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ORIGINAL RESEARCH

Associations Between Serum TNF-α, IL-6, hs-CRP and GLMD in Obese Children and Adolescents: A Cross-Sectional Study

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Purpose: To explore the relationships between serum tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), high-sensitivity C-reactive protein (hs-CRP) levels and glucolipid metabolism disorders (GLMD) in obese children and adolescents.

Patients and Methods: In this cross-sectional study, 105 obese children and adolescents were selected for the detection of TNF-α, IL-6, hs-CRP, and glycolipid metabolism indicators. All participants were divided into elevated TNF-α group (≥8.1 pg/mL; n=49) and normal TNF-α group (<8.1 pg/mL; n=56), elevated IL-6 group (≥5.9 pg/mL; n=13) and normal IL-6 group (<5.9 pg/mL; n=92), elevated hs-CRP group (≥3.0 mg/L; n=44) and normal hs-CRP group (<3.0 mg/L; n=61), respectively.

Results: Low-density lipoprotein cholesterol (LDL-C) in the elevated TNF-α group was higher than that in the normal TNF-α group (P=0.010). TNF-α was positively correlated with LDL-C (P=0.005). Fasting insulin (FINS) and homeostasis model assessment of insulin resistance (HOMA-IR) in the elevated IL-6 group were higher than those in the normal IL-6 group (all for P <0.05), while high-density lipoprotein cholesterol (HDL-C) in the elevated IL-6 group was lower than that in the normal IL-6 group (P<0.001). IL-6 was positively correlated with FINS, 2-hour postprandial insulin, HOMA-IR and triglyceride (all for P <0.01), while was negatively correlated with HDL-C (P=0.006). Moreover, hs-CRP was positively correlated with FINS and HOMA-IR (all for P <0.05).

Conclusion: There may be correlations between serum TNF-α, IL-6, hs-CRP levels and GLMD in obese children and adolescents. Attention should be paid to monitoring serum inflammatory factors and preventing their elevation in obese children and adolescents, thus reducing the occurrence of GLMD.

Keywords: tumor necrosis factor-alpha, interleukin-6, high-sensitivity C-reactive protein, glucolipid metabolism disorders, obesity, children and adolescents

Introduction

Obesity, or excess adiposity, is a chronic and multifactorial disease, characterized by an imbalance between energy intake and expenditure, resulting in excessive energy storage.[1] From 1975 to 2016, the age-standardized prevalence of obesity among children and adolescents aged from 5 to 19 years jumped from 0.9% (95% credible interval: 0.5–1.3) to 7.8% (6.7–9.1) for boys and from 0.7% (0.4–1.2) to 5.6% (4.8–6.5) for girls on a global scale.[2] In the China Health and Nutrition Surveys, the prevalence of overweight and obesity among children and adolescents aged 7–18 years, respectively, raised from 1.1% and 0.1% in 1985 to 3.8% and 1.2% in 1995, 7.9% and 3.8% in 2005, and 12.1% and 7.3% in 2014.[3] Recently, accumulated evidences showed that obesity in children and adolescents may be related with hypertension,[4] diabetes,[5] hyperlipidemia,[6] asthma,[7] non-alcoholic fatty liver disease,[8] and psychological disorders.[9] Most notably, the increased prevalence of glycolipid metabolism disorders (GLMD) in children and adolescents had a well-established correlation with cardiovascular diseases and type 2 diabetes mellitus (T2DM) in adulthood.[10]

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In addition, excess adiposity was closely associated with low-grade systemic inflammation in children and adolescents, with the elevated concentrations of various inflammatory markers, such as tumor necrosis factor-alpha (TNF-α), interleukin (IL)-6, IL-8, high-sensitivity C-reactive protein (hs-CRP), interferon-gamma, and monocyte chemoattractant protein-1.[11–13] It is worth noting that, TNF-α, IL-6 and hs-CRP were the most studied inflammatory parameters, which may be involved in the development of obesity in children and adolescents.[12–14]

Research has shown that inflammatory factors (TNF-α, IL-6 and hs-CRP) may play an important role in the pathophysiological process of GLMD.[15,16] However, to our knowledge, data on the associations between inflammatory factors (TNF-α, IL-6 and hs-CRP) and GLMD in obese children and adolescents are limited,[17] particularly in non-Caucasian ethnicities. Therefore, the purpose of our study is to investigate the relationships between serum TNF-α, IL-6, hs-CRP levels and GLMD in obese children and adolescents in China, which is expected to provide a potential formula for early intervention of GLMD.

Materials and Methods

Participants and Ethics

In this cross-sectional study, a total of 105 obese children and adolescents who attended the Nutrition Outpatient Clinic for Obesity at the Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (Shanghai, China) were recruited from April 2020 to January 2022. The general demographic data of 105 obese children and adolescents are summarized in Table 1. According to the reference ranges provided by the inflammatory factors (TNF-α, IL-6 and hs-CRP) detection kit, obese children and adolescents were divided into elevated TNF-α group (≥8.1 pg/mL; n=49) and normal TNF-α group (<8.1 pg/mL; n=56), elevated IL-6 group (≥5.9 pg/mL; n=13) and normal IL-6 group (<5.9 pg/mL; n=92), elevated hs-CRP group (≥3.0 mg/L; n=44) and normal hs-CRP group (<3.0 mg/L; n=61), respectively.

The inclusion criteria were as follows: (i) Children and adolescents aged from 6 to 18 years; (ii) At the outpatient visit, the weight of the participants exceeded 10% of standard weight corresponding to height; (iii) All participants

Table 1 The General Demographic Data of 105 Obese Children and Adolescents

Parameter	Value
Gender	
Boy	74 (70.48%)
Girl	31 (29.52%)
Age*, years	10.49 ± 2.48
Child	80 (76.19%)
Adolescent	25 (23.81%)
Height#, cm	146.80 (22.45)
Body weight#, kg	56.50 (29.10)
Waist circumference#, cm	87.00 (14.75)
Hip circumference#, cm	94.00 (16.15)
BMI#, kg/m^2	26.40 (5.95)
Obesity degree	
Overweight	7 (6.67%)
Mild obesity	30 (28.57%)
Moderate obesity	45 (42.86%)
Severe obesity	23 (21.90%)
TNF-α (≥8.1 pg/mL)	49 (46.67%)
IL-6 (≥5.9 pg/mL)	13 (12.38%)
hs-CRP (≥3.0 mg/L)	44 (41.90%)

Notes: Value in No. (%), *Mean ± standard deviation or #median (interquartile range).

Abbreviations: BMI, body mass index; TNF-α, tumor necrosis factor-α; IL-6, interleukin-6; hs-CRP, high-sensitivity C-reactive protein.

completed the determinations of inflammatory factors and glycolipid metabolism indicators, including TNF-α, IL-6, hs-CRP, fasting blood glucose (FBG), 2-hour postprandial blood glucose (2hPBG), fasting insulin (FINS), 2-hour post-prandial insulin (2hINS), total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C); (iv) Participants and their parents or guardians signed written informed consent.

The exclusion criteria were as follows: (i) Obesity caused by inherited metabolic diseases or endocrine diseases; (ii) Within the last year, suffering from other diseases, such as infectious diseases and Gaucher's diseases, which affected the indicators of serum inflammatory factors or glycolipid metabolism; (iii) Within the last year, taking drugs, such as antibiotics and glucocorticoids, which affected the indicators of serum inflammatory factors or glycolipid metabolism; (iv) Participants with incomplete clinical information.

This study was reviewed and approved by the Ethics Committee of Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (Approval No. XHEC-D-2022-015), and written informed consents were obtained from all participants and their parents or guardians. The protocol of the present study was conducted in accordance with the principles of the Declaration of Helsinki (7th revised edition in Brazil in 2013).

Detection of Observation Indicators

At least 8 hours after the overnight fasting and 2 hours after the meal, blood samples of antecubital veins were drawn from all participants into plastic centrifuge tubes containing ethylenediaminetetraacetic acid, respectively. The samples in tubes were allowed to clot at room temperature, and immediately spun at 3000 rpm for 15 minutes in the Allegra® X-12R benchtop centrifuge (Beckman Coulter Inc., Brea, CA, USA) to obtain serum for the determinations of TNF-α, IL-6, hs-CRP, FBG, 2hPBG, FINS, 2hINS, TC, TG, HDL-C and LDL-C. Then, TNF-α and IL-6 were estimated by the chemiluminescence method, with the TNF-α and IL-6 assay kit (Siemens AG, Germany), respectively. Besides, hs-CRP was determined by the latex enhanced immunoturbidimetry, with the hs-CRP assay kit (Wako Pure Chemical Industries, Ltd., Tokyo, Japan). The glucose assay kit (Wako Pure Chemical Industries, Ltd., Tokyo, Japan) was used by the hexokinase method to determine the FBG and 2hPBG. FINS and 2hINS were detected by the chemiluminescence method, with the insulin assay kit (Beckman Coulter Inc., Brea, CA, USA). The concentrations of TC, TG, HDL-C and LDL-C were tested by the Hitachi 7600 automatic biochemical analyzer (Hitachi Ltd., Tokyo, Japan) with reagents obtained from Wako Pure Chemical Industries Ltd. (Tokyo, Japan). Homeostasis model assessment of insulin resistance (HOMA-IR) was calculated by the formula, as follows:

HOMA-IR=FBG (mmol/L) × FINS (μU/mL)/22.5

Moreover, measurement methods of somatic indexes were as follows: (i) Height (cm): Participants kept their body upright and heels were placed together, and the height was measured using the SECA model 217 stadiometer (SECA, Corp., Hamburg, Germany) and recorded; (ii) Body weight (kg): Participants took off their shoes, wore thin clothes and urinated, and then body weight was measured using the Inbody 720 body composition analyzer (Biospace Co., Ltd., Seoul, Korea) and recorded; (iii) Waist circumference (cm): Waist circumference was the horizontal circumference through the center of the umbilicus measured with a flexible tape; (iv) Hip circumference (cm): Hip circumference was measured as the maximum circumference at the level of the buttocks; (v) Body mass index (BMI; kg/m^2): BMI was calculated as weight divided by height squared.

Diagnostic Criteria

The diagnosis of overweight and obesity for school-age children and adolescents referred to the health industry standard of the People's Republic of China "WS/T 586–2018 Screening for overweight and obesity among school-age children and adolescents". The obesity degree was diagnosed using the following reference standards: under the condition of the same age, gender and height, when the actual weight exceeded 10%-19% of the ideal weight, it was considered as overweight; 20%-29% was slight obesity; 30%-49% was moderate obesity; and 50% or above was severe obesity.

Statistical Analysis

All data were analyzed with SPSS 26.0 statistical software package (IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test was performed to evaluate the hypothesis of normal distribution for all continuous variables. Next, continuous variables with normal distribution were described as mean ± standard deviation, while continuous variables with non-normal distribution were presented as median and interquartile range. For comparisons between two groups, Student's *t*-test was performed for parametric data, while the Mann–Whitney *U*-test was conducted for non-parametric data. Correlation between continuous variables was carried out by using Pearson correlation for parametric data and Spearman correlation for non-parametric data. Two-sided *P* values <0.05 were considered as statistically significant.

Results

Difference Analysis of Glycolipid Metabolism Between Elevated Inflammatory Factors Group and Normal Group

LDL-C in the elevated TNF-α group was significantly higher than that in the normal TNF-α group (*P*=0.010). There were no significant differences in FBG, 2hPBG, FINS, 2hINS, HOMA-IR, TC, TG and HDL-C between the elevated TNF-α group and the normal TNF-α group (*P*>0.05) (Table 2). FINS and HOMA-IR in the elevated IL-6 group were significantly higher than those in the normal IL-6 group (*P*=0.017 and 0.016, respectively), while HDL-C in the elevated IL-6 group was significantly lower than that in the normal IL-6 group (*P*<0.001). There were no significant differences in FBG, 2hPBG, 2hINS, TC, TG and LDL-C between the elevated IL-6 group and the normal IL-6 group (*P*>0.05) (Table 3). There were no significant differences in FBG, 2hPBG, FINS, 2hINS, HOMA-IR, TC, TG, HDL-C and LDL-C between the elevated hs-CRP group and the normal hs-CRP group (*P*>0.05) (Table 4).

Correlation Analysis of Inflammatory Factors and Glycolipid Metabolism

TNF-α was positively correlated with LDL-C (r=0.274, *P*=0.005), but had no significant correlations with FBG, 2hPBG, FINS, 2hINS, HOMA-IR, TC, TG and HDL-C (*P*>0.05). IL-6 was positively correlated with FINS, 2hINS, HOMA-IR and TG (r=0.342, *P*<0.001; r=0.265, *P*=0.006; r=0.348, *P*<0.001; r=0.328, *P*=0.001, respectively), while was negatively correlated with HDL-C (r=−0.267, *P*=0.006). IL-6 had no significant correlations with FBG, 2hPBG, TC and LDL-C (*P*>0.05). Hs-CRP was positively correlated with FINS and HOMA-IR (r=0.205, *P*=0.035; r=0.193, *P*=0.048, respectively), while had no significant correlations with FBG, 2hPBG, 2hINS, TC, TG, HDL-C and LDL-C (*P*>0.05) (Table 5).

Table 2 The Difference Analysis of Glycolipid Metabolism Indexes Between Elevated TNF-α Group and Normal TNF-α Group

Parameter	TNF-α		*P* value
	Elevated Group (n=49)	Normal Group (n=56)	
FBG#, mmol/L	5.15 (0.52)	5.23 (0.32)	0.223
2hPBG#, mmol/L	5.98 (1.24)	6.10 (0.96)	0.880
FINS#, pmol/L	109.89 (90.17)	114.05 (80.48)	0.637
2hINS#, pmol/L	389.86 (444.45)	381.40 (414.14)	0.418
HOMA-IR#	3.65 (2.99)	3.76 (2.78)	0.693
TC#, mmol/L	4.43 (1.03)	4.50 (0.70)	0.995
TG#, mmol/L	1.30 (1.02)	0.90 (1.00)	0.074
HDL-C#, mmol/L	1.21 (0.28)	1.25 (0.23)	0.312
LDL-C#, mmol/L	2.70 (1.19)	2.51 (0.77)	0.010

Note: #Value in median (interquartile range).

Abbreviations: TNF-α, tumor necrosis factor-α; FBG, fasting blood glucose; 2hPBG, 2-hour postprandial blood glucose; FINS, fasting insulin; 2hINS, 2-hour postprandial insulin; HOMA-IR, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Table 3 The Difference Analysis of Glycolipid Metabolism Indexes Between Elevated IL-6 Group and Normal IL-6 Group

Parameter	IL-6		*P* value
	Elevated Group (n=13)	Normal Group (n=92)	
FBG#, mmol/L	5.23 (0.54)	5.17 (0.40)	0.194
2hPBG#, mmol/L	6.37 (1.07)	5.93 (0.99)	0.055
FINS#, pmol/L	164.70 (142.89)	107.88 (75.29)	0.017
2hINS#, pmol/L	526.98 (827.52)	384.29 (454.91)	0.376
HOMA-IR#	5.54 (9.80)	3.57 (2.55)	0.016
TC#, mmol/L	4.45 (0.62)	4.46 (0.76)	0.719
TG#, mmol/L	1.51 (0.76)	1.13 (1.04)	0.067
HDL-C#, mmol/L	1.03 (0.27)	1.25 (0.24)	<0.001
LDL-C#, mmol/L	3.00 (0.96)	2.61 (0.79)	0.215

Notes: #Value in median (interquartile range).
Abbreviations: IL-6, interleukin-6; FBG, fasting blood glucose; 2hPBG, 2-hour postprandial blood glucose; FINS, fasting insulin; 2hINS, 2-hour postprandial insulin; HOMA-IR, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Table 4 The Difference Analysis of Glycolipid Metabolism Indexes Between Elevated Hs-CRP Group and Normal Hs-CRP Group

Parameter	hs-CRP		*P* value
	Elevated group (n=44)	Normal group (n=61)	
FBG#, mmol/L	5.16 (0.35)	5.17 (0.45)	0.948
2hPBG#, mmol/L	6.04 (0.91)	6.06 (1.13)	0.531
FINS#, pmol/L	111.29 (84.00)	110.99 (86.95)	0.290
2hINS#, pmol/L	381.28 (285.78)	389.86 (636.62)	0.568
HOMA-IR#	3.69 (3.00)	3.65 (3.13)	0.391
TC#, mmol/L	4.45 (1.00)	4.46 (0.63)	0.818
TG#, mmol/L	1.36 (1.14)	1.06 (1.01)	0.203
HDL-C#, mmol/L	1.20 (0.24)	1.27 (0.30)	0.071
LDL-C#, mmol/L	2.71 (0.80)	2.57 (0.80)	0.176

Note: #Value in median (interquartile range).
Abbreviations: hs-CRP, high-sensitivity C-reactive protein; FBG, fasting blood glucose; 2hPBG, 2-hour postprandial blood glucose; FINS, fasting insulin; 2hINS, 2-hour postprandial insulin; HOMA-IR, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

Discussion

Obese children and adolescents not only had a low-grade inflammatory state, but also usually had GLMD.[5,6,11] The latter also was a high-risk factor for T2DM and hyperlipidemia in adulthood.[10] Our study demonstrated that there may be correlations between serum TNF-α, IL-6, hs-CRP levels and GLMD in obese children and adolescents. The results may provide a potential solution for the early prevention and treatment of GLMD.

In the obese state, pro-inflammatory adipokines were excessively synthesized and secreted by dysfunctional adipocytes; conversely, anti-inflammatory adipokines were generated with a less extent.[18] Notably, some adipokines, including cytokines, hormones and proteins, such as TNF-α, IL-6 and hs-CRP, possessed pro-inflammatory properties.[18,19] Sönmez et al[20] found that serum levels of TNF-α, IL-6 and hs-CRP in 53 obese children and adolescents were significantly higher than those in 20 healthy children and adolescents (4.05 ± 8.73 pg/mL versus 1.70 ± 2.52 pg/mL, 3.21 ± 0.92 pg/mL versus 2.04 ± 0.81 pg/mL, 0.31 ± 0.12 mg/dL versus 0.07 ± 0.33 mg/dL, respectively). Moreover, Jain et al[21] reported that 54.4% (43/79) and 49.4% (39/79) of all overweight and obese children between 7–15 years had elevated levels of

Table 5 The Correlation Analysis of TNF-α, IL-6, Hs-CRP and Glycolipid Metabolism Indexes

Parameter	TNF-α		IL-6		hs-CRP	
	r	*P* value	r	*P* value	r	*P* value
FBG, mmol/L	−0.157	0.110	0.191	0.051	0.077	0.433
2hPBG, mmol/L	0.030	0.759	0.173	0.077	−0.109	0.268
FINS, pmol/L	−0.088	0.371	0.342	<0.001	0.205	0.035
2hINS, pmol/L	0.027	0.783	0.265	0.006	0.032	0.747
HOMA-IR	−0.095	0.335	0.348	<0.001	0.193	0.048
TC, mmol/L	0.048	0.625	−0.036	0.714	0.017	0.860
TG, mmol/L	0.119	0.225	0.328	0.001	0.104	0.291
HDL-C, mmol/L	−0.061	0.538	−0.267	0.006	−0.150	0.126
LDL-C, mmol/L	0.274	0.005	0.086	0.385	0.088	0.374

Abbreviations: TNF-α, tumor necrosis factor-α; IL-6, interleukin-6; hs-CRP, high-sensitivity C-reactive protein; FBG, fasting blood glucose; 2hPBG, 2-hour postprandial blood glucose; FINS, fasting insulin; 2hINS, 2-hour post-prandial insulin; HOMA-IR, homeostasis model assessment of insulin resistance; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol.

serum IL-6 and hs-CRP, respectively. In the present study, we revealed that the proportions for the elevated levels of serum TNF-α, IL-6 and hs-CRP in obese children and adolescents were 46.67% (49/105), 12.38% (13/105) and 41.90% (44/105), respectively. Such a result was consistent with the conclusion made by Jain.[21] These studies suggested that serum TNF-α, IL-6 and hs-CRP may be involved in the occurrence and development of obesity in children and adolescents.

The release of chemokines from hypertrophic adipocytes in obese patients induced the accumulation of macrophages in adipose tissue.[22] Macrophages accumulating in adipose tissue produced nitric oxide and pro-inflammatory cytokines, such as TNF-α, IL-6 and IL-1β, and these inflammatory changes caused adipocytokine dysregulation.[22,23] The latter was characterized by an increase in pro-inflammatory adipocytokines, and a decrease in anti-inflammatory adipocytokines and insulin sensitizing.[22] Adipocytokine dysregulation eventually resulted in obesity-related metabolic syndrome, including hypertension, hyperlipidemia, diabetes mellitus, and nonalcoholic steatohepatitis.[22] Moreover, Patel et al[24] revealed that, for 478 diabetic patients and 502 age-matched non-diabetic individuals, TNF-α transcription levels were negatively correlated with HDL-C (r=0.39, *P*=0.001). In the present study, we found that LDL-C in the elevated TNF-α group was significantly higher than that in the normal TNF-α group, and HDL-C in the elevated IL-6 group was significantly lower than that in the normal IL-6 group. Besides, TNF-α was positively correlated with LDL-C. Meanwhile, IL-6 was positively correlated with TG, while negatively correlated with HDL-C. Recently, Shin et al[17] reported that, for 1723 youths (918 boys, 53.28%) aged 10–18 years, hs-CRP was negatively associated with HDL-C (β= −0.025, *P*=0.029), after adjusting for multiple variables, including sex, age, BMI, physical activity, white blood cell count, and nutritional factors; To a certain extent, hs-CRP may be a reliable indicator for abnormal lipid metabolism in the pediatric population. In our study, we found that hs-CRP was positively correlated with FINS and HOMA-IR. Of note, this is the first study which has specifically investigated the associations between serum TNF-α, IL-6, hs-CRP levels and GLMD in Chinese obese children and adolescents, so that the findings for this age group of obese participants may not be directly compared with any existing literature.

The increasing prevalence of insulin resistance (IR), T2DM and metabolic syndrome was associated with an obesity epidemic.[25] Adipose tissue secreted proteins which may influence insulin sensitivity.[26] Among them, TNF-α has been proposed as a connection between adiposity and the development of IR, because the majority of patients with T2DM were obese, and obese mice lacking either TNF-α or its receptors revealed protection for the development of IR.[26,27] After exposure to TNF-α, activation of pro-inflammatory pathways induced a state of IR in terms of glucose uptake in adipocytes and myocytes that impaired insulin signaling at the levels of insulin receptor substrate proteins.[26] In brown adipocytes, a complex mechanism of IR in the presence of TNF-α may involve:[26] (a) Ser/Thr phosphorylation of insulin receptor

substrate-2 by p38MAPK and ERK; (b) Generation of ceramide and activation of phosphatase PP2A; (c) Modulation of PTP1B activity. In addition, most adipokines were secreted by macrophages; Therefore, there may be an imbalance in the generation and action of cytokines, including IL-6. Then, elevated IL-6 levels performed its role through soluble IL-6 receptor via the trans-signaling pathway to initiate a pathway that produced pathological effects of IL-6, leading to IR and increased hs-CRP from the liver. Eventually, hs-CRP mediated its action to initiate a cascade response that promoted IL-6 production and IR, decreased sensitivity and β-cell percentage, and increased insulin secretion.[28] Recent studies have shown that in obesity, increased fat stores promoted inflammatory cytokine-induced IR, ultimately leading to a metabolic disorder known as T2DM.[29,30] Furthermore, Shin et al[17] reported that, for 1723 youths (918 boys, 53.28%) aged 10–18 years, hs-CRP was positively related with HbA1c (β=0.036, P=0.012) and BMI z-score (β=0.60, P<0.001), after adjusting for multiple variables, including sex, age, BMI, physical activity, white blood cell count, and nutritional factors; Hence, hs-CRP may be a reliable indicator for prediabetes and adiposity in the pediatric population. In the present study, we found that FINS and HOMA-IR in the elevated IL-6 group were significantly higher than those in the normal IL-6 group. Moreover, IL-6 was positively correlated with FINS, 2hINS and HOMA-IR. Meanwhile, hs-CRP was positively correlated with FINS and HOMA-IR.

However, this study still has several limitations. First, the study is a cross-sectional study, which cannot infer causal relationships between serum TNF-α, IL-6, hs-CRP levels and GLMD in obese children and adolescents. Second, the sample size included in this study is relatively small, so further stratification analysis, such as grouping by sex or developmental stage, is relatively difficult, and the study results may be biased. Therefore, in forthcoming studies, sufficient sample size should be recruited to implement the prospective multi-center randomized controlled clinical trials for further verification.

Conclusions

In conclusion, there may be correlations between serum TNF-α, IL-6, hs-CRP levels and GLMD in obese children and adolescents. Attention should be paid to monitoring serum inflammatory factors and preventing their elevation in obese children and adolescents.

Abbreviations

GLMD, glycolipid metabolism disorders; T2DM, type 2 diabetes mellitus; TNF-α, tumor necrosis factor-alpha; IL, interleukin; hs-CRP, high-sensitivity C-reactive protein; FBG, fasting blood glucose; 2hPBG, 2-hour postprandial blood glucose; FINS, fasting insulin; 2hINS, 2-hour postprandial insulin; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; BMI, body mass index; IR, insulin resistance.

Ethics Approval and Informed Consent

This study was reviewed and approved by the Ethics Committee of Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine (Approval No. XHEC-D-2022-015), and written informed consents were obtained from all participants and their parents or guardians. The protocol of the present study was conducted in accordance with the principles of the Declaration of Helsinki (7th revised edition in Brazil in 2013).

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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.

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Disclosure

The authors declare that they have no conflict of interest.

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