Lipids in Health and Disease

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Changes in polyunsaturated fatty acids are linked to metabolic syndrome in children with steroid-sensitive nephrotic syndrome—a clinical observation

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Abstract

Objective Alterations in lipid metabolic pathways constitute a pivotal characteristic of Steroid-Sensitive Nephrotic Syndrome (SSNS). Despite the significance, there has been scant exploration into the influence of polyunsaturated fatty acids (PUFAs) on metabolic syndrome (MetS) in children with SSNS. This study endeavors to elucidate the association between PUFAs and MetS in this specific pediatric population.

Methods This study enrolled a total of 185 children aged 0–7 years with SSNS between May 2023 and May 2024. Based on international guidelines for MetS, patients were classified into a MetS group ($n=73$) and a non-MetS group ($n=112$). A healthy control group ($n=82$) was also established. Surveys, anthropometric measurements, and blood samples were used to assess lipid profiles, glucose, insulin, and Hemoglobin A1C (HbA1C). The concentrations of serum PUFAs were quantitatively analyzed utilizing gas chromatography-mass spectrometry (GC-MS) techniques.

Results The MetS group exhibited significantly elevated levels of fasting blood glucose, triglyceride (TG), low-density lipoprotein (LDL) cholesterol, HbA1C, insulin, the ratio of TG to high-density lipoprotein (HDL) cholesterol, and the ratio of total cholesterol to HDL cholesterol compared to the non-MetS group. Significant differences were observed among healthy controls, MetS group, and non-MetS group in terms of ω-3 alpha-linolenic acid (ALA), ω-3 docosahexaenoic acid (DHA), ω-6 arachidonic acid, and ω-6 to ω-3 ratio.

Conclusions High ω-6 arachidonic acid, ω-6/ω−3 ratio and low ω-3 ALA and ω-3 DHA were associated with elevated TG levels. An elevation in TG concentrations among pediatric patients with SSNS may have been implicated to MetS.

Keywords Gas chromatography-mass spectrometry, Polyunsaturated fatty acids, Metabolic risk, Steroid-sensitive nephrotic syndrome, Children

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Introduction

MetS is prevalent in many areas, with its incidence rising with increasing age [1]. Given the escalating prevalence of severe MetS among children, and the subsequent rise in its associated complications [2–3], there is an urgent need for the development of tools that can aid in the early identification of metabolic disturbances and facilitate the timely adoption of preventive measures or medical interventions [4].

Nephrotic syndrome, which exhibits sensitivity to steroids, is an immunological disorder that is orchestrated by circulating factors of undefined nature [5]. These factors specifically target podocytes, leading to damage of the filtration barrier and, consequently, the occurrence of proteinuria [6]. Alterations in lipid metabolism stand out as a prominent feature of SSNS [7]. In the realm of healthcare research for children, fatty acid metabolism has emerged as a pivotal area of study, transcending mere nutritional considerations [8]. Instead, it adopts a more holistic and comprehensive perspective, with the aim of identifying potential biomarkers for assessing cardiovascular risk [9]. Increased serum lipid concentrations do not necessarily align with disease activity and can persist for extended durations, particularly in pediatric patients with a propensity for frequent relapses of nephrotic syndrome [10]. Recognizing the unique risk profile of children with SSNS is essential in addressing the heightened risk of MetS.

Fatty acids play diverse and crucial biological roles. Notably, they play intricate roles in cell signaling and inflammatory responses. Fatty acids can be categorized into three fundamental groups: Saturated Fatty Acids (SFAs), Monounsaturated Fatty Acids (MUFAs), and PUFAs [11]. PUFAs encompass the Essential Fatty Acids linoleic acid (18:2n–6) and α-linolenic acid (18:3n–3), which are solely obtainable through dietary intake [12]. Within the PUFA category, the ω-3 and ω-6 series hold the most significance in terms of biological function. These fatty acid series possess the capability to regulate the expression of numerous genes and are crucial in cell signaling and inflammatory pathways [13]. Notably, arachidonic acid, a pivotal ω-6 fatty acid, is liberated from membrane phospholipids in response to cellular stress [14].

The advantageous impacts of ω-3 PUFAs on insulin resistance, blood pressure, and dyslipidemia have demonstrated an inverse correlation with the risk of developing metabolic disorders [15]. There is a potential association exists between long-chain ω-3 PUFAs and Mets, but the relevant mechanism of action remains unclear. ω-3 PUFAs may further exert physiological effects by enhancing adipose tissue insulin sensitivity and modulating insulin signaling pathways. And it may compete with ω-3 in various physiological processes, leading to increased levels of inflammatory eicosanoids, which in turn increases the risk of chronic disease. These fatty acids and their metabolites, including eicosanoids, cytokines, may play crucial pathogenic roles in patients with SSNS [16]. Equally, elevated blood levels of arachidonic acid, and more broadly ω-6 fatty acid compounds, can serve as biomarkers during periods of clinical remission and the management of the unique metabolic risks in SSNS [17].

Given the sparse data on the connection between PUFAs and MetS in children with steroid-sensitive nephrotic syndrome, the goal of this retrospective research is to explore the presence of MetS in pediatric patients diagnosed with steroid-sensitive nephrotic syndrome. The study suggests a specific ratio of fats in blood may be linked to a higher risk of MetS in children with steroid-sensitive nephrotic syndrome, providing valuable insights into the underlying mechanisms contributing to Mets.

Methods

Study design and subjects

Between May 2023 and May 2024, the Institute of Kunming Children's Hospital & Children's Hospital Affiliated to Kunming Medical University conducted the retrospective study. Given the retrospective nature of this study, the consent for participation was approved by the Ethics Committee of Kunming Children's Hospital & Children's Hospital Affiliated to Kunming Medical University, and ethical approval has been reviewed by the same Ethics Committee. All personal identifiers were removed from the datasets prior to analysis to anonymize the participants and all data were collected and recorded by physicians through the electronic case system.

The study involved 185 children with SSNS. Based on international guidelines for Metabolic syndrome, 185 children were further classified into a MetS group ($n=73$) and a non-MetS group ($n=112$). The inclusion criteria were hospitalized children (<7 years old) with diagnosis of SSNS. SSNS was defined based on the following criteria: a urine protein-to-creatinine ratio (UPr/UCr) of less than 0.2 mg/mg, a total serum protein concentration exceeding 6.4 g per deciliter (gr/dl), a serum albumin level above 4 gr/dl, and a duration of remission lasting more than 30 days subsequent to the cessation of the most recent proteinuric episode [18]. The diagnosis of MetS was based on the 2007 International Diabetes Federation definition [19]. Exclusion criteria involved individuals with chronic conditions unrelated to MetS (e.g., type 1 diabetes, thyroid disorders, or irregularities in thyroid hormones), or recent dietary changes. Additionally, a control group of 82 healthy children (average age 5 years, 48% males) was established. The healthy control group was selected to match the age and gender of

the SSNS patients, and they had no concurrent inflammatory, metabolic, or genetic disorders. The flowchart of the study design is shown in Fig. 1.

The study was conducted in three phases and included socio-demographic details and laboratory tests. Participants were enrolled in accordance with the Helsinki Declaration statement.

Anthropometric measurements

By detailing the precision instruments used, such as the SECA measuring tape for Waist Circumference (WC), SECA-certified medical scale for body weight and height. The Waist-to-Height Ratio (WHtR) is calculated by dividing WC by their height. This systematic approach to anthropometric assessment allows for a comprehensive evaluation of participants' body composition and metabolic health status. Anthropometric measurements, including body mass (kg) and WC (cm), were conducted in accordance with World Health Organization guidelines [20]. Body Mass Index (BMI) and the corresponding percentiles were calculated utilizing the Centers for Disease Control and Prevention (CDC) Growth Charts.

Gas chromatography-mass spectrometry

During routine assessments, a blood specimen of 200 µL was obtained. A 50 µL aliquot was dispensed into vials and subsequently methylated. The samples were incubated at a temperature of 90 °C for one hour, followed by a refrigeration step at 4 °C for ten minutes. Subsequently, 2 milliliters (mL) of KCl solution and 330 µl (µL) of hexane were added to the samples. The samples underwent vortex mixing prior to centrifugation at a rotational speed of 3000 rpm for a period of ten minutes. Ultimately, the hexane layer, situated atop each vial, was extracted and transferred into gas chromatography vials for the purpose of fatty acid profiling using a gas chromatograph equipped with a 30-meter fused silica capillary column allows for the separation and analysis of various compounds, including fatty acids, based on their chemical properties and interactions with the stationary phase of the column. The outcomes of the gas chromatography analysis were meticulously examined utilizing Clarity software (Data Apex).

Laboratory analysis

Blood samples were obtained from pediatric patients with steroid-sensitive nephrotic syndrome during a phase of sustained remission. These samples were collected in the morning, specifically between 7:00 a.m. and 9:30 a.m. The measurements included insulin, Fasting Plasma Glucose (FPG), HbA1C, Total Cholesterol (TC), HDL cholesterol, LDL cholesterol, and TG levels. Additionally, the individual fatty acids were quantified as a percentage of the total fatty acid content.

Statistical analysis

Statistical analyses for this study were performed utilizing SPSS version 25.0 software. Linear regression models were employed to explore the potential relationships between various biochemical parameters and the levels of PUFAs. Additionally, Pearson's correlation analyses were utilized to determine relationships, although the specific details of what was being correlated were not mentioned. A statistical significance threshold of $P < 0.05$ was established for interpreting the results.

Results

The study included a total of 267 children, with 141 girls and 126 boys. The participants were divided into three main groups based on their nephrotic syndrome status and the presence or absence of MetS. Specifically, there were: 82 healthy children (control group),73 children with both SSNS and MetS (MetS group),112 children with SSNS but without MetS (non-MetS group).

Statistical comparisons among these three groups revealed no significant differences in age, height, WC, and weight. In contrast, significant differences were observed in BMI and WHtR across the groups. Patients in the MetS group had significantly higher BMI and WHtR compared to the control group and non-MetS group ($P < 0.05$) (Table 1).

Significant differences were noted in various parameters such as FPG, TG, HDL, HbA1C, insulin, TG/HDL ratio, TC/HDL ratio, and LDL/HDL ratio across the groups. The MetS group exhibited notably higher levels of FPG, TG, HbA1C, insulin, TG/HDL ratio, LDL/HDL

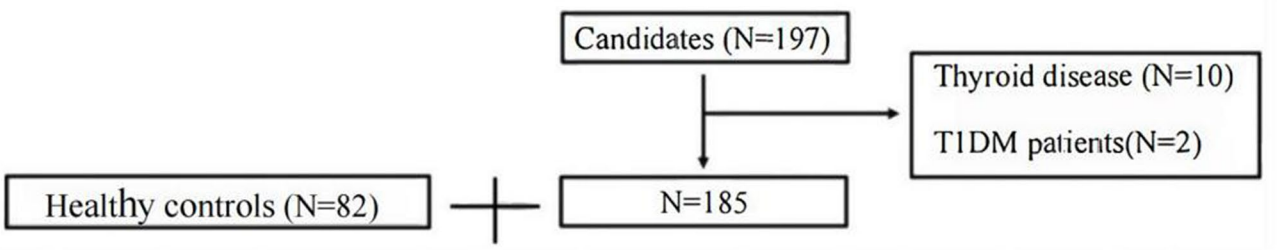

Fig. 1 Patients selection flow chart

Table 1 Characteristics in the study groups (x ± s)

Characteristic	Healthy controls (*N* = 82)	Children with steroid-sensitive nephrotic syndrome (*N* = 185)		*P*-value
		MetS group (*N* = 73)	Non-MetS group (*N* = 112)	
Age (month)	51.93 ± 9.14	51.01 ± 9.82	52.21 ± 9.54	0.695
BMI (kg/m2)	21.46 ± 1.39	27.60 ± 3.88	22.62 ± 1.44	< 0.001
WHtR (%)	0.48 ± 0.06	0.60 ± 0.06	0.47 ± 0.06	< 0.001
Height (m)	1.40 ± 0.23	1.38 ± 0.22	1.39 ± 0.22	0.507
Weight (kg)	39.23 ± 13.37	37.49 ± 12.76	38.41 ± 13.10	0.277
WC (cm)	0.51 ± 0.09	0.61 ± 0.28	0.55 ± 0.07	0.07

Footnote: BMI-body mass index, WHtR-waist/height ratio, WC-Waist Circumference

ratio, and TC/HDL ratio compared to both control group and non-MetS group ($P < 0.05$) (Table 2).

The study found significant differences in the concentrations of PUFAs based on the participants' case status, specifically whether they had MetS or not. The mean concentrations of certain types of PUFAs, including ω-3 PUFAs (α-linolenic acid, and docosahexaenoic acid) and the ω-6 PUFA arachidonic acid, were notably higher in individuals with MetS compared to those without MetS ($P < 0.05$) (Table 3).

In this study, the relationships between the concentrations of various PUFAs, such as ω-3 ALA, ω-3 DHA, ω-6 arachidonic acid, the ω-6/ω−3 ratio, and different metabolic parameters including lipid profile were evaluated. Significant correlations were observed between specific PUFA concentrations (ω−3 ALA, ω-3 DHA, ω-6 arachidonic acid, and ω-6/ω−3 ratio) and clinical indicators such as FPG, HbA1c, HDL, LDL, insulin. This study demonstrates that ω-3 ALA, ω-3 DHA, ω-6 arachidonic acid, and ω-6/ω−3 ratio were all associated with TG through the correlation analysis. Correlations were observed between TG and ω-6 arachidonic acid ($r = 0.205$, $P<0.001$), TG and the ω-6/ω−3 ratio ($r = -0.269$, $P<0.001$), TG and ω-3 ALA ($r = 0.152$, $P = 0.018$), and TG and ω-3 DHA ($r = 0.186$, $P = 0.014$) (Table 4).

Table 2 Biochemical parameters of the study groups (x ± s)

Variables	Healthy controls (*N* = 82)	Children with steroid-sensitive nephrotic syndrome (*N* = 185)		*P*-value
		MetS Group (*N* = 73)	Non-MetS Group (*N* = 112)	
FPG (mg/dL)	83.63 ± 8.99	112.24 ± 18.89	86.72 ± 9.67	0.004
TC (mg/dL)	119.79 ± 43.47	121.93 ± 17.49	120.61 ± 40.47	0.936
TG (mg/dL)	73.35 ± 18.10	93.81 ± 29.43	78.35 ± 17.58	< 0.001
HDL (mg/dL)	40.93 ± 3.95	21.52 ± 10.34	40.88 ± 3.81	< 0.001
LDL (mg/dL)	94.47 ± 17.02	111.90 ± 23.27	93.46 ± 17.66	0.057
HbA1C (%)	4.78 ± 0.47	6.83 ± 1.31	4.78 ± 0.54	< 0.001
Insulin (μIU/mL)	11.62 ± 5.25	17.05 ± 4.08	10.55 ± 5.25	< 0.001
TG/HDL ratio	1.81 ± 0.48	10.73 ± 33.49	1.93 ± 0.47	< 0.001
TC/HDL ratio	2.95 ± 1.09	13.64 ± 41.28	2.97 ± 1.02	< 0.001
LDL/HDL ratio	2.33 ± 0.46	11.01 ± 28.09	2.30 ± 0.47	< 0.001

Footnote: TG–triglyceride, TC–total cholesterol, HDL–high-density lipoprotein, LDL–low-density lipoprotein, MetS-metabolic syndrome, FPG-fasting plasma glucose, HbA1C-hemoglobin A1C, mg-milligram, dL-deciliter, IU-international unit

Table 3 Distribution of serum PUFA% in the study groups (x ± s)

PUFA	Healthy controls (*N* = 82)	Children with steroid-sensitive nephrotic syndrome (*N* = 185)		*P*-value
		MetS Group (*N* = 73)	Non-Mets Group (*N* = 112)	
ω−3 arachidonic acid (%)				
18:3 ω-3 ALA	0.41 ± 0.27	0.28 ± 0.20	0.31 ± 0.18	< 0.001
20:5 ω-3 EPA	0.31 ± 0.14	0.29 ± 0.14	0.31 ± 0.17	0.535
22:5 ω-3 DPA	0.47 ± 0.23	0.52 ± 0.31	0.51 ± 0.26	0.498
22:6 ω-3 DHA	1.92 ± 1.34	1.40 ± 0.80	1.72 ± 1.19	0.018
Total ω-3 arachidonic acid	3.56 ± 2.42	2.54 ± 1.11	3.14 ± 1.72	0.003
ω−6 arachidonic acid (%)				
18:2 ω-6 linoleic acid	26.89 ± 3.67	25.98 ± 3.25	26.51 ± 3.93	0.44
18:3 ω-6 γ-linolenic acid	0.25 ± 0.12	0.28 ± 0.14	0.25 ± 0.11	0.18
20:2 ω-6 EPA	0.22 ± 0.07	0.23 ± 0.05	0.26 ± 0.18	0.42
20:4 ω-6 arachidonic acid	31.90 ± 13.60	37.42 ± 12.36	33.85 ± 13.46	0.033
Total ω-6 arachidonic acid	5.89 ± 1.70	6.61 ± 1.48	6.08 ± 1.47	0.006
ω−6/ω−3 ratio	12.53 ± 9.49	18.71 ± 13.61	13.31 ± 7.80	< 0.001

Footnote: PUFAs: polyunsaturated fatty acid, MetS-metabolic syndrome, ALA–α-linolenic acid, EPA–eicosapentaenoic acid, DPA-docosapentaenoic acid, DHA-docosahexaenoic acid

Table 4 Correlations between the concentrations of PUFAs in children

Variables	ω−3 ALA		ω−3 DHA		ω−6 PUFA		ω−6/ω−3 ratio	
	r*	P	r*	P	r*	P	r*	P
FPG (mg/dL)	−0.123	0.002	−0.077	0.711	0.038	0.538	0.155	0.069
HbAlc (%)	−0.102	0.346	−0.153	0.035	0.107	0.081	0.127	0.015
HDL (mg/dL)	−0.041	0.448	−0.022	0.278	−0.19	0.056	0.047	0.664
insulin (mg/dL)	0.005	0.856	−0.060	0.308	0.023	0.710	0.160	0.011
LDL (mg/dL)	−0.134	0.003	0.034	0.181	0.091	0.139	0.127	0.033
TC (mg/dL)	−0.077	0.207	0.005	0.665	0.085	0.166	0.004	0.801
TG (mg/dL)	0.152	0.018	0.186	0.014	0.205	< 0.001	−0.269	< 0.001

Footnote: PUFAs-polyunsaturated fatty acid, ALA-α-linolenic acid, DHA-docosahexaenoic acid, FPG-fasting plasma glucose, HbAlc-hemoglobin A1C, HDL-high-density lipoprotein, LDL-low-density lipoprotein, TC-total cholesterol, TG-triglyceride, mg-milligram, dL-deciliter

*The Spearman correlation analysis correlation coefficients between PUFA concentrations and various metabolic parameters

Table 5 Logistic regression analysis of factors associated with MetS in children with steroid-sensitive nephrotic syndrome

Variables	Univariate					Multivariate				
	β	S.E	Z	*P*	OR (95%CI)	β	S.E	Z	*P*	OR (95%CI)
TG	0.04	0.01	5.11	< 0.001	1.04 (1.02 ~ 1.05)	0.04	0.01	4.81	< 0.001	1.04 (1.02 ~ 1.05)
ω−3 ALA	−1.82	0.75	−2.44	0.015	0.16 (0.04 ~ 0.70)	−1.96	0.82	−2.40	0.016	0.14 (0.03 ~ 0.70)
ω−3 EPA	−1.07	0.97	−1.10	0.272	0.34 (0.05 ~ 2.30)					
ω−3 DHA	−0.35	0.14	−2.51	0.012	0.71 (0.54 ~ 0.93)	−0.41	0.15	−2.69	0.007	0.67 (0.50 ~ 0.90)
ω−3 DPA	0.38	0.50	0.77	0.443	1.46 (0.55 ~ 3.87)					
Total ω-3 PUFA	−0.33	0.11	−2.99	0.003	0.72 (0.58 ~ 0.89)	−0.38	0.13	−2.94	0.003	0.69 (0.53 ~ 0.88)
Total ω-6 arachidonic acid	0.02	0.01	2.37	0.018	1.02 (1.01 ~ 1.05)	0.03	0.01	2.16	0.031	1.03 (1.01 ~ 1.05)

Footnote: MetS-metabolic syndrome, TG-triglyceride, ALA-α-linolenic acid, DHA-docosahexaenoic acid, EPA-eicosapentaenoic acid, DPA-docosapentaenoic acid

β coefficients represent estimated effect sizes, S.E. represents standard error, Z represents the Z-statistic, and OR (95% CI) represents the proportion of odds ratios and the corresponding 95% confidence intervals

In the multivariate analysis, after adjusting for confounding factors, TG, ALA, DHA, ω-3 arachidonic acid, and ω-6 arachidonic acid remained significant predictors of MetS. The study's findings indicate that higher TG levels are associated with an increased risk of MetS in children with SSNS. Specifically, TG levels had a significant 1.04-fold increased risk of developing MetS. Additionally, the study examined the relationship between ω-3 ALA, ω-3 PUFA, ω-3 DHA and the risk of developing MetS in these children. However, the odds ratio (OR) values reflecting this association were relatively modest, indicating that while there is a statistically significant relationship, the magnitude of the effect may not be large. Overall, these results suggest that various metabolic, as well as specific fatty acids (DHA and ALA), may play a role in influencing the development or prevalence of MetS in children with SSNS (Table 5).

Discussion

This study focused on investigating the serum PUFA levels, biochemical parameters, and anthropometric characteristics in relation to MetS. The recognition of the impact of serum PUFA levels on the risk of Mets, which underscoring the importance of identifying risk factors early and implementing preventive measures in children with SNSS.

Children with SNSS may experience tubulointerstitial damage in the renal tubules, which can result in the persistent excretion of fatty acids into the urine, particularly in infants with congenital nephrotic syndrome [21]. Currently, there is a lack of standardized diagnostic criteria for defining MetS in childhood [22]. MetS encompasses risk factors that are linked to insulin resistance, which is postulated to stem from underlying mechanisms such as adipocyte dysfunction, systemic inflammation, and oxidative stress [23]. This study selected the 2007 International Diabetes Federation criteria for the diagnosis of MetS due to their widespread acceptance and use in both adult and pediatric populations. These criteria provide a comprehensive framework for identifying individuals with MetS, which is crucial for understanding the risks associated with this condition. While these criteria are not specific to pediatric populations, central obesity remains essential for the diagnosis of MetS in children. Based on this, this study included WHtR and BMI as key screening indicators for central obesity. Recent research has shown that children with SNSS exhibit an abnormal fatty acid profile and elevated arachidonic acid levels in their blood even during remission [24]. This observation suggests these patients may maintain a persistent inflammatory state, regardless of the absence of proteinuria. Convergent studies suggest that PUFAs may modulate the levels of inflammatory factors by increasing levels of

eicosapentaenoic acid (EPA), DHA and ALA, potentially positively impacting the overall health status of the children with SNSS [25].

The results of this study show lower levels of ω-3 ALA and ω-3 DHA, and higher levels of ω-6 arachidonic acid and the ω-6/ω−3 ratio in children with Mets, particularly in children with SSNS. These differences in PUFAs levels, especially the observed decrease in ω-3 PUFAs, align with the existing literature associating Mets with metabolic disturbances and inflammation, possibly mediated by proinflammatory eicosanoids derived from arachidonic acid of the ω-6 family [26]. For children with SSNS and Mets, the availability of a larger pool of arachidonic acid can enhance the activation of ω-6 metabolism when triggered by infection, which may exacerbate the disease. However, the specific mechanistic pathways remain unclear. Moveover, These findings indicate lower levels of PUFAs in Mets, are consistent with previous studies, further underscoring the potential role of PUFAs in metabolic health [27]. Furthermore, this research has revealed associations between specific PUFAs and metabolic parameters like TG, which are key components of Mets, particularly in children with SSNS. These associations suggest potential links between PUFA levels and markers of metabolic health in this population, providing valuable insights into the underlying mechanisms contributing to Mets in children with SSNS.

The significant findings of this study regarding the association between TG and metabolic parameters in children with SSNS and MetS provide valuable insights into potential risk markers for metabolic diseases. Children with MetS exhibit higher levels of TG compared to those without MetS, which is consistent with existing research indicating that these elevations are associated with an increased risk of type 2 diabetes [28]. These abnormalities increase the risk of metabolic diseases. The significant associations found in this study, for example, a 1.04-fold increased risk of Mets associated with higher TG values, emphasize the potential utility of these parameters as screening tools for identifying children with SSNS at risk for Mets. Research has established that ω-3 arachidonic acid effectively lowers total cholesterol concentrations [29], and also decreases the risk of disease [17]. However, ω-6 arachidonic acid have been implicated in promoting inflammation [25]. Dietary patterns and medication history significantly affect PUFA levels in childhood [30]. Recent research has indicated that the Mediterranean diet is a healthy dietary pattern associated with high levels of beneficial ω-3 fatty acids, which have anti-inflammatory effects. It also helps manage hypercholesterolemia, a risk factor for nephrotic syndrome [31]. Therefore, it is advisable to decrease the consumption of ω-6 arachidonic acid in the diet to achieve a more favorable dietary ω-6/ω−3 ratio, especially for children with SNSS.

Study strengths and limitations

Strengths

The strength of this research lies in its retrospective analysis of cases from pediatric specialty hospitals in the local region, incorporating a larger sample size and examining the correlation among various indicators. Moreover, this study offers a novel viewpoint on the metabolic difficulties encountered by children with SSNS, emphasizing the potential significance of regulating PUFAs in mitigating these risks.

Limitations

This study indeed had some limitations. First, it is prudent to acknowledge the limitations the cross-sectional design. Longitudinal data would provide insights into the temporal associations between PUFA levels and metabolic outcomes. Second, the lack of measurement of dietary data and free fatty acids, presents a gap in the study that could be addressed in further investigations. Third, the study's focus on Chinese children limits the generalizability of the findings to other racial or ethnic groups, and the single-center retrospective nature of this study limits the generalizability. Also, potential biases and limitations arising from applying adult-derived criteria to a pediatric population have been considered. To address these limitations and further validate the findings, multicenter studies would be conducted in future research to better understand the prevalence and implications of MetS in pediatric populations using more appropriate and specific criteria.

Conclusions

The study contributes to the understanding of the complex interplay between fatty acids and MetS in children with SSNS, which could help in developing better strategies to prevent and manage MetS in this patient population.

Abbreviations

MetS	Metabolic Syndrome
SSNS	Steroid-Sensitive Nephrotic Syndrome
SFAs	Saturated Fatty Acids
MUFAs	Monounsaturated Fatty Acids
PUFAs	Polyunsaturated Fatty Acids
WHtR	Waist-to-Height Ratio
BMI	Body Mass Index
HbA1C	Hemoglobin A1C
HDL	High-Density Lipoprotein
TC	Total Cholesterol
LDL	Low-Density Lipoprotein
FPG	Fasting Plasma Glucose
TG	Tri-Glycerides
ALA	α-linolenic Acid
DHA	Docosahexaenoic Acid
EPA	Eicosapentaenoic Acid

WC Waist Circumference
DPA Docosapentaenoic Acid

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-025-02535-4.

Supplementary Material 1

Supplementary Material 2

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Not applicable.

Author contributions
Conceived and designed the research: Feng Li Analyzed the data: Kai Liu, Hongmin-Fu, Yuan LiaoWriting-original draft preparation: Pei-long Li, Jia-wu YangWriting-review and editing: Feng Li.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethical approval
The study was approved by the Ethics Committee of Kunming Children's Hospital & Children's Hospital Affiliated to Kunming Medical University (approval No. 2023—05—058-K01) and all methods were performed in accordance with relevant guidelines and regulations.

Consent for participate
As this research merely employs pre-existing medical records and data, without infringing upon the identities or privacy of the participants and without imparting any risks or harm to participants, the consent for participate waived by the Ethics Committee of Kunming Children's Hospital & Children's Hospital Affiliated to Kunming Medical University in view of the retrospective nature of the study.

Competing interests
The authors declare no competing interests.

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