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Prevalence of Impaired Fasting Glucose (IFG) and Associated Prediabetes Metabolic Markers Among Adolescents in Saudi Arabia

Haifa Alfaraidi[1,2,3] | Amir Babiker[1,2,3] | Fahad Al Juraibah[1,2,3] | Waleed Tamimi[1,4] | Mohammed Al Dubayee[1,3,5] | Motasim Badri[3,6] | Ibrahim Al Alwan[1,2,3]

[1]College of Medicine, King Saud Bin Abdulaziz University for Health Sciences, National Guard Health Affairs, Riyadh, Saudi Arabia | [2]Division of Pediatric Endocrinology, King Abdullah Specialized Children Hospital, National Guard Health Affairs, Riyadh, Saudi Arabia | [3]Research Office, King Abdullah International Medical Research Centre, National Guard Health Affairs, Riyadh, Saudi Arabia | [4]Department of Pathology and Laboratory Medicine, King Abdulaziz Medical City, National Guard Health Affairs, Riyadh, Saudi Arabia | [5]Division of Pediatric Endocrinology, King Abdullah Children Hospital, National Guard Health Affairs, Al Qassim, Saudi Arabia | [6]College of Public Health and Health Informatics, King Saud bin Abdulaziz University for Health Sciences, National Guard Health Affairs, Riyadh, Saudi Arabia

Correspondence: Ibrahim Al Alwan (profialalwan@gmail.com)

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ABSTRACT

Background: Type 2 diabetes (T2D) is a growing health concern among adolescents, driven by rising obesity rates. Early identification of prediabetes, particularly impaired fasting glucose (IFG), can guide interventions to reduce long-term risks. Despite the global burden of diabetes, limited data exist on Saudi adolescents, a population experiencing high rates of obesity.

Objective: To determine the prevalence and associated factors for IFG in a representative sample of Saudi adolescents.

Methods: We conducted a cross-sectional analysis on a subgroup of participants from the national Jeeluna study (2011–2012), which sampled adolescents aged 10–19 years from all 13 regions of Saudi Arabia. Anthropometric measurements, fasting plasma glucose levels, and lifestyle data were collected. Dysglycemia (IFG or diabetes) was defined using American Diabetes Association (ADA) criteria. A logistic regression analysis was conducted to identify factors associated with dysglycemia.

Results: The study included 5,421 participants (50.8% females; mean ± SD age was 15.9 ± 1.8 years). Prevalence of dysglycemia was 4.8% (IFG: 4.1%; diabetes: 0.7%). Dysglycemia was more prevalent in obese adolescents (8.2%) compared to overweight (4.8%) and nonobese/nonoverweight peers (4.1%), $p < 0.0001$. Regional differences were noted with the highest prevalence in Mecca (6.1%). Compared with nondysglycemic patients, those who were dysglycemic had higher proportion of individuals consuming fast food meals per week ($p = 0.03$), body mass index (BMI) ($p < 0.0001$), tri-ponderal mass (TMI) ($p < 0.001$), waist-to-height ratio ($p = 0.001$) and systolic BP ($p < 0.001$) and lower triglycerides ($p < 0.0001$). Factors independently associated with dysglycemia included systolic BP (OR = 1.03; 95% CI 1.01–1.04, $p < 0.0001$), triglyceride levels (OR = 1.60; 95% CI 1.27–2.00, $p < 0.0001$) and geographical region (Mecca OR = 1.54, 95% CI 1.07–196, Riyadh OR = 0.61,95% CI 0.42–0.89, $p < 0.001$, compared with other regions combinedly).

Conclusion: Our study highlights the prevalence of dysglycemia (4.8%) among Saudi adolescents, particularly in those with obesity. Risk factors included higher BMI and increased fast food consumption. Notably, regional differences were observed, with Mecca reporting the highest prevalence. Our findings underscore the need for targeted interventions in obesity, focusing on promoting healthy lifestyles and early screening for T2D in this vulnerable population.

1 | Introduction

Type 2 diabetes (T2D) is a growing health concern worldwide with obesity, increased adiposity, and insulin resistance playing an important role in its development [1]. While T2D was previously considered a disease of adulthood, increasing rates of T2D are occurring in older children and adolescents, paralleling the rise of obesity rates in this population [2–4]. Increased adiposity, especially central adiposity, leads to insulin resistance with ensuing hyperinsulinism to maintain normoglycemia [1, 5, 6]. However, with persistent or worsening insulin resistance associated with b-cell dysfunction, dysglycemia or impaired glucose tolerance develops over time with the risk of further progression to diabetes [7–10].

Therefore, current guidelines suggest screening overweight or obese children for prediabetes or T2D every 3 years using fasting glucose levels, hemoglobin A1c or an oral glucose tolerance test [11–13]. This allows for early identification and intervention to mitigate the detrimental effects of abnormal glucose metabolism, hyperinsulinism and insulin resistance. Measuring fasting glucose levels is an easy and simple test, it requires one blood sample, and has a higher reproducibility compared to the oral glucose tolerance test [14]. Evaluating for impaired fasting glucose (IFG) by measuring a fasting plasma glucose level may help in identifying adolescents with insulin resistance [15].

Saudi Arabia, like many other countries, suffers from high rates of overweight and obesity in its population, with more than 50% of the population being either overweight or obese [16]. According to the World Health Survey conducted in 2019 by the Saudi Ministry of Health, the prevalence of overweight was 38% and the prevalence of obesity was 20% [17]. Additionally, Saudi Arabia is among the top five countries in the Middle East and North Africa region with regards to the prevalence of diabetes, with a prevalence of 18.7% [18]. The Saudi population is mainly composed of young adults with a median population age of 30 years, and adolescents constitute a significant proportion of the Saudi population [19]. Studies that have evaluated the prevalence of overweight and obesity among Saudi children and adolescents have reported prevalence rates that range between 20% and 30% [20–22]. In view of the high rates of overweight and obesity, evaluating the prevalence of pre-diabetes in Saudi adolescents is essential to understand their risks and needs.

Jeeluna study was a national cross-sectional population-based study conducted during 2011 and 2012 that focused on Saudi adolescent needs and health status [23]. Enrolled participants from the Jeeluna cohort were from all 13 regions of Saudi Arabia, therefore, this cohort adequately represents the Saudi adolescent population at the time of the study. As part of the Jeeluna study, participants who consented to having a blood sample drawn, were tested for metabolic markers including fasting plasma glucose levels [23].

The aim of the current study is to determine the prevalence of IFG in a subgroup of Jeeluna participants who had fasting plasma glucose levels available. Additionally, we evaluate the association of several risk factors and lifestyle habits with the occurrence of IFG. The tri-ponderal mass index (TMI) has recently emerged as an anthropometric measure to estimate adiposity in children and adolescents [24, 25]. TMI is calculated as weight divided by height cubed and may offer a better reflection of adiposity in the growing child, compared to the body mass index (BMI). TMI correlates well with total adiposity measured by dual-energy X-ray absorptiometry scans in older children and adolescents [24, 25], and correlates well with waist-to-height ratio, a surrogate marker of visceral adiposity [26, 27]. Given the emerging role of TMI as a surrogate marker of adiposity in the pediatric population, we included it among the risk factors that we evaluated, in order to determine its association with IFG, in addition the other traditional anthropometric markers such as BMI and waist-to-height ratio.

We believe that understanding the prevalence of IFG and its associated risk factors will allow early identification and intervention in Saudi adolescents with an increased risk of developing pre-diabetes.

2 | Materials and Methods

Our study includes a subgroup of adolescents that participated in the national Jeeluna study, that was conducted during the years 2011 and 2012. Jeeluna was a population-based field study, that included adolescents between the ages of 10 to 19 years who attended intermediate and secondary schools from Saudi Arabia's 13 geographical regions. Its aim was to assess the needs of Saudi adolescents, with a holistic focus on health and its biopsychosocial factors.

2.1 | Study Design

Jeeluna is a cross-sectional study that employed a multi-stage, stratified, cluster random sampling to recruit adolescents; the sampling technique commensurates with student population per region and district, gender, and grade level. The detailed methodology of the Jeeluna study has been published previously [23, 28]. The Saudi Ministry of Health provided a comprehensive list of all schools, both public and private, which was used as a sampling frame. A computer-based random sampling technique was used to select schools and classes within the schools at random. Written informed consent was obtained from students and their parents with an opt-out option for drawing blood. The procedures of the study were all in line with the standards of the Helsinki Declaration. Approval was obtained from the Institutional Review Board and the Ethics Committee at the King Abdullah International Medical Research Center (KAIMRC), ethics approval number (RC08-092).

2.2 | Study Population

We included Saudi participants of Jeeluna who had a fasting serum glucose result available, aged 10 years and above and still enrolled in the school system. We excluded those who self-reported having diabetes or any other chronic disease. We also excluded participants with missing height or weight values.

2.3 | Data Collection

The main data components collected for the Jeeluna study comprised anthropometric measurements, self-administered questionnaires encompassing various domains, and blood samples for those who consented for different laboratory measures.

Detailed information regarding the collected data variables have been previously published [23, 28].

2.4 | Demographics and Baseline Characteristics

Data regarding demographics, psycho-social factors, dietary habits, physical activity, screen use, sleeping habits, and smoking were captured by a self-administered questionnaire.

2.5 | Anthropometric Measurements

Weight was measured using an electronic scale (OmronSC100 digital scale, USA). Weight values were rounded to the nearest tenth of a kilogram and height values were rounded to the nearest 0.5 cm. The BMI was calculated using by dividing the weight in kilograms by the square of the height measured in meters. BMI was then classified based on the Center for Disease Control and Prevention (CDC) BMI charts for each gender [29, 30]. Participants were classified into 3 groups: underweight/normal if their BMI was less than the 85th percentile for age and gender, overweight if their BMI was between the 85th and 95th percentile, and obese if their BMI was above the 95th percentile.

The TMI, which has been described as a marker of adiposity in adolescents [25], was calculated by dividing the weight in kilograms by the height cubed measured in meters.

Waist-to-height ratio was calculated by dividing the waist circumference in centimeters by the height measured in centimeters. A waist-to-height ratio of less than 0.5 was considered as normal, while a ratio of 0.5 or greater was considered abnormal and taken to reflect central adiposity [31, 32].

2.6 | Blood Pressure (BP)

An electronic BP measuring device was used (Omrin M2, Netherlands). Two BP readings were taken on the upper right arm, a few minutes apart. The average systolic and diastolic BP were captured.

2.7 | Laboratory Investigations

Participants who consented to blood samples had two samples drawn. Samples were cooled and transported to the main hospital laboratory. Serum gel separator tubes were used for chemistry tests. They were left for an hour for a clot to form then underwent centrifugation for 10–15 min at 3000 rounds/min in order to extract the serum. An automated chemistry analyzer (Architect c16000; Abbott, USA) performed the chemistry tests.

2.8 | Definitions of Glycemia

Based on the American Diabetes Association (ADA), IFG is defined as a fasting glucose level of 5.6 to 6.9 mmol/L [33]. According to guidance from the World Health Organization (WHO), IFG is defined as a fasting glucose level between 6.1 and 6.9 mmol/L [34]. Both ADA and WHO classify a fasting plasma glucose level of 7 mmol/L as diagnostic for diabetes mellitus [33, 34]. We defined dysglycemia as adolescents with either IFG or fasting plasma glucose levels in the diabetes range. We elected to implement the ADA criteria for the purpose of our study, as they have a higher sensitivity for detecting IFG compared to the WHO criteria, therefore allowing for earlier pick-up and intervention. The use of the term dysglycemia will refer to participants with IFG or fasting glucose levels in the diabetes range, based on the ADA criteria, unless otherwise specified.

2.9 | Statistical Analysis

Continuous variables were initially tested for normality using the Shapiro–Wilks test and were accordingly expressed as means (SD) or medians (IQR) and compared using the *t*-test or non-para-metric Mann–Whitney test. Categorical variables were expressed as frequencies (%) and compared using the $\chi 2$ test. Data were considered for imputation if their missing data were 20% or less. However, none of the included factors had more than 3% missing data. We conducted a binary logistic regression analysis to identify factors associated with dysglycemia using the Complex Sample module of the IBM SPSS software (Version 28, IBM Corp, NY, USA) to adjust for complex sampling design. The final multivariate model included significant factors found in the univariate analysis. All tests were two-sided and a p-value $\leq$ 0.05 was considered statistically significant.

3 | Results

3.1 | Baseline Characteristics of Study Participants

A total of 5421 participants were included in this study, out of which 2753 participants (50.80%) were females. The mean age of participants was 15.9 ($\pm$1.8) years, with a median of 16 years (interquartile range 14 to 17 years). Most participants were between the ages of 14 and 17 years ($n = 3646$, 67.30%), with 621 (11.50%) participants aged 10 to 13 years and 1154 (21.30%) participants older than 18 years. Most of the participants were from the Riyadh region, followed by the Mecca region. With regards to BMI, there were 772 (14.20%) participants in the overweight category and 834 (15.40%) participants in the obese category (Table 1).

3.2 | Prevalence of Dysglycemia Among the Study Cohort

The prevalence of fasting glucose levels in the diabetes range among all participants of the cohort was 0.7% ($n = 38$). The prevalence of IFG was variable based on the diagnostic criteria used. When applying the ADA diagnostic criteria, the prevalence of IFG was 4.1% (224/5421), compared to 0.9% (51/5421) when using the WHO diagnostic criteria (Table 2). The overall prevalence of dysglycemia based on the ADA criteria was 4.8% (262/5421).

With regards to the prevalence of dysglycemia by region, Mecca region had the highest prevalence (82/1340, 6.10%), followed by Riyadh region (61/1546, 4.0%). The prevalence of dysglycemia by gender was slightly higher in males (134/2668, 5.0%) compared to females (128/2753, 4.6%). The prevalence of dysglycemia was higher in participants with obesity (68/834, 8.2%). (Table 3)

Based on BMI category (nonobese/nonoverweight, overweight, obese), the prevalence of IFG was 4.1%, 4.8%, and 8.2%,

TABLE 1 | Baseline characteristics of study participants.

Characteristics	*N* (%)
Age (years)	
10–13	621 (11.5)
14–17	3646 (67.3)
18 or older	1154 (21.3)
Gender	
Female	2753 (50.8)
Male	2668 (49.2)
BMI category	
Nonobese, nonoverweight	3811 (70.3)
Overweight	772 (14.2)
Obese	834 (15.4)
Waist-to-height ratio	
<0.5	3764 (69.9)
>0.5	1621 (30.1)
Region	
Riyadh region	1546 (28.5)
Mecca region	1340 (24.7)
Other regions	2539 (46.9)

Note: N, Number of dysglycemia cases.

TABLE 2 | Distribution of adolescents glycemia status based on ADA and WHO diagnostic criteria.

Classification	ADA *N* (%)	WHO *N* (%)
Normal	5159 (95.2)	5332 (98.4)
Impaired fasting glucose	224 (4.1)	51 (0.9)
Diabetes	38 (0.7)	38 (0.7)
Total	5421(100)	5421 (100)

Note: N, Number of dysglycemia cases.
Abbreviations: ADA, American Diabetes Association; WHO, World Health Organization.

TABLE 3 | Prevalence of dysglycemia by sociodemographic and anthropometric characteristics.

Characteristic	Sample size *N*	Prevalence *N* (%)
Age category, years		
10–13 years	621	36 (5.8)
14–17 years	3646	174 (4.8)
≥18 years	1154	52 (4.5)
Gender		
Female	2753	128 (4.6)
Male	2668	134 (5.0)
BMI Category		
Nonobese, nonoverweight	3811	157 (4.1)
Overweight	772	37 (4.8)
Obese	834	68 (8.2)
Waist-to-height ratio		
<0.5	167 (4.4%)	3764
>0.5	95 (5.9%)	1621
Region		
Riyadh region	1546	61 (4.0)
Mecca region	1340	82 (6.1)
Other regions	2539	119 (4.7)

Note: *N*, Number of dysglycemia cases.

respectively. (Table 3) When combining both overweight and obese groups, the prevalence of IFG was 6.5% (105/1606).

3.3 | Characteristics of Adolescents With Dysglycemia Compared to Those Without Dysglycemia

Table 4 describes the characteristics of adolescents with dysglycemia compared to adolescents with normal fasting glucose. These include baseline characteristics, psychosocial factors such as parents' level of education, relationship with parents, and academic performance, in addition to dietary habits, sleeping habits, and physical activity.

Table 5 compares both groups of adolescents with regards to anthropometric measures such as BMI and TMI, and with regards to components of the metabolic syndrome such as abdominal obesity as reflected by waist-to-height ratio, BP, and lipid profile.

3.4 | Multivariate Analysis for Factors Associated With Dysglycemia

The univariate logistic analysis for factors associated with dysglycemia, diagnosed based on the ADA criteria, demonstrated a significant association between anthropometric measures and dysglycemia. There was a 3%–4% increased likelihood of dysglycemia with increasing BMI and TMI values, and more than 6 folds with increasing waist-to-height ratio. However, these associations were no longer statistically significant in the multivariate model. We ran the multivariate logistic regression analysis with BMI, TMI, and waist-to-height ratio as categorical variables instead of continuous variables with similar results.

We then performed the multivariate logistic regression analysis with dysglycemia, defined as per WHO diagnostic criteria, as the dependent variable. There was a statistically significant increased likelihood of dysglycemia with increasing BMI. However, the association between TMI and waist-to-height ratio with dysglycemia was not statistically significant.

TABLE 4 | Characteristics of adolescents with dysglycemia compared to those without dysglycemia (categorical variables).

Characteristics	Dysglycemia *N* (%)	No dysglycemia *N* (%)	*p*
Age category, years			
10–13	36 (13.7)	585 (11.3)	0.460
14–17	174 (66.4)	3472 (67.3)	
≥ 18	52 (19.8)	1102 (21.4)	
Gender			
Female	128 (48.9)	2625 (50.9)	0.730
Male	134 (51.1)	2534 (49.0)	
BMI category			
Nonobese, nonoverweight	157 (59.9)	3654 (70.9)	< 0.0001
Overweight	37 (14.1)	735 (14.3)	
Obese	68 (26.0)	766 (14.9)	
Waist-to-height ratio			
<0.5	167 (63.7)	3597 (70.2)	0.026
>0.5	95 (36.3)	1526 (29.8)	
Region			
Riyadh	61 (23.3)	1485 (28.7)	0.023
Mecca	82 (31.3)	1258 (24.4)	
Other	119 (45.4)	2420 (46.9)	
Psychosocial factors			
Education level of father			
Illiterate	19 (7.3)	323 (6.4)	0.400
Elementary to secondary school education	142 (54. 8%)	2645 (52.7)	
Tertiary	64 (24.7)	1473 (29.4)	
Unknown	34 (13.1)	574 (11.4)	
Education level of mother			
Illiterate	26 (10.0)	768 (15.3)	0.135
Elementary to secondary school education	146 (56.4)	2724 (54.3)	
Tertiary	65 (25.1)	1128 (22.5)	
Unknown	22 (8.5)	401 (8.0)	
Monthly income			
Low	66 (25.6)	1238 (24.8)	0.453
Average	40 (15.5)	650 (13.0)	
High	48 (18.6)	862 (17.3)	
Unknown	104 (40.3)	2242 (44.9)	
Relationship with father			
Good	226 (88.6)	5148 (83.8)	0.042
Not good	29 (11.4)	801 (16.2)	
Relationship with mother			
Good	245 (95.7)	4619 (92.6)	0.061

(Continues)

TABLE 4 | (Continued)

Characteristics	Dysglycemia *N* (%)	No dysglycemia *N* (%)	*p*
Not good	11 (4.3%)	370 (7.4%)	
Academic performance			
Good to excellent	239 (92.6)	4678 (93.2)	0.182
Not good	11 (4.3)	261 (5.2)	
Unknown	8 (3.1)	83 (1.7)	
Dietary habits			
Eating breakfast			
Yes	193 (74.2)	3743 (74.2)	0.985
No	67 (25.8)	1303 (25.8)	
Main meals per day			
No main meal	7 (2.7)	167 (3.3)	0.815
1–2	109 (41.9)	2047 (40.7)	
≥ 3	144 (55.4)	2821 (56.0)	
Snacks per day			
No snack	21 (8.0)	421 (8.4)	0.726
1–2	182 (69.7)	3405 (67.6)	
≥3	58 (22.2)	1208 (24.0)	
Fruits per day			
Not daily	158 (60.8)	3258 (64.5)	0.434
1–2	75 (28.8)	1286 (25.5)	
≥3	27 (10.4)	508 (10.1)	
Vegetables per day			
Not daily	119 (45.6%)	2330 (46.1)	0.844
1–2	124 (47.5%)	2333 (46.2)	
≥3	18 (6.9%)	391 (7.7)	
Carbonated beverages per day			
Once or more per day	173 (66.3)	3064 (60.7)	0.070
No or not daily	88 (33.7)	1986 (39.3)	
Energy drinks per day			
Once or more day	62 (23.8)	1113 (22.1)	0.524
No or not daily	199 (76.2)	3929 (77.9)	
Milk consumption per day			
Once or more per day	122 (47.1)	2213 (44.1)	0.350
No or not daily	137 (52.9)	2800 (55.9)	
Fast food meals days per week			
None	68 (26.4)	1043 (20.8)	0.034
1–2	102 (39.5)	2353 (47.0)	
≥3	88 (34.1)	1610 (32.2)	
Currently on a diet for weight loss			
Yes	42 (16.3)	718 (14.5)	0.428

(Continues)

TABLE 4 | (Continued)

Characteristics	Dysglycemia *N* (%)	No dysglycemia *N* (%)	*p*
No	216 (83.7)	4236 (85.5)	
Previously on a diet for weight loss			
Yes	79 (30.5)	1246 (25.1)	0.054
No	180 (69.5)	3709 (74.9)	
Activities			
Days of exercising 30 min or more during the previous week			
None	118 (45.4)	2303 (46.0)	0.738
1–2	75 (28.8)	1342 (26.8)	
≥3	67 (25.8)	1365 (27.2)	
Physical activity at school			
Yes	80 (41.0)	1702 (43.5)	0.501
No	115 (59.0)	2213 (56.5)	
Daily hours spent watching TV			
<1	102 (39.2)	1623 (32.4)	0.022
≥1	158 (60.8)	3390 (67.6)	
Daily hours spent playing video games			
<1	189 (72.4)	3853 (76.4)	0.140
≥1	72 (27.6)	1190 (23.6)	
Sleeping habits			
Weeknight sleep hours			
<8	148 (57.8)	2899 (58.1)	0.937
≥8	108 (42.2)	2094 (41.9)	
Weekend sleep hours			
<8	110 (43.5)	2088 (41.7)	0.580
≥8	143 (56.5)	2917 (58.3)	
Afternoon nap days per week			
≤2	108 (42.4)	1976 (39.5)	0.359
≥3 days or more	147 (57.6)	3030 (60.0)	
Smoking			
Yes	51 (19.7)	885 (17.6)	0.391
No	208 (80.3)	4142 (82.4)	

Note: N, Number of dysglycemia cases.
Abbreviation: BMI, body mass index.

Of note, we calculated the variance inflation factor and correlation matrix to investigate the multicollinearity of BMI, TMI and waist-to-height ratio. None of these tests were statistically significant.

In the multivariate logistic regression analysis model, factors independently associated with dysglycemia included systolic BP [odds ratio (OR) = 1.03; 95%CI 1.01–1.04, $p < 0.0001$], triglyceride levels (OR = 1.60; 95%CI 1.27–2.00, $p < 0.0001$), and geographical region (Mecca OR = 1.54, 95%CI 1.07–196, Riyadh OR = 0.61,95%CI 0.42–0.89, $p < 0.001$, compared with other regions combinedly) (Table 6).

4 | Discussion

Based on the results of this subgroup analysis of 5421 adolescents of the Jeeluna cohort, the prevalence of abnormal glucose metabolism in Saudi adolescents was 4.8%; 4.1% had fasting plasma glucose levels falling within the IFG category and 0.7% had fasting plasma glucose levels within the diabetes range. The prevalence of dysglycemia was similar in both genders, and as expected, dysglycemia was most prevalent among obese adolescents (8.2%). Systolic BP and triglyceride levels were both associated with dysglycemia.

TABLE 5 | Characteristics of adolescents with dysglycemia compared to those without dysglycemia (continuous variables).

Characteristics	Dysglycemia Median (IQR)	No dysglycemia Median (IQR)	*p*
Age (years)	16.00 (14.00–17.00)	16.00 (14.00–17.00)	0.281
BMI (kg/m^2)	22.62 (18.66–27.80)	21.34 (18.44–25.32)	< 0.0001
TMI (kg/m^3)	14.2 (11.8–17.6)	13.4 (11.6–15.9)	< 0.0001
Waist-to-height ratio	0.46 (0.41–0.54)	0.45 (0.40–0.51)	0.001
Systolic BP (mmHg)	124 (116–132)	120 (112–128)	< 0.0001
Diastolic BP (mmHg)	70 (64–76)	69 (63–76)	0.352
LDL-C (mmol/L)	2.38 (1.99–2.77)	2.41 (2.04–2.83)	0.845
HDL-C (mmol/L)	1.25 (1.08–1.44)	1.27 (1.11–1.47)	0.282
Triglycerides (mmol/L)	0.82 (0.62–1.26)	0.77 (0.60–1.03)	< 0.0001

Abbreviations: BMI, body mass index; BP, blood pressure; HDL-C, high-density lipoprotein; IQR, interquartile range; LDL-C, low-density lipoprotein; SD, standard deviation; TMI, tri-ponderal mass index.

TABLE 6 | Univariate and multivariate logistic regression analysis for factors associated with dysglycemia.

Factor	Univariate analysis OR (95% CI)	*p*-Value	Multivariate analysis OR (95% CI)	*p*-Value
BMI	1.03 (1.02–1.05)	< 0.0001	0.99 (0.93–1.08)	0.981
TMI	1.04 (1.01–1.06)	0.002	1.02 (0.91–1.13)	0.821
Waist-to-height ratio	6.25 (1.89–20.62)	0.003	1.38 (0.31–6.11)	0.671
Systolic blood pressure	1.03 (1.02–1.04)	< 0.0001	1.03 (1.01–1.04)	< 0.0001
Triglyceride (mmol/L)	1.77 (1.46–2.16)	< 0.0001	1.60 (1.27–2.00)	< 0.0001
Geographical region	—	0.024	—	0.001
Mecca	1.33 (0.99–1.77)	—	1.45 (1.07–1.96)	—
Riyadh	0.84 (0.61–1.15)	—	0.61 (0.42–0.89)	—
Other	1	—	1	—

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio; TMI, tri-ponderal mass index.

The prevalence of dysglycemia was the highest among adolescents from Mecca region, followed by Riyadh region. Both Mecca and Riyadh regions are among the most populated regions in Saudi Arabia. Additionally, Mecca, Jeddah, and Riyadh, Saudi Arabia's largest cities, are in these two regions. The higher prevalence observed in these areas may be attributed to greater urbanization, which is often associated with more sedentary lifestyles and unhealthy dietary habits. Factors such as high traffic congestion, reduced walkability, limited opportunities for physical activity, and easier access to fast food may contribute to the elevated rates of glucose dysregulation among adolescents living in these regions. Furthermore, the Mecca region is characterized by a diverse mix of ethnicities and racial backgrounds, which may contribute to varying genetic predispositions to insulin resistance and glucose dysregulation.

The prevalence of prediabetes in adolescents and young adults reported in different studies is variable, depending on the parameter used for the diagnosis of prediabetes such as fasting glucose level, oral glucose tolerance test or HbA1c level. With regards to

abnormal glucose metabolism based on fasting plasma glucose levels specifically, the prevalence of IFG in our study is slightly lower than the prevalence of IFG in Saudi children and adolescents reported by Alrubeaan (4.1% vs 6.1%) [35]. The study conducted by Alrubeaan was a population-based study that included children and adolescents from across the 13 regions of Saudi Arabia between the years 2007 and 2009 [35]. Based on data from the National Health and Nutrition Examination Survey that assessed 2606 adolescents in the United States between the years 2005 and 2016, the prevalence of IFG in this population was much higher, affecting 11.1% [36]. The reported prevalence of IFG in other studies was variable, with a prevalence of up to 19% in a small study involving 192 aboriginal youth [37]. Interestingly, a population-based cross-sectional study that involved Chinese children and adolescents reported an overall prevalence of 2.6% for IFG, but the prevalence of IFG differed between ethnic groups [38]. The prevalence of IFG was the lowest in in Kazakhs at 0.6%, despite having the highest prevalence of overweight/obesity at 40.8% [38]. The prevalence of IFG in the other two ethnic groups, the Hans and the Uyghurs, were 4.6% and 3.3%, respectively, with overweight/obesity prevalence of 17.7% in the Hans and 7.1% in the Uyghurs [38]. These results suggest that ethnicity plays a significant role in insulin resistance and in the predisposition to develop T2D.

When determining the prevalence of dysglycemia in overweight/obese adolescents, we found that the prevalence of dysglycemia was 6.5% in this group, with a prevalence of 8.2% in the obese group and 4.8% in the overweight group. Several studies have focused on the prevalence of IFG in the higher-risk adolescents with overweight/obesity, with the reported prevalence of IFG ranging from 3.2% to 6.9% [39–41]. In our study, dysglycemia was associated with higher systolic BP readings and higher triglyceride levels, both components of the metabolic syndrome with insulin resistance as a common underlying contributing factor. Similarly, IFG was associated with higher systolic BP and higher triglycerides in a cross-sectional study that included 2150 Danish children and adolescents, where the prevalence of IFG was 14.1% in overweight/obese participants and 4.3% in those with normal weight [42].

Interestingly, anthropometric indices, which included BMI, TMI, and waist-to-height ratio, lost significance in multivariate models. This finding may be explained by the influence of potential confounders and by methodological factors. These indices are highly interrelated and may exhibit multicollinearity, leading to attenuation of their individual effects when entered simultaneously into the model. However, this explanation is less likely since test of collinearity were not statistically significant. Other metabolic and lifestyle variable, such as physical activity level, dietary habits, and socioeconomic factors, may partially mediate or confound the relationship between adiposity and dysglycemia. It is also possible that the inclusion of overlapping measures of body composition reduced the independent explanatory power of each anthropometric index in predicting glucose dysregulation.

The prevalence of IFG in this subgroup of Saudi adolescents varied based on the fasting plasma glucose cut-off level applied, with a prevalence of 4.1% when applying ADA criteria and 0.9% when applying WHO criteria. This variation in prevalence of IFG is expected, as the fasting plasma glucose cut-off level used by the WHO is higher than that used by the ADA. A cross-sectional, nationwide registry study that included 32,907 and 2726 obese children and adolescents from Germany and Sweden, respectively, reported the prevalence of IFG according to ADA and WHO criteria [43]. The prevalence of IFG in the German cohort was 5.7% based on ADA criteria and 1.1% based on WHO criteria [43]. In the Swedish cohort, the prevalence of IFG was 17.1% and 3.9%, according to ADA and WHO criteria, respectively [43].

The prevalence of IFG in a population may vary over time. The Tehran Lipid and Glucose Study, a population-based study, reported the prevalence of IFG between the years 1999 and 2005, and the years 2011 and 2014 at 7% and 16.6%, respectively, [44]. This increase was accompanied by an increase in the prevalence of both central and general obesity [44]. Data from the Korean National Health and Nutrition Examination Study also demonstrated an increase in IFG prevalence among adolescents [45]. The prevalence of IFG was 5.39% during the years 2007 through 2009 and increased to 11.66% during the years 2016 through 2018 [45]. Furthermore, in a cohort of 3980 middle school students, IFG persisted or progressed to T2D in almost half of the children with initial IFG over a 2-year follow up period [46]. Moreover, adolescents with higher fasting plasma glucose levels may be at higher risk of developing T2D as adults [47, 48]. Therefore, understanding the burden of IFG in an adolescent population and monitoring its progression over time is of paramount importance. The prevalence of IFG in the adolescent population is an important factor to consider when designing policies and allocating resources. Adolescent population data should guide policymakers to develop strategies and programs that will enhance adolescent health and well-being, by promoting healthy dietary choices, encouraging physical activity, and limiting easy access to calorie-dense foods and beverages and those with high sugar content.

The major strength of our study is that it reports findings from a representative sample of Saudi adolescents from all 13 regions of the country. Participants from the Jeeluna cohort were selected based on computer-generated random sampling in a multi-stage, stratified, and cluster sampling manner, to ensure adequate representation of the Saudi adolescent population. The student population per district, region, and grade level were all considered. Additionally, students from both public and private schools were included. Moreover, this sub analysis included a large sample size, consisting of more than 5400 adolescents. Over the last decade, there has been a deterioration in healthy lifestyle habits. Sedentary behavior and screen time have increased with the widespread use of smartphones and social media. Easy access to highly dense caloric food has also increased with the availability of delivery applications and services. Additionally, during the COVID-19 pandemic, there was an increased in the prevalence of overweight and obesity in children and adolescents, with increasing weight and BMI reported by various studies [49–51]. Moreover, the COVID-19 lockdowns may have led to the long-term adoption of unhealthy dietary habits [52]. The Jeeluna study was conducted during 2011 and 2012, prior to the application of the previously mentioned practices. This may be considered as both a strength, as our results reflect the rates of IFG during a time where adolescents were "healthier," and as a limitation, because the generalizability of our findings to adolescents of the post-pandemic era may be restricted. We suspect that the prevalence of IFG in our population may have increased over the last decade

secondary to the adoption of unhealthy lifestyle habits. Further studies are needed to assess the current prevalence and contributing factors of IFG among Saudi adolescents, considering the evolving lifestyle and environmental changes of the past decade.

Another limitation of our study lies within the limitations of fasting plasma glucose levels as a test. While fasting plasma glucose levels have reasonable agreement between visits [14], the concordance rate of IFG in children and adolescents is low when a fasting plasma glucose level is repeated [53]. Additionally, fasting plasma glucose correlates weakly with HbA1c levels and 2-h plasma glucose levels during an oral glucose tolerance test [54]. However, in youth with diabetes and clearly abnormal glucose metabolism, fasting plasma glucose has good repetitiveness and correlates well with HbA1c and with the 2-h post-prandial glucose [53–55]. Another caveat to using fasting plasma glucose is that it may miss adolescents with impaired glucose tolerance. Brar et al. [56] evaluated the ability of fasting plasma glucose, HbA1c levels and the combination of both to detect diabetes and prediabetes in a group of obese adolescents. The sensitivity of fasting plasma glucose to detect diabetes or prediabetes was 75% [56]. However, the combination of HbA1c and fasting plasma glucose improved sensitivity to 95.8% [56]. Further research is required to understand the best screening modality to apply for the identification of abnormal glucose metabolism in population-based screening of children and adolescents.

Our study's cross-sectional design limits the ability to establish causal relationships between lifestyle factors and IFG. While the findings highlight important associations, longitudinal studies are needed to track changes in glucose regulation over time and to identify predictors of progression from normal glucose levels to prediabetes and diabetes. Future epidemiological research should aim to capture the full spectrum of glucose dysregulation to better inform prevention and intervention strategies among Saudi adolescents.

5 | Conclusion

Our study highlights the prevalence of abnormal glucose metabolism in a large cohort of Saudi adolescents, which was 4.8%. Abnormal glucose metabolism was associated with systolic BP and triglyceride levels. IFG may be an early marker of insulin resistance, therefore, understanding the prevalence of IFG and identifying adolescents with IFG is essential to guide health policies and to develop appropriate health promotion programs among this population.

Author Contributions

Haifa Alfaraidi: methodology, data curation, writing – original draft, final draft: writing, reviewing & editing. **Amir Babiker:** data curation, resources, writing – original draft, contributed to writing and editing, final draft: writing, reviewing & editing. **Fahad Al Juraibah:** data curation, writing, reviewing & editing of the final draft. **Waleed Tamimi:** methodology, data curation, resources, interpretation of the results, final draft: reviewing & editing. **Mohammed Al Dubayee:** methodology, data curation, resources, final draft: reviewing & editing. **Motasim Badri:** methodology, formal analysis and interpretation of the results, writing – original draft, final draft: reviewing & editing. **Ibrahim Al Alwan:** conceived the idea, conceptualization, methodology, data curation, original draft: editing, final draft: contributed to writing, reviewing & editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. B. Valaiyapathi, B. Gower, and A. P. Ashraf, "Pathophysiology of Type 2 Diabetes in Children and Adolescents," *Current Diabetes Reviews* 16, no. 3 (2020): 220–229.

2. A. Abbasi, D. Juszczyk, C. H. M. van Jaarsveld, and M. C. Gulliford, "Body Mass Index and Incident Type 1 and Type 2 Diabetes in Children and Young Adults: A Retrospective Cohort Study," *Journal of the Endocrine Society* 1, no. 5 (2017): 524–537.

3. T. P. Candler, O. Mahmoud, R. M. Lynn, A. A. Majbar, T. G. Barrett, and J. P. H. Shield, "Continuing Rise of Type 2 Diabetes Incidence in Children and Young People in the UK," *Diabetic Medicine* 35, no. 6 (2018): 737–744.

4. E. Elizabeth, J. Mayer-Davis, D. Dabelea, et al., "Incidence Trends of Type 1 and Type 2 Diabetes Among Youths, 2002–2012," *New England Journal of Medicine* 376, no. 15 (2017): 1419–1429.

5. E. D'Adamo and S. Caprio, "Type 2 Diabetes in Youth: Epidemiology and Pathophysiology," *Diabetes Care* 34, no. 2 (2011): S161–S165.

6. S. K. Tanamas, S. P. Reddy, M. A. Chambers, et al., "Effect of Severe Obesity in Childhood and Adolescence on Risk of Type 2 Diabetes in Youth and Early Adulthood in an American Indian Population," *Pediatric Diabetes* 19, no. 4 (2018): 622–629.

7. L. Bervoets, A. Mewis, and G. Massa, "The Shape of the Plasma Glucose Curve during an Oral Glucose Tolerance Test as an Indicator of Beta Cell Function and Insulin Sensitivity in End-Pubertal Obese Girls," *Hormone and Metabolic Research* 47, no. 6 (2015): 445–451.

8. N. Gungor, F. Bacha, R. Saad, J. Janosky, and S. Arslanian, "Youth Type 2 Diabetes: Insulin Resistance, Beta-Cell Failure, or Both?" *Diabetes Care* 28, no. 3 (2005): 638–644.

9. J. Y. Kim, S. F. Michaliszyn, A. Nasr, et al., "The Shape of the Glucose Response Curve During an Oral Glucose Tolerance Test Heralds Biomarkers of Type 2 Diabetes Risk in Obese Youth," *Diabetes Care* 39, no. 8 (2016): 1431–1439.

10. G. Nolfe, M. R. Spreghini, R. W. Sforza, G. Morino, and M. Manco, "Beyond the Morphology of the Glucose Curve following an Oral Glucose Tolerance Test in Obese Youth," *European Journal of Endocrinology* 166, no. 1 (2012): 107–114.

11. American Diabetes Association Professional Practice Committee, "14. Children and Adolescents: Standards of Medical Care in Diabetes-2022." *American Diabetes Care* 45, no. Suppl 1 (2022): S208–S31.

12. C. Panagiotopoulos, S. Hadjiyannakis, and M. Henderson, "Type 2 Diabetes in Children and Adolescents," *Canadian Journal of Diabetes* 42 (2018): S247–S54.

13. A. S. Shah, P. S. Zeitler, J. Wong, et al., "ISPAD Clinical Practice Consensus Guidelines 2022: Type 2 Diabetes in Children and Adolescents," *Pediatric Diabetes* 23, no. 7 (2022): 872–902.

14. I. M. Libman, E. Barinas-Mitchell, A. Bartucci, R. Robertson, and S. Arslanian, "Reproducibility of the Oral Glucose Tolerance Test in Overweight Children," *The Journal of Clinical Endocrinology & Metabolism* 93, no. 11 (2008): 4231–4237.

15. P. Di Bonito, M. R. Licenziati, D. Corica, et al., "Phenotypes of Prediabetes and Metabolic Risk in Caucasian Youths With Overweight or Obesity," *Journal of Endocrinological Investigation* 45, no. 9 (2022): 1719–1727.

16. M. M. Al-Nozha, Y. Y. Al-Mazrou, M. A. Al-Maatouq, et al., "Obesity in Saudi Arabia," *Saudi Medical Journal* 26, no. 5 (2005): 824–829.

17. Health SMo, "World Health Survey Saudi Arabia," 2019, https://www.moh.gov.sa/en/Ministry/Statistics/Population-Health-Indicators/Documents/World-Health-Survey-Saudi-Arabia.pdf.

18. International Diabetes Federation, (IDF Diabetes Atlas, 2021).

19. Saudi Census Report-, Saudi Arabia [Available from: https://portal.saudicensus.sa/portal.

20. A. Al-Hussaini, M. S. Bashir, M. Khormi, et al., "Overweight and Obesity Among Saudi Children and Adolescents: Where do we Stand Today?" *Saudi Journal of Gastroenterology* 25, no. 4 (2019): 229–235.

21. S. AlEnazi, R. AlAjlan, H. AlKhalaf, et al., "Prevalence of Obesity Among Children and Adolescents in Saudi Arabia: A Multicenter Population-Based Study," *Saudi Journal of Medicine & Medical Sciences* 11, no. 1 (2023): 19–25.

22. A. O. Musaiger, M. Al-Mannai, A. R. Al-Haifi, et al., "Prevalence of Overweight and Obesity Among Adolescents in Eight Arab Countries: Comparison Between Two International Standards (ARABEAT-2)," *Nutrición Hospitalaria* 33, no. 5 (2016): 567.

23. F. S. AlBuhairan, H. Tamim, M. Al Dubayee, et al., "Time for an Adolescent Health Surveillance System in Saudi Arabia: Findings From "Jeeluna"," *Journal of Adolescent Health* 57, no. 3 (2015): 263–269.

24. A. De Lorenzo, L. Romano, L. Di Renzo, et al., "Triponderal Mass Index Rather Than Body Mass Index: An Indicator of High Adiposity in Italian Children and Adolescents," *Nutrition* 60 (2019): 41–47.

25. C. M. Peterson, H. Su, D. M. Thomas, et al., "Tri-Ponderal Mass Index vs Body Mass Index in Estimating Body Fat During Adolescence," *JAMA Pediatrics* 171, no. 7 (2017): 629–636.

26. V. K. Moselakgomo and M. Van Staden, "Diagnostic Accuracy of Tri-Ponderal Mass Index and Body Mass Index in Estimating Overweight and Obesity in South African Children," *African Journal of Primary Health Care & Family Medicine* 11, no. 1 (2019): e1–e7.

27. E. D. Sims, K. W. Wang, A. Fleming, et al., "Tri-Ponderal Mass Index in Survivors of Childhood Brain Tumors: A Cross-Sectional Study," *Scientific Reports* 8, no. 1 (2018): 16336.

28. L. Nasreddine, H. Tamim, A. Mailhac, and F. S. AlBuhairan, "Prevalence and Predictors of Metabolically Healthy Obesity in Adolescents: Findings From the National "Jeeluna" Study in Saudi-Arabia," *BMC Pediatrics* 18, no. 1 (2018): 281.

29. R. J. Kuczmarski, C. L. Ogden, L. M. Grummer-Strawn, et al., "CDC Growth Charts: United States," *Advance Data* 314 (2000): 1–27.

30. R. J. Kuczmarski, C. L. Ogden, S. S. Guo, et al., "CDC Growth Charts for the United States: Methods and Development," *Vital Health Statistics* 2002, no. 246 (2000): 1–190.

31. L. M. Browning, S. D. Hsieh, and M. Ashwell, "A Systematic Review of Waist-to-Height Ratio as a Screening Tool for the Prediction of Cardiovascular Disease and Diabetes: 0.5 Could Be a Suitable Global Boundary Value," *Nutrition Research Reviews* 23, no. 2 (2010): 247–269.

32. X. Zong, R. Kelishadi, Y. M. Hong, et al., "Establishing International Optimal Cut-Offs of Waist-to-Height Ratio for Predicting Cardiometabolic Risk in Children and Adolescents Aged 6–18 Years," *BMC Medicine* 21, no. 1 (2023): 442.

33. American Diabetes Association Professional Practice Committee, "2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2022." *Diabetes Care* 45, no. 1 (2022): S17–S38.

34. World Health Organization, "Definition and Diagnosis of Diabetes Mellitus and Intermediate Hyperglycemia 2006 [Available from:" https://www.who.int/publications/i/item/definition-and-diagnosis-of-diabetes-mellitus-and-intermediate-hyperglycaemia.

35. K. Al-Rubeaan, "National Surveillance for Type 1, Type 2 Diabetes and Prediabetes among Children and Adolescents: A Population-Based Study (SAUDI-DM)," *Journal of Epidemiology and Community Health* 69, no. 11 (2015): 1045–1051.

36. L. J. Andes, Y. J. Cheng, D. B. Rolka, E. W. Gregg, and G. Imperatore, "Prevalence of Prediabetes Among Adolescents and Young Adults in the United States, 2005–2016," *JAMA Pediatrics* 174, no. 2 (2020): e194498.

37. A. Zorzi, G. Wahi, A. J. Macnab, and C. Panagiotopoulos, "Prevalence of Impaired Glucose Tolerance and the Components of Metabolic Syndrome in Canadian Tsimshian Nation Youth," *Canadian Journal of Rural Medicine* 14, no. 2 (2009): 61–67.

38. W. L. Yan, X. S. Li, Q. Wang, et al., "Overweight, High Blood Pressure and Impaired Fasting Glucose in Uyghur, Han, and Kazakh Chinese Children and Adolescents," *Ethnicity & Health* 20, no. 4 (2014): 365–375.

39. P. Di Bonito, L. Pacifico, C. Chiesa, et al., "Impaired Fasting Glucose and Impaired Glucose Tolerance in Children and Adolescents With Overweight/Obesity," *Journal of Endocrinological Investigation* 40, no. 4 (2017): 409–416.

40. M. H. Moadab, R. Kelishadi, M. Hashemipour, M. Amini, and P. Poursafa, "The Prevalence of Impaired Fasting Glucose and Type 2 Diabetes in a Population-Based Sample of Overweight/Obese Children in the Middle East," *Pediatric Diabetes* 11, no. 2 (2010): 101–106.

41. N. Smetanina, R. Valickas, A. Vitkauskiene, K. Albertsson-Wikland, and R. Verkauskiene, "Prevalence of Metabolic Syndrome and Impaired Glucose Metabolism among 10- to 17-Year-Old Overweight and Obese Lithuanian Children and Adolescents," *Obesity Facts* 14, no. 3 (2021): 271–282.

42. J. T. Kloppenborg, C. E. Fonvig, T. R. H. Nielsen, et al., "Impaired Fasting Glucose and the Metabolic Profile in Danish Children and Adolescents With Normal Weight, Overweight, or Obesity," *Pediatric Diabetes* 19, no. 3 (2018): 356–365.

43. E. Hagman, T. Reinehr, J. Kowalski, A. Ekbom, C. Marcus, and R. W. Holl, "Impaired Fasting Glucose Prevalence in Two Nationwide Cohorts of Obese Children and Adolescents," *International Journal of Obesity* 38, no. 1 (2014): 40–45.

44. V. Eidkhani, D. Parizadeh, M. Hasheminia, F. Azizi, and F. Hadaegh, "Impaired Fasting Glucose Prevalence Surge Among Iranian Adolescents in a Decade: The Tehran Lipid and Glucose Study," *Pediatric Diabetes* 20, no. 8 (2019): 1064–1071.

45. S. E. Yoo, J. H. Lee, J. W. Lee, H. S. Park, H. A. Lee, and H. S. Kim, "Increasing Prevalence of Fasting Hyperglycemia in Adolescents Aged 10-18 Years and its Relationship With Metabolic Indicators: The Korea National Health and Nutrition Examination Study (KNHANES), 2007-2018," *Annals of Pediatric Endocrinology & Metabolism* 27, no. 1 (2022): 60–68.

46. J. B. Buse, F. R. Kaufman, B. Linder, et al., "Diabetes Screening With Hemoglobin A(1c) versus Fasting Plasma Glucose in a Multiethnic Middle-School Cohort," *Diabetes Care* 36, no. 2 (2013): 429–435.

47. M. Mirbolouk, A. Derakhshan, P. Charkhchi, K. Guity, F. Azizi, and F. Hadaegh, "Incidence and Predictors of Early Adulthood Pre-Diabetes/Type 2 Diabetes, among Iranian Adolescents: The Tehran Lipid and Glucose Study," *Pediatric Diabetes* 17, no. 8 (2016): 608–616.

48. C.-Y. Yang, H.-Y. Li, F.-C. Sung, E. C.-Hui Tan, J.-N. Wei, and L.-M. Chuang, "Relationship Between Fasting Plasma Glucose and Incidence of Diabetes in Children and Adolescents," *Diabetic Medicine* 36, no. 5 (2019): 633–643.

49. L. N. Anderson, Y. Yoshida-Montezuma, N. Dewart, et al., "Obesity and Weight Change During the COVID-19 Pandemic in Children and Adults: A Systematic Review and Meta-Analysis," *Obesity Reviews* 24, no. 5 (2023): e13550.

50. T. H. Chang, Y. C. Chen, W. Y. Chen, et al., "Weight Gain Associated With COVID-19 Lockdown in Children and Adolescents: A Systematic Review and Meta-Analysis," *Nutrients* 13, no. 10 (2021): 3668.

51. C. R. Pelicciari, T. O. Artioli, C. A. Longui, O. Monte, and C. Kochi, "The Impact of COVID-19 in Children and Adolescents With Obesity in Brazil," *Archives of Endocrinology and Metabolism* 66, no. 2 (2022): 256–260.

52. M. Al-Tannir, I. AlFayyad, M. Altannir, A. Alosaimi, A. Alonazi, and A. Alqarni, "Long-Term Impact of Post COVID-19 Pandemic Quarantine on Eating Habits Changes among Adult Residents of Riyadh, Saudi Arabia," *Frontiers in Nutrition* 10 (2023): 1243288.

53. E. Kostopoulou, S. Skiadopoulos, I. Partsalaki, A. P. Rojas Gil, and B. E. Spiliotis, "Repetitiveness of the Oral Glucose Tolerance Test in Children and Adolescents," *World Journal of Clinical Pediatrics* 10, no. 3 (2021): 29–39.

54. S. Ehehalt, S. Wiegand, A. Korner, et al., "Low Association Between Fasting and OGTT Stimulated Glucose Levels With HbA1c in Overweight Children and Adolescents," *Pediatric Diabetes* 18, no. 8 (2017): 734–741.

55. M. S. Kim, D. S. Jo, and D. Y. Lee, "Comparison of HbA1c and OGTT for the Diagnosis of Type 2 Diabetes in Children at Risk of Diabetes," *Pediatrics & Neonatology* 60, no. 4 (2019): 428–434.

56. P. C. Brar, L. Mengwall, B. H. Franklin, and A. H. Fierman, "Screening Obese Children and Adolescents for Prediabetes and/or Type 2 Diabetes in Pediatric Practices: A Validation Study," *Clinical Pediatrics* 53, no. 8 (2014): 771–776.