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CHILDHOOD OBESITY AND METABOLIC SYNDROME: UNRAVELING THE INTERPLAY OF LIFESTYLE, GENETICS, AND ENVIRONMENTAL FACTORS

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ABSTRACT

Background: Childhood obesity is a significant health issue that is highly linked to the premature onset of metabolic syndrome (MetS), which depends on lifestyle, genetic and environmental factors.

Objective: To determine the relationships between the lifestyle behaviours, family history, anthropometric measurements, and metabolic risk factors and indicators among children aged less than 18 years.

Methods: The study was an analytical cross-sectional study that was carried out in Peshawar, MMC General Hospital, Pediatric department, among 180 children. Structured questionnaires, anthropometric measurements with body mass index (BMI) and biochemical analyses of fasting blood glucose, lipid profile, and blood pressure were used to gather data. Descriptive statistics, correlation, regression and mediation analysis were used as the statistical methods.

Results: There was a high incidence of overweight and premature metabolic abnormalities. The screen time and consumption of fast food were found to be significantly linked to an elevated BMI and metabolic risk, whereas the physical activity was found to be protective. Family history of obesity or diabetes was also associated with an increased metabolic syndrome risk score. There was some mediation of BMI between lifestyle behaviours and metabolic risk.

Conclusion: Childhood obesity and metabolic syndrome are caused by various factors, which interact in a complex manner, such as lifestyle, genetic disposition, and environmental factors. The preventive measures need to be aimed at physical activity, improvement of diet and family-based interventions.

KEYWORDS: Childhood Obesity, Metabolic Syndrome, Sedentary Behavior, Body Mass Index.

INTRODUCTION

The nutritional transition in Pakistan is swift, with children and adolescents eating more energy-dense foods, being sedentary, and being physically less active [1]. Recent national and regional studies show that childhood overweight and obesity have emerged as a significant public health problem. A series of school-based cross-sectional studies conducted in various major cities, such as Lahore, Karachi, Islamabad, and Peshawar, have documented the rising prevalence of overweight/ obesity among school-aged children in the age range 5-16 years, ranging from about 10% to more than 25% of the children by age, geographic location, and diagnostic criteria [2]. The results indicated that there is a growing trend of overnutrition among children and adolescents in Pakistan [3]. Childhood obesity in Pakistan has also been linked to higher rates of metabolic abnormalities such as central obesity, insulin resistance, dyslipidaemia, hypertension, and metabolic syndrome [4]. A few cross-sectional studies have been conducted in Pakistan that showed that overweight and obese children have a significantly higher level of cardiometabolic risk factors compared to children of normal body weight, highlighting the need to identify children at risk and provide early interventions to prevent such risk [5]. Despite these findings, data are still scarce in many areas of the country, and more studies are needed to further define the burden of metabolic syndrome and associated risk factors in Pakistani children [6].

Besides behavioral factors, genetic risk factors and environmental factors are also major contributors to the risk of obesity [7]. Positive family history of obesity, diabetes, hypertension, or dyslipidemia suggests a genetic predisposition which adverse lifestyle exposures may aggravate. Environmental factors that contribute to the risk comprise living in urban settings, inaccessibility to recreational spaces, socioeconomic disparities, and obesogenic food settings [8]. Combined, these elements point to the idea that childhood obesity and metabolic syndrome are multifactorial diseases that are the result of a complex interaction between genetics, behavior, and environment [9].

Although the burden is on the rise, few studies have been carried out in Pakistan to identify the combined influence of lifestyle, genetic and environmental factors on childhood obesity and metabolic syndrome [10]. Current

research is mainly dedicated to prevalence or single risk factors, with many gaps in the available knowledge of the combined pathways that lead to the development of the disease in children. These gaps need to be addressed to design effective context-specific prevention strategies. Hence, this study aimed to assess the prevalence of metabolic syndrome and associated factors in children of Pakistan and provide locally relevant evidence for implementing preventive strategies and public health policies.

Objective

To determine the relationships between the lifestyle behaviors, family history, anthropometric measurements, and metabolic risk factors and indicators among children aged less than 18 years.

THEORETICAL FRAMEWORK

This paper used three theories, which are complementary, in order to comprehend the complex interaction between factors causing childhood obesity and metabolic syndrome (MetS): Behavioral Susceptibility Theory (BST), Social Cognitive Theory (SCT), and the Socio-Ecological (or Ecological Systems) Model. These frameworks combined gave a multi-level perspective of the association between individual predisposition, behavioral process, and environmental circumstances.

Behavioral Susceptibility Theory (BST)

According to Behavioral Susceptibility Theory, genetic variation affects the control of appetite, with certain children more susceptible to overeating in obesogenic conditions. This vulnerability is manifested by features such as low satiety responsiveness or high food responsiveness and mediates the relationship between genetic risk and obesity. It describes the reason behind the fact that only genetically susceptible children become obese or develop metabolic syndrome in the same environmental conditions.

Social Cognitive Theory (SCT)

Social Cognitive Theory describes behavior in terms of mutual interactions between individual, behavioral, and environmental forces. It brings out the role of self-efficacy, social support, outcome expectations, and perceived barriers in the diet and physical activity among children, in the context of obesity research. Parental beliefs and modeling have a great influence on lifestyle behaviors and determine the results of obesity and metabolic risks (Figure 1).

Socio-Ecological Model (SEM) / Ecological Systems Theory

The Socio-Ecological Model describes behavior as a result of the interaction of various levels, starting with individual and family factors, to the community, environmental, and policy factors. It has been used in childhood obesity studies to demonstrate the interaction between neighborhood design, food access, socioeconomic status and community resources and the risk of obesity and metabolic syndrome in conjunction with personal and genetic factors.

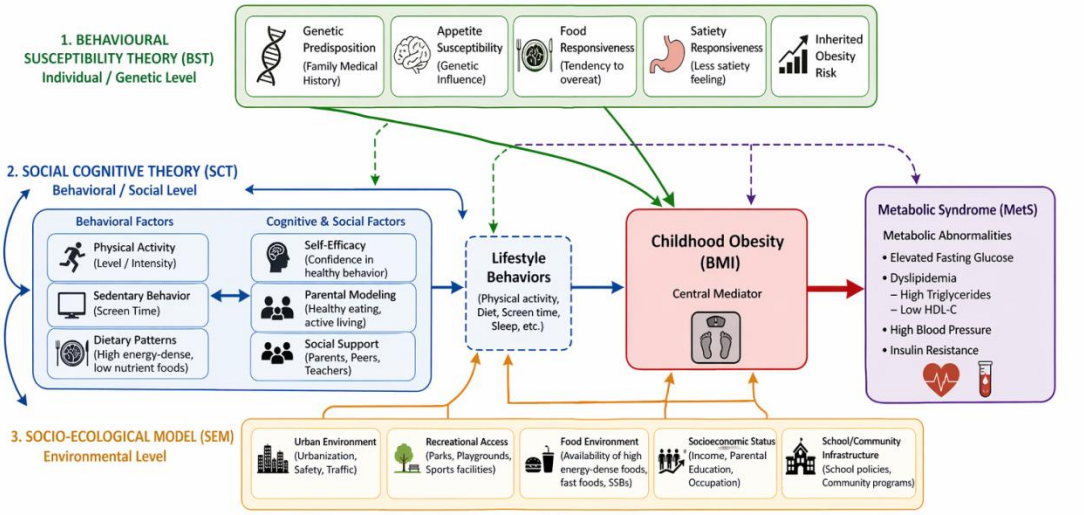

Figure 1: (Theoretical Framework) Interplay of lifestyle, Genetics and Environmental Factors in Childhood Obesity

MATERIALS AND METHODS

Research Design

The research design used was an analytical cross-sectional study that considered the interaction between lifestyle and genetic predispositions and environmental factors in relation to childhood obesity and metabolic syndrome (MetS). This was chosen as it enabled the researcher to test more than a number of variables at the same time and

determine the statistical relationship between anthropometry, biochemistry, lifestyle, and environmental variables. IRB approval letter number is 71/MMCGH/11/25.

Research Population and Site

Children aged below 18 years were involved in the study at the pediatric unit of MMC General Hospital, Peshawar, and the sample size was 180. The diagnosis of metabolic syndrome was made based on the International Diabetes Federation (IDF) consensus definition for children and adolescents (2007) [11]. People 10–18 years old were considered to have metabolic syndrome if they had central obesity (waist circumference ≥90th percentile for age and sex) and had two or more of the following abnormalities: serum triglycerides ≥150 mg/dL; HDL cholesterol <40 mg/dL; fasting plasma glucose ≥100 mg/dL, or previously diagnosed diabetes; systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg. Adult IDF criteria were used for participants over 18 years [12].

Fasting plasma glucose, serum triglycerides, HDL cholesterol, and blood pressure were chosen as markers because they are internationally accepted markers of cardiometabolic health and form the main components for assessing metabolic syndrome and cardiovascular risk in children and adolescents. The International Diabetes Federation (IDF) consensus definition for pediatric metabolic syndrome and the guidelines for pediatric cardiovascular risk assessment recommend their measurement [13]. These biomarkers are clinically relevant and give data on glucose metabolism, abnormalities in lipids, and hypertension, all of which are major determinants of future cardiovascular disease and type 2 diabetes.

Anthropometric Measurements

Trained research staff followed standard protocols to obtain anthropometric measurements. Body weight was determined using a calibrated digital weighing scale, height was measured with a stadiometer attached to the wall and waist circumference was measured with a non-stretchable measuring tape. All measurements were taken twice, and the mean was used for analysis. Body mass index (BMI) was determined by using the formula weight (kg)/height (m^2). Two blood pressure readings were taken after 5 minutes of rest in a well-calibrated, automated sphygmomanometer with a cuff of the correct size, with the mean of the two readings recorded. Venous blood samples were taken after 8–12 hours of an overnight fast and were analysed on an automated clinical chemistry analyser that was routinely analysed under internal quality control. All equipment was calibrated to the manufacturer's specifications, and standardised procedures were used in all measurements to reduce measurement bias and ensure data reliability.

A cross-sectional design is used to estimate the prevalence of such outcomes as childhood obesity (as proportions, e.g., BMI-defined cases) at a single point in time, with a formula that provides the desired level of precision (d) and confidence (Z) [14].

$$\mathbf{n} = \frac{\mathbf{Z^2 \cdot p \cdot (1-p)}}{\mathbf{d^2}}$$

n= Sample size required
Z= Z-score (Confidence interval)
p= Estimated prevalence of outcomes
d= Margin of error

Sampling Technique and Sample Size

The data were gathered by use of structured questionnaire, clinical tests and laboratory tests. The questionnaire was modified after already tested tools of assessment of pediatric obesity and consisted of four sub-sections: (a) demographic, (b) diet, (c) physical activity and sedentary behavior, and (d) family medical history, i.e., obesity and diabetes. The study used the five-point Likert scale developed by [Rensis Likert], a validated instrument in studies post its original publication [15]. The instrument consists of 25 items and 6 domains. Items are marked on a five-point Likert scale, whereby 1 is (Strongly Disagree), and 5 is (Strongly Agree). The instrument total score is in the range of the minimum score to the maximum score. The higher the total score, the higher the level of knowledge/attitude regarding the domains. Sample size criteria were determined in G-Power version 3.1.9.7 [16]. The value of α was 0.05, the statistical power (1 − β) was 80%, and the projected effect size was analogous to comparable studies. The Sample size was determined based on the parameters that would allow the identification of statistically significant differences between the experimental groups with the lowest probability of committing Type I and Type II errors.

Data Collection

The procedures of data collection were carried out in three months. Parents or guardians were informed on the purpose of the study and signed the informed consent forms before being allowed to take part in the study. A very short clinical examination was conducted and an anthropometric measurement and laboratory tests performed on children according to the hospital procedures. The questionnaire was done in the structured format with parents being taken through an interview based questionnaire so as to ensure they were accurate with their information since it pertains to the dietary and lifestyle habits.

Inclusion Criteria
Adult participants aged 18 years and above who gave written informed consent and were accessible during the period of data collection were used in the study. Only the individuals, who had gone through fasting laboratory tests, such as fasting blood glucose and triglyceride tests, were deemed eligible. Participants were also required to be willing to participate in the questionnaire-based interview and laboratory assessments.

Exclusion Criteria
The people were not to be included when they were pregnant or lactating because of a physiological change in metabolic aspects. Individuals with known severe chronic diseases like advanced renal failure, liver cirrhosis or malignancy were also excluded, as these diseases may confound the biochemical results.

Data Analysis
Data were analyzed using SPSS version 26. Descriptive statistics were used to report the study variables. Before performing inferential analyses, continuous variables were assessed for normality with the Shapiro–Wilk test. Given that the correlation analysis variables met the normality assumption ($p > 0.05$), the relationships between the continuous variables were assessed using Pearson's correlation coefficient. Significance was set to the customary alpha level of $p < 0.05$. The statement regarding the multiple linear regression analysis has been deleted, as this analysis was not performed as part of this study.

RESULTS
Pearson correlation coefficients were calculated to determine the strength and direction of associations among lifestyle behaviors, obesity indicators, and metabolic variables.

Table 1: Correlation Matrix for Key Study Variables (N = 180)

Variables	BMI kg/m²	Screen Time mins/day	Physical Activity hrs/day	Fasting Glucose	Triglycerides
BMI	1	0.41	–0.33	0.36	0.39
Screen Time	0.41	1	–0.45	0.29	0.34
Physical Activity	–0.33	–0.45	1	–0.21	–0.27
Fasting Glucose	0.36	0.29	–0.21	1	0.43
Triglycerides	0.39	0.34	–0.27	0.43	1

Table 1 describes the average age of the participants was 11.42 years which portrays a wide range of children of school going age (517 years). The mean BMI calculated at 23.81 kg/m 2 which put most of the participants in the overweight category as age related. Another central obesity was central abdominal adiposity (waist circumference = M = 72.14 cm). The hours of screen time were 3.41, which are significantly more than the recommended screen time of pediatric patients, and the differences in favor of physical activity were close to 42.57 minutes per day, which indicates an inadequate level of moderate-vigorous physical activity. Metabolic parameters indicated a borderline extreme level of fasting glucose (M = 98.72mg/dL) and triglycerides (M = 134.53mg/dL), which were close to the clinical limit of metabolic impairment. HDL cholesterol was rather low (M = 43.26 mg/dL) and systolic blood pressure (M = 112.48 mmHg) indicated early cardio metabolic demand in the part of the sample.

Multiple regression analysis was conducted to evaluate whether lifestyle behaviors predicted BMI scores.

Table 2: Regression Analysis: Lifestyle Predictors of BMI (N = 180)

Predictor	B	SE	β	t	p
Screen Time (mins/day)	1.14	0.21	.38	5.42	0.001*
Physical Activity (hrs/day)	–0.06	0.02	–.27	–3.52	0.001*
Fast Food Frequency	0.92	0.31	.23	2.98	0.003*

Model Summary: $R^2 = .34$, $F(3,176) = 30.44$, $p < .001$(* indicates statistical significance at $p \leq 0.05$)

Table 2 presents a multiple regression that evaluated the lifestyle behavior differences in predicting BMI. The model accounted a middle degree of predictive power (R 2 =.34) which explained 34 percent of the variation in BMI. The most significant (r =.38, p =.001) was found to be screen time, indicating that every 1-hour of screen time increased the amount of BMI by 1.14 units. Exercise had a large negative prediction error (**β**= -.27, p =. 001) which is indicative of the protective influence of increased activity; one minute of more activity decreased the BMI by 0.6 units. BMI was also greatly determined by fast-food (**β** =.23, p =.003), which goes to show that it plays a big part in the unhealthy accumulation of weight.

A mediation analysis was conducted to determine whether obesity mediated the relationship between lifestyle behaviors (screen time, physical activity) and metabolic syndrome.

Table 3: Mediation Analysis: BMI as Mediator between Lifestyle and Metabolic Risk

Path	Effect Size	SE	p
Screen Time → BMI	1.14	0.21	0.001*
BMI → MetS Score	0.28	0.07	0.001*
Indirect Effect (Screen Time → MetS via BMI)	0.319	0.08	0.001*
Physical Activity → BMI	–0.06	0.02	0.001*
Indirect Effect (Physical Activity → MetS via BMI)	–0.017	0.007	0.014*

* indicates statistical significance at $p \leq 0.05$

Table 3 illustrates mediation data in order to establish whether there was a mechanism through BMI between the lifestyle behaviors and the risk of metabolic syndrome. The screen time vs. BMI (B = 1.14, p =.001) and vs. MetS score (B =.28, p =. 001) also have significant path. Partially, mediation was validated when the indirect effect of screen time on MetS through BMI (0.319, p =.001) indicated that screen time raised the risk of metabolic syndrome both directly and indirectly through the heightening of the risk of obesity. Likewise, physical activity also had a great impact on BMI (B = -0.06, p =.001) and the indirect influence of physical activity on MetS through BMI (-0.017, p =.014) was a partial mediation.

DISCUSSION

The present research confirms considerable correlations between lifestyle behaviors and obesity and cardiometabolic risk in Pakistani school-aged children. The positive association of BMI with screen time, fasting glucose, and triglycerides, and the negative association of physical activity with these metabolic parameters, are similar to recent cross-sectional studies in Lahore, Karachi, Islamabad, and Peshawar, Pakistan [7, 17]. These studies have shown that children with greater recreational screen time and insufficient physical activity are at higher risk of overweight or obesity and poor lipid and glucose profiles. The nutrition transition in Pakistan is rapid and is marked by increased intake of energy-dense processed foods, sugar-sweetened beverages, and fast foods, along with reduced physical activity and a sedentary lifestyle. These environmental and lifestyle changes have been considered significant factors in the rise of metabolic dysfunction in childhood obesity [18].

Regression analysis revealed that screen time, physical inactivity, and frequent fast-food consumption were significant predictors of BMI. This is also supported by recent Pakistani studies showing the importance of unhealthy lifestyle behaviors in childhood overweight and obesity [19]. Studies have also shown that too much screen time and fast-food consumption are independently associated with increased BMI and central obesity among school-going children in Punjab and Sindh [20].

The mediation analysis also showed that the association between lifestyle behaviors and metabolic risk was partially mediated by BMI, suggesting that excess adiposity could be one pathway through which cardiometabolic risk is increased by lifestyle behaviors. This finding is in line with Pakistani studies reporting a relationship between obesity and insulin resistance, dyslipidemia, low-grade chronic inflammation, and impaired glucose regulation in children and adolescents [21].

Additionally, there is a known predisposition in South Asian populations to developing central adiposity and insulin resistance at relatively lower BMI levels, especially children of Pakistani origin [22]. The findings highlight the importance of implementing school-based health promotion programs, conducting regular obesity and cardiometabolic screening, and enacting public health policies to facilitate dietary changes in the Pakistani population, increase physical activity, and decrease recreational screen time among children.

Limitations: This cross-sectional study can't conclude causality and conducted in a restricted geographic area; the results may not be generalizable. Recall and reporting bias could also apply to self-reported lifestyle behaviors.

Future Perspectives: Multicenter longitudinal studies are needed in the future using various Pakistani population groups to assess dietary patterns, socio-economic factors, genetic susceptibility and interventions to understand and prevent childhood obesity and cardiometabolic risk.

CONCLUSION

The results of the research show that childhood metabolic danger is a result of a complicated association among behavioral, physiological and family factors. High levels of screen time, low levels of physical activity, and high intake of fast-food were also strong predictors of high BMI, whereas BMI also served as a powerful predictor of metabolic syndrome along with the family history of diabetes. A further observation that the patterns of correlation made was that there was a cluster of unhealthy lifestyle behaviors with poor metabolic indicators, the early signs of cardio metabolic dysfunction. The mediation analysis established that BMI partially mediated the impacts of

lifestyle behaviors on metabolic risk with a predominant role of adiposity towards which the behavioral exposures had the capacity to influence metabolic health.

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