarifying the associations among GLP-2, LEP, and ADPN in this population.

This study utilized a cross-sectional design; therefore, while GLP-2 was identified as a potential biomarker for NAFLD, causal relationships cannot be inferred. The relatively small sample size may also limit the generalizability of the findings. Future studies with larger cohorts are warranted to validate these results. After adjusting for BMI as a confounding factor, multivariable logistic regression analysis indicated that ADPN is an independent protective factor against NAFLD onset. Moreover, unmeasured confounding factors, such as dietary patterns, physical activity, and genetic predisposition, may also contribute to NAFLD progression in pediatric obesity. Therefore, further research is needed to elucidate the complex interplay among these factors.

As the prevalence of NAFLD continues to rise in the pediatric population, there is an urgent need for research into prevention and treatment strategies, particularly in children and adolescents, to slow disease progression and reduce long-term complications.[42] During clinical evaluation, measurement of GLP-2, ADPN, and LEP levels in children with obesity may improve the accuracy of early NAFLD identification and diagnosis. Although effective pharmacological treatments for pediatric NAFLD are limited, dietary modification and lifestyle interventions remain the cornerstone of therapy.[43–45] Appropriate dietary adjustments and regular physical activity have been shown to improve liver function parameters and reduce hepatic fat deposition in NAFLD.[46,47] Recent advances in GLP-2 biology suggest that targeting the GLP-2 receptor may represent a promising therapeutic approach for managing obesity and related metabolic disorders.

Conclusion

This study highlights the potential role of GLP-2 in children with obesity and NAFLD. GLP-2 concentrations were significantly higher in children with NAFLD compared with those with simple obesity and were positively correlated with markers of IR and dyslipidemia. GLP-2 was identified as a potential biomarker for NAFLD in pediatric obesity,

addressing a gap in current non-invasive diagnostic indicators and suggesting a novel target for early screening. Its involvement in the regulation of hepatic lipid metabolism also points to a possible therapeutic pathway, offering new directions for drug development.

Future studies should aim to elucidate the underlying mechanisms of GLP-2 in NAFLD pathogenesis and to validate its clinical value as a biomarker and therapeutic target. Larger-scale studies in human populations, prospective longitudinal studies, interventional trials, and evaluations of GLP-2 receptor–targeted therapies are warranted.

Clinical Registration Details

Register URL link: www.medicalresearch.org.cn
Register date: 2024/08/21
Trial registration number: MR-33-24-037003

Abbreviations

NAFLD, non-alcoholic fatty liver disease; GLP-2, glucagon-like peptide-2; LEP, leptin; ADPN, adiponectin; WHR, waist-to-hip ratio; BMI, body mass index; TC, total cholesterol; TG, triglyceride; LDL-C, low-density lipoprotein cholesterol; FPG, fasting blood glucose; INS, insulin; HOMA-IR, insulin resistance index; HDL-C, lower adiponectin, high-density lipoprotein cholesterol; IR, insulin resistance; CNS, central nervous system; GLP-2R, GLP-2 receptor; ELISA, enzyme-linked immunosorbent assay; SD, standard deviation; IQR, interquartile range; ORs, odds ratios; CIs, confidence intervals; HFD, high-fat diet.

Data Sharing Statement

The datasets used or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was conducted with approval from the Ethics Committee of the Second Hospital of Jiaxing (No.the Second Hospital of Jiaxing Ethics Review No. 092 for Research 2024, 2024-076-02). This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This research was supported by Science and Technology Program of Jiaxing (No. 2024AD30089).

Disclosure

The authors declare that they have no conflict of interest regarding this work.

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