Relationship Between Adiposity and Pulmonary Function in School-Aged Canadian Children

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Reduced lung function has been observed in adults with excess adiposity; however, in children, the relationship between adiposity and lung function is not clearly understood. A sample of 1,583 children, less than 18 years of age, from the Canadian Health Measures Survey (CHMS) was used to examine the associations of various anthropometric and skinfold measures with lung function parameters. The mean age of the sample was 12.15 (0.096). In normal weight boys, body mass index (BMI) was positively associated with forced vital capacity (FVC), $FEV_{0.75}$ and FEV_1 ; while in overweight or obese boys, waist circumference (WC) and waist-to-hip ratio showed inverse correlations with pulmonary function measures. Similarly, in normal weight girls, BMI and WC had positive associations with lung function measures but no inverse effect of adiposity was observed in overweight or obese girls. Skinfold analysis showed that only triceps skinfold had a significant inverse association with FVC and borderline significant associations with $FEV_{0.75}$ and FEV_1 in normal weight boys; while in overweight or obese boys, all the skinfold indicators displayed inverse correlations with lung function. The best predictor of lung function was triceps skinfold with $\beta_{std} = -0.3869$ for FVC, -0.3496 for $FEV_{0.75}$ and -0.3668 for FEV_1 . No inverse correlations between skinfolds and lung function were observed in girls. Adiposity had differing effects on respiratory function that were dependent on sex and BMI group with the most significant effect on the overweight or obese boys. The most important indicator of adiposity in boys with BMI $<30 \text{ kg/m}^2$ was triceps skinfold. In girls, adiposity was not associated with poor lung function.

Introduction

OBESITY AMONG CHILDREN is a significant risk factor for the development of asthma, both of which are becoming increasingly widespread worldwide. There is also limited evidence that adiposity might be linked to poor lung function among children; however, the results of the previous findings are controversial.¹ Some studies have shown no significant difference in lung function parameters between mildly obese and normal weight children.^{2–4} Others have shown that higher body mass index (BMI) is associated with increased forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1) in both sexes.^{5–7} In contrast, a few investigations have demonstrated a significant reduction in lung function in the overweight or obese children as compared with the normal weight children.^{1,8} The stark differences in previous findings indicate that BMI is not suitable for examining the effect of adiposity on pulmonary function in children. This is due to the fact that BMI cannot differentiate between fat and muscle tissue, which affect lung function in opposite ways and it does not provide any information regarding the distribution of fat in the body.^{6,9} Moreover, BMI is closely related to body size, which positively predicts pulmonary function.⁹

Only 1 cross-sectional study in children has been conducted to date using skinfold measurements.⁷ The study illustrated no significant effect of body fat percentage on lung function parameters when adjusted for height. However, when lung function measures were adjusted for height and weight, an inverse correlation between body fat percentage and both FVC and FEV_1 was found in children as a whole. Our investigation explored all the anthropometric measures available and tried to determine the association of each measure with lung function in children.

Materials and Methods

Study sample

For this study, cross-sectional data from cycle 1 of the Canadian Health Measures Survey (CHMS) were used. The complete information about this national survey conducted by Statistics Canada has been previously presented.¹⁰ The children's sample consisted of participants younger than 18 years of age at the time of the household survey. There were 1,883 participants who were 6–17 years of age in this sample. Participants who were eligible for pulmonary function

tests included 1,876 children (7 observations were deleted). The sample that had all the relevant spirometric data available consisted of 1,736 people (140 cases with either not applicable or not stated status or with 0 acceptable maneuvers out of 8 trials were deleted). Moreover, participants with highly questionable reproducibility and quality for FVC and FEV₁ were also deleted (152 cases), thus leaving us with 1,584 observations. One person with missing waist-to-hip ratio (WHR), waist circumference (WC), and hip circumference was also deleted, leaving us with a sample of 1,583 children for data analysis.

Pulmonary function tests

Lung function was determined using a Koko spirometer. The participants had to exhale for at least 6 or 3 s for children between the ages of 6 and 10, while sitting in an upright position and wearing a nose clip. A minimum of 3 acceptable spirograms were acquired based on the ATS/ERS guidelines.^{11,12} If all 3 trials met the criteria, the testing was ended; otherwise, it continued with additional trials for a maximum of 8 tests.¹⁰ Data from the best trial were used, which was determined by the sum of FVC and FEV₁. Pulmonary function measures studied were the largest FVC in liters, the largest FEV₁, and the best FEV₁/FVC ratio. Due to small airway size in children, largest forced expiratory volume at 0.75 seconds (FEV_{0.75}) was also examined as an outcome.

Adiposity measures

BMI, WC, WHR, and skinfolds were the different measures used to estimate adiposity in children. BMI was calculated using the individual's height and weight, where height was measured using a fixed stadiometer and weight was measured using a digital scale. WC was determined as the midpoint between the last floating rib and the top of the iliac crest. Hip circumference was recorded as the largest circumference over the buttocks.

Skinfold measurements were made at 5 different sites: iliac crest, biceps, medial calf, triceps, and subscapular areas using the Harpenden skinfold caliper. For the procedure, the jaw of the caliper was placed at the 1 cm mark below the point where the skinfold was lifted and the measurement was recorded. At each site, 2 measurements were taken to the nearest 0.2 mm, and a third was also obtained if the difference between the first 2 measurements was larger than

0.4 mm. Then, the average thickness of the 2 (or 3 if all were equidistant) most closely related values was recorded for each site. The sum of all 5 skinfolds was also obtained by adding the average value for each of the 5 skinfold sites.

Measurements were limited to participants with BMI < 30 kg/m². The BMI categories (normal weight, overweight, and obese) for children were based on the U.S. Center for Disease Control (CDC) BMI-for-age classification system, and some children classified as obese were still eligible for skinfold measurements because their BMI was < 30 kg/m². There were 58 out of 1,583 children who were missing a value for the sum of 5 skinfolds variable. Among those, 50 children had BMI > 30, which meant that they did not meet the eligibility criteria. The other 8 individuals were eligible but their skinfold measurements were missing. The final number of children included in the skinfold analysis was 1,525.

Statistical analysis

The mean values of adiposity and pulmonary function variables were calculated by sex and compared using unpaired *t*-tests. Two-stage multiple linear regression analysis was used to examine the association between each measure of adiposity with the measures of pulmonary function. In the first stage, each lung function variable was regressed on height, age, and ethnicity. Quadratic terms for age and height were also tested and kept in the models if *P* values were < 0.10. Separate models were developed for boys and girls, resulting in a total of 8 models, which are shown in Table 1.

In the second stage, the residuals (difference between measured and predicted lung function values) from the 8 regression models (Table 1) were regressed against each of the adiposity measures. Smoking and other lifestyle factors displayed no significant effect on the association between adiposity measures and lung function parameters, and, therefore, they were excluded from the regression models. Each adiposity measure was entered separately into the models to avoid multi-collinearity. The standardized beta coefficients were also calculated in order to compare the magnitude and direction of the impact of various anthropometric parameters on residual ventilatory function testing variables. The analysis was also stratified by BMI group, in which the dataset was separated into 2 BMI groups (normal weight and overweight or obese) due to the relatively small sample sizes in the overweight and obese groups. Statistical

TABLE 1. STAGE 1 REGRESSION MODELS DEVELOPED FOR PREDICTING LUNG FUNCTION USING AGE, HEIGHT, AND ETHNICITY

	Model	R ²
Boys <i>n</i> = 789	FVC = (−0.9519)height + (2.0838)height ² − (0.3040)age + (0.0155)age ² + (0.3352)ethnicity	0.9005
	FEV _{0.75} = (−2.5838)height + (2.1008)height ² − (0.2112)age + (0.0111)age ² + (0.1043)ethnicity	0.8695
	FEV ₁ = (−2.6736)height + (2.3188)height ² − (0.2505)age + (0.0128)age ² + (0.1613)ethnicity	0.8850
	FEV ₁ /FVC = (−0.6301)height + (0.1994)height ² − (0.0355)ethnicity	0.0518
Girls <i>n</i> = 794	FVC = (−6.1477)height + (3.4365)height ² + (0.0671)age + (0.3814)ethnicity	0.8403
	FEV _{0.75} = (−1.3967)height + (1.3898)height ² + (0.0621)age + (0.2021)ethnicity	0.8335
	FEV ₁ = (−2.8269)height + (2.0014)height ² + (0.0687)age + (0.2584)ethnicity	0.8473
	FEV ₁ /FVC = (−0.1315)height + (0.0221)age − (0.0007)age ² − (0.0232)ethnicity	0.0378

FVC, forced vital capacity; FEV_{0.75}, forced expiratory volume in 0.75 second; FEV₁, forced expiratory volume in 1 second; FEV₁/FVC, ratio of FEV₁ to FVC.

significance was determined by a P value of <0.05 . In order to account for the complex survey design, all results were weighted to represent the Canadian population and variance estimates were obtained using the bootstrap method. All the statistical analyses were conducted using a statistical software package (SAS, version 9.3; SAS Institute; Cary, NC).

Results

The child study sample had 1,583 respondents: 789 boys and 794 girls. The weighted mean age was 12.15 [standard error (SE) 0.096]. The baseline characteristics of the study sample are shown in Table 2. Standing height, weight, and WHR were significantly higher in boys as compared with girls. FVC, FEV_{0.75}, and FEV₁ were significantly higher in boys, while FEV₁/FVC ratio was significantly higher in girls. The examination in the skinfold sample displayed that all the skinfold measures were significantly higher in girls. The observed differences in adiposity and lung function measures between boys and girls were as expected, since girls typically have more fat, and boys, in general, are taller, thus having higher lung function values.

Data analysis stratified by sex only showed a significant positive association between BMI, WC, and residual FVC in boys ($\beta=0.0137$, SE=0.0059, and $\beta=0.0027$, SE=0.0014, respectively). In girls, BMI and WC were positively associated with residual FVC (BMI: $\beta=0.0245$, SE=0.0042; WC: $\beta=0.0065$, SE=0.0029) and residual FEV₁ (BMI: $\beta=0.0144$, SE=0.0044; WC: $\beta=0.0033$, SE=0.0013), respectively. A statistically significant inverse correlation was also found between BMI and residual FEV₁/FVC ratio in boys ($\beta=-0.0016$, SE=0.0007) and girls ($\beta=-0.0019$, SE=0.0006).

Lung function was also examined by sex and BMI group. In normal weight boys, BMI had a significant positive effect on residual FVC, FEV_{0.75}, and FEV₁ indicated by the positive values of the regression coefficients (Table 3). WC and WHR did not significantly correlate with any of the lung function measures in normal weight boys. Among overweight or obese boys, WC and WHR had significant (or almost significant) inverse associations with residual FVC, FEV_{0.75}, and FEV₁. BMI also showed inverse correlations with residual FVC and FEV₁, both of which were borderline significant. WHR was the best predictor of residual FVC ($\beta_{\text{std}}=-0.2666$), FEV_{0.75} ($\beta_{\text{std}}=-0.2365$), and FEV₁ ($\beta_{\text{std}}=-0.2703$) in the overweight or obese group. Only WHR showed a significant inverse association with FEV₁/FVC ratio in normal weight boys, and none of the measures were correlated with FEV₁/FVC in the overweight or obese group (Table 3).

Normal weight girls showed significant (or borderline significant) positive correlations for BMI, and WC with residual FVC, FEV_{0.75}, and FEV₁ (Table 4). WHR was not associated with any of the lung function measures in this group. For overweight or obese girls, only BMI displayed a significant positive association with residual FVC ($\beta_{\text{std}}=0.1949$; $P=0.0103$) and a borderline significant correlation with residual FEV₁ ($\beta_{\text{std}}=0.1047$; $P=0.0996$). FEV₁/FVC was inversely correlated with BMI, WC, and WHR in the normal weights; while in the overweight or obese, there was no significant correlation between any of the adiposity factors and FEV₁/FVC ratio.

Analysis on skinfold sample stratified by sex and BMI group was also conducted. The results showed that only triceps skinfold had a significant inverse association with residual FVC in boys classified as normal according to the CDC BMI-for-age system (Table 5). In the same group,

TABLE 2. MEAN VALUES OF ANTHROPOMETRIC AND SPIROMETRIC MEASURES OF THE CHILDREN'S SAMPLE FOR BOYS AND GIRLS SEPARATELY

Full sample (n=1583)	Boys (n=789)	Girls (n=794)	P value
Age (years)	12.21 (0.12)	12.16 (0.13)	0.7601
Standing height (m)	1.56 (0.0074)	1.51 (0.0068)	<0.0001
BMI (kg/m ²)	20.55 (0.36)	20.15 (0.25)	0.2831
WC (cm)	70.63 (1.06)	68.32 (0.88)	0.0633
WHR	0.83 (0.0027)	0.80 (0.0058)	<0.0001
FVC (L)	3.51 (0.069)	2.99 (0.026)	<0.0001
FEV _{0.75} (L)	2.60 (0.039)	2.31 (0.022)	<0.0001
FEV ₁ (L)	2.89 (0.047)	2.54 (0.023)	<0.0001
FEV ₁ /FVC	0.83 (0.0048)	0.85 (0.0018)	<0.0001
Skinfold subsample (n=1,525)	Boys (n=762)	Girls (n=763)	P value
Average thickness (mm)			
Triceps	11.54 (0.29)	14.75 (0.30)	<0.0001
Biceps	5.89 (0.15)	7.34 (0.22)	<0.0001
Subscapular	8.88 (0.31)	11.21 (0.35)	<0.0001
Iliac crest	12.75 (0.58)	17.03 (0.65)	<0.0001
Medial calf	11.46 (0.27)	14.83 (0.40)	<0.0001
Sum of 5 skinfolds	50.52 (1.50)	65.16 (1.84)	<0.0001
FVC (L)	3.44 (0.067)	2.95 (0.035)	<0.0001
FEV _{0.75} (L)	2.56 (0.041)	2.29 (0.028)	<0.0001
FEV ₁ (L)	2.84 (0.048)	2.51 (0.031)	<0.0001
FEV ₁ /FVC	0.83 (0.0045)	0.86 (0.0016)	<0.0001

BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio.

TABLE 3. LINEAR REGRESSION ANALYSIS FOR ANTHROPOMETRIC MEASURES ASSOCIATED WITH RESIDUAL PULMONARY FUNCTION MEASURES BY BODY MASS INDEX GROUP IN BOYS (N=789)

	Normal weight (n=573)			Overweight or obese (n=216)		
	BMI (kg/m ²)	WC (cm)	WHR	BMI (kg/m ²)	WC (cm)	WHR
FVC (L)						
β	0.0328	0.0048	0.5290	-0.0119	-0.0058	-1.7108
SE	0.0072	0.0036	0.6607	0.0062	0.0018	0.6937
β _{std}	0.2091	0.1021	0.0583	-0.1495	-0.2094	-0.2666
P	0.0000	0.1850	0.4234	0.0522	0.0011	0.0137
FEV _{0.75} (L)						
β	0.0222	0.0018	-0.3729	-0.0087	-0.0042	-1.4222
SE	0.0077	0.0023	0.3899	0.0062	0.0026	0.7859
β _{std}	0.1722	0.0480	-0.0501	-0.1157	-0.1616	-0.2365
P	0.0039	0.4141	0.3388	0.1607	0.1028	0.0703
FEV ₁ (L)						
β	0.0244	0.0021	-0.3721	-0.0103	-0.0050	-1.6701
SE	0.0076	0.0025	0.4625	0.0059	0.0023	0.7777
β _{std}	0.1769	0.0501	-0.0466	-0.1341	-0.1882	-0.2703
P	0.0013	0.4082	0.4211	0.0828	0.0333	0.0317
FEV ₁ /FVC						
β	-0.0010	-0.0006	-0.2115	-0.0006	-0.0002	-0.1097
SE	0.0014	0.0003	0.0539	0.0011	0.0004	0.0827
β _{std}	-0.0427	-0.0814	-0.1565	-0.0504	-0.0521	-0.1109
P	0.4863	0.1024	0.0001	0.5739	0.5840	0.1843

β, regression coefficient; β_{std}, standardized regression coefficient; HC, hip circumference; SE, standard error.

triceps skinfold and residual FEV_{0.75} and FEV₁ showed inverse correlations that were borderline significant ($P=0.0810$ and $P=0.0879$, respectively). Medial calf skinfold also showed inverse correlations with lung function measures that tended toward significance. In the overweight or obese category, all of the skinfold indicators

displayed inverse correlations with all 3 lung function measures (FVC, FEV_{0.75}, and FEV₁). According to the standardized β values, the best predictor of lung function measures was triceps skinfold with standardized regression coefficient values of -0.3869 for residual FVC, -0.3496 for residual FEV_{0.75}, and -0.3668 for residual FEV₁.

TABLE 4. LINEAR REGRESSION ANALYSIS FOR ANTHROPOMETRIC MEASURES ASSOCIATED WITH RESIDUAL PULMONARY FUNCTION MEASURES BY BODY MASS INDEX GROUP IN GIRLS (N=794)

	Normal weight (n=626)			Overweight or obese (n=168)		
	BMI (kg/m ²)	WC (cm)	WHR	BMI (kg/m ²)	WC (cm)	WHR
FVC (L)						
β	0.0371	0.0071	0.2859	0.0125	0.0023	0.2769
SE	0.0119	0.0029	0.3191	0.0049	0.0018	0.4022
β _{std}	0.2705	0.1613	0.0375	0.1949	0.1071	0.0610
P	0.0018	0.0150	0.3703	0.0103	0.1878	0.4912
FEV _{0.75} (L)						
β	0.0195	0.0026	-0.3239	0.0049	0.0005	0.2454
SE	0.0073	0.0016	0.2512	0.0040	0.0013	0.3810
β _{std}	0.1910	0.0801	-0.0569	0.0894	0.0266	0.0640
P	0.0078	0.1056	0.1972	0.2252	0.7095	0.5196
FEV ₁ (L)						
β	0.0238	0.0034	-0.3370	0.0060	0.0006	0.1943
SE	0.0084	0.0017	0.2509	0.0037	0.0011	0.3454
β _{std}	0.2164	0.0968	-0.0550	0.1047	0.0324	0.0480
P	0.0045	0.0450	0.1793	0.0996	0.5567	0.5737
FEV ₁ /FVC						
β	-0.0027	-0.0008	-0.1532	-0.0011	-0.0003	-0.0020
SE	0.0011	0.0003	0.0756	0.0014	0.0004	0.1019
β _{std}	-0.1224	-0.1166	-0.1271	-0.0954	-0.0847	-0.0026
P	0.0143	0.0150	0.0427	0.4396	0.4089	0.9840

TABLE 5. LINEAR REGRESSION ANALYSIS FOR SKINFOLD MEASURES ASSOCIATED WITH RESIDUAL LUNG FUNCTION MEASURES BY BODY MASS INDEX GROUP IN BOYS ($N=762$)^a

Normal weight (n = 573)							Overweight or obese (n = 189)					
	Triceps	Biceps	Subscapular	Iliac crest	Medial calf	Sum of 5 skinfolds	Triceps	Biceps	Subscapular	Iliac crest	Medial calf	Sum of 5 skinfolds
FVC (L)												
β	-0.0136	-0.0268	0.0038	-0.0035	-0.0114	-0.0023	-0.0295	-0.0304	-0.0157	-0.0125	-0.0186	-0.0052
SE	0.0068	0.0162	0.0151	0.0067	0.0066	0.0022	0.0086	0.0126	0.0050	0.0040	0.0055	0.0015
β _{std}	-0.1275	-0.1273	0.0243	-0.0490	-0.1185	-0.0896	-0.3869	-0.2701	-0.2582	-0.3264	-0.3003	-0.3608
P	0.0454	0.0983	0.8001	0.5989	0.0829	0.3135	0.0006	0.0155	0.0016	0.0017	0.0008	0.0006
FEV _{0.75} (L)												
β	-0.0125	-0.0203	0.0037	-0.0051	-0.0094	-0.0022	-0.0276	-0.0268	-0.0166	-0.0112	-0.0152	-0.0047
SE	0.0072	0.0144	0.0121	0.0046	0.0053	0.0018	0.0068	0.0094	0.0029	0.0031	0.0045	0.0010
β _{std}	-0.1421	-0.1165	0.0280	-0.0848	-0.1177	-0.1034	-0.3496	-0.2307	-0.2630	-0.2836	-0.2375	-0.3192
P	0.0810	0.1578	0.7633	0.2709	0.0789	0.2246	0.0001	0.0042	0.0000	0.0003	0.0007	0.0000
FEV ₁ (L)												
β	-0.0135	-0.0249	0.0034	-0.0058	-0.0113	-0.0025	-0.0297	-0.0300	-0.0183	-0.0126	-0.0172	-0.0053
SE	0.0079	0.0159	0.0135	0.0055	0.0062	0.0020	0.0074	0.0101	0.0033	0.0035	0.0048	0.0012
β _{std}	-0.1441	-0.1342	0.0245	-0.0913	-0.1337	-0.1131	-0.3668	-0.2508	-0.2833	-0.3097	-0.2608	-0.3450
P	0.0879	0.1175	0.8016	0.2870	0.0692	0.2179	0.0001	0.0030	0.0000	0.0003	0.0004	0.0000
FEV ₁ /FVC												
β	-0.0009	-0.0013	-0.0006	-0.0011	-0.0007	-0.0003	-0.0020	-0.0023	-0.0018	-0.0008	-0.0010	-0.0004
SE	0.0007	0.0009	0.0012	0.0004	0.0005	0.0001	0.0011	0.0016	0.0007	0.0004	0.0006	0.0002
β _{std}	-0.0570	-0.0413	-0.0260	-0.0992	-0.0511	-0.0705	-0.1543	-0.1204	-0.1775	-0.1241	-0.0998	-0.1562
P	0.2147	0.1603	0.6160	0.0024	0.1084	0.0445	0.0821	0.1580	0.0067	0.0752	0.0923	0.0151

^aSkinfold measurements are in millimeters (mm).

Significant inverse associations were found between iliac crest, sum of 5 skinfolds, and FEV₁/FVC ratio among normal weights. In the overweight or obese boys, subscapular and sum of 5 skinfolds were inversely correlated with the outcome (Table 5).

In normal weight girls, no association was found between any of the skinfolds and lung function parameters (data not shown) except biceps skinfold, which had a significant inverse effect on the FEV₁/FVC ratio in normal weights ($\beta = -0.0030$, SE = 0.0012, $P = 0.0097$, and $\beta_{\text{std}} = -0.1119$). In overweight or obese girls, only triceps skinfold showed a positive association with FEV_{0.75} ($\beta = 0.0056$, SE = 0.0027, $P = 0.0399$, and $\beta_{\text{std}} = 0.1291$) and FEV₁/FVC ($\beta = 0.0022$, SE = 0.0007, $P = 0.0008$, and $\beta_{\text{std}} = 0.2445$).

Discussion

Our analysis illustrated that only BMI was positively associated with residual FVC, FEV_{0.75}, and FEV₁ in normal weight boys. All the other adiposity indices were nonsignificant. For normal weight female children, BMI and WC showed a significant (or borderline significant) positive relationship with all 3 lung function measures. A unit increment in BMI was associated with about a 33 mL increase in residual FVC, a 22 mL increase in residual FEV_{0.75}, and a 24 mL increase in residual FEV₁ among boys and a 37 mL increase in residual FVC, a 20 mL increase in residual FEV_{0.75}, and a 24 mL increase in residual FEV₁ among girls. The sex differences for these parameters were not significant.

In the case of overweight or obese boys, WC and WHR had significant (or almost significant) inverse associations with residual FVC, FEV_{0.75}, and FEV₁. In girls, only BMI had a significant positive effect on residual FVC and a borderline significant effect on residual FEV₁.

The ratio of FEV₁/FVC was inversely affected by WHR in normal weight boys, because WHR had a positive association with FVC and an inverse association with FEV₁. No other relationship was statistically significant. In normal weight girls, BMI, WC, and WHR displayed an inverse relationship with FEV₁/FVC ratio. Similar to the results in boys, WHR had a positive correlation with FVC and an inverse correlation with FEV₁, leading to an inverse correlation with the ratio. BMI and WC had a positive relationship with both FVC and FEV₁, but the relationship was much stronger with FVC, leading to an inverse association with the FEV₁/FVC ratio.

Overall, the negative effect of adiposity on pulmonary function is only seen in overweight boys with WHR being the most important predictor. Similar conclusions were drawn by another study of 1,586 children, where a positive relationship was observed between BMI and lung function in normal and overweight girls. Likewise, a positive correlation was observed in normal weight boys but not in the overweight group.¹³

A few other reports have also examined the effect of adiposity on pulmonary function in children; however, the results have not been stratified by BMI category. Thus, we compared our combined analysis with previous investigations, which showed that BMI and WC were positively associated with FVC and FEV₁ in girls and with only FVC in boys. In addition, the FEV₁/FVC ratio was inversely correlated with BMI in both sexes. Similar to our results, in

a cross-sectional study of 14,654 children aged 13–16, Chu et al. showed that increases in BMI were associated with an increase in FVC and FEV₁ in both sexes; whereas FEV₁/FVC declined with an increase in BMI in both male and female children.⁵ A randomized clinical trial of 1,041 asthmatic children noted higher FVC and FEV₁ and lower FEV₁/FVC values with increasing BMI.¹⁴ A study of Canadian children aged 6–17 years conducted by Chen et al. reported that WC was positively associated with FVC and FEV₁ in children.¹⁵ Another study in students between the ages of 8 and 20 illustrated that lung function improved with an increase in BMI in children 8–11 years old, but in older children and youth, FVC and FEV₁ levels reached a plateau and actually declined in children with the largest BMI values.¹⁶

One potential mechanism that helps explain our results is the differing pattern of fat distribution in males and females. Obese girls tend to deposit fat peripherally whereas obese boys tend to deposit fat in the abdominal region, which may lead to reduction in FVC and FEV₁ by a decrease in expiratory reserve volume.¹³ Since BMI cannot distinguish between different types of body tissue, it may indicate the strength of respiratory muscles, thus explaining the positive relationship in normal weight children. However, in overweight or obese individuals, BMI represents body fat more closely.¹³

For skinfold analysis in children, it was observed that triceps skinfold was the only measure to have a significant inverse effect on FVC in normal weight boys. Moreover, inverse relationships that tended toward significance were also found between triceps skinfold with FEV_{0.75} and FEV₁ and biceps skinfold with FVC, FEV_{0.75}, and FEV₁. In overweight or obese boys, all the skinfold measures had a significant inverse association with all 3 lung function measures. Triceps skinfold had the strongest effect on overweight or obese boys, where a 1 mm increase in the skinfold was associated with a 30 mL decline in FVC, a 28 mL decline in FEV_{0.75}, and a 30 mL decline in FEV₁. In girls, skinfold measures seemed to have no impact on FVC, FEV_{0.75}, and FEV₁ in normal weight and overweight or obese groups, except triceps skinfold, which was positively associated with FEV_{0.75} in the overweight or obese group.

One previous investigation⁷ has carried out a skinfold analysis in 9-, 12-, and 15-year-old children. The authors calculated total body fat percentage (TBF%) for each subject using sex-specific regression equations based on skinfold measurements and found an inverse correlation between TBF% and height- and weight-adjusted FVC and FEV₁ for each age and sex group. Almost the same results were found when the sum of skinfolds (biceps, triceps, subscapular, and suprailiac) was used. In our findings, an inverse relationship was not observed between skinfold measures and respiratory function in girls, which could have been the result of having excluded individuals with BMI $\geq 30 \text{ kg/m}^2$ from the skinfold analysis.

The results for the correlation between skinfold indices and ratio of FEV₁/FVC were quite varied. Iliac crest and sum of 5 skinfolds were important inverse predictors of FEV₁/FVC ratio in normal weight male children, while subscapular and sum of 5 skinfold were inversely correlated with the FEV₁/FVC ratio in overweight or obese boys. This was due to the fact that these measures had a stronger inverse relationship with FEV₁ as compared with FVC,

leading to a negative impact on the ratio. In normal weight girls, only biceps skinfold had an inverse relationship with the ratio of FEV₁/FVC because this skinfold had a much stronger positive correlation with FVC than FEV₁. On the contrary, in overweight or obese female children, triceps skinfold had a positive effect on FEV₁/FVC, as it was inversely correlated with FVC and positively with FEV₁.

The results of children's data demonstrate that adiposity is linked with impaired pulmonary function in boys only. Lung function testing variables in boys were affected by both anthropometric measures (WC and WHR) and skinfold measures. The most important skinfold indicator was triceps skinfold. This skinfold measure negatively affected FVC in normal weight boys, and it was the strongest predictor of FVC, FEV_{0.75}, and FEV₁ in overweight or obese male children. Triceps skinfold also showed a stronger inverse correlation with respiratory function as compared with any other skinfold and anthropometric measure. When triceps skinfold and either WC or WHR were entered into the equations for predicting FVC, FEV_{0.75}, and FEV₁, triceps skinfold was the only significant term in all the models for overweight or obese boys with BMI lower than 30 kg/m². Adiposity was not associated with impaired lung function in female children.

This is one of the few studies which provides evidence that excess body fat among male children is associated with poor lung function. The current investigation also found that pulmonary function was affected by both abdominal and subcutaneous fat in the boys and that skinfolds were more sensitive measures of adiposity in comparison to anthropometric measures. The best indicator of adiposity affecting lung function in boys was triceps skinfold. Additional studies among children are needed to corroborate these findings and to determine whether skinfolds are good predictors of lung function in obese children with BMI > 30 kg/m². In addition, the present study included pre- to post-pubertal children. Age and sex hormones are expected to have an important impact on adiposity distribution over this age range. It would be of interest to examine the associations further stratified by age when a larger sample is available in the future.

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References

1. Spathopoulos D, Paraskakis E, Trypsianis G, et al. The effect of obesity on pulmonary lung function of school aged children in Greece. *Pediatr Pulmonol* 2009; 44:273–280.
2. Boran P, Tokuc G, Pisgin B, et al. Impact of obesity on ventilatory function. *J Pediatr* 2007; 83:171–176.
3. Kalhoff H, Breidenbach R, Smith HJ, et al. Spirometry in preschool children: time has come for new reference values. *J Physiol Pharmacol* 2009; 60 Suppl 5:67–70.
4. Li AM, Chan D, Wong E, et al. The effects of obesity on pulmonary function. *Arch Dis Child* 2003; 88:361–363.
5. Chu Y, Chen W, Wang T, et al. Extreme BMI predicts higher asthma prevalence and is associated with lung function impairment in school-aged children. *Pediatr Pulmonol* 2009; 44:472–479.
6. He Q, Wong T, Du L, et al. Respiratory health in overweight and obese Chinese children. *Pediatr Pulmonol* 2009; 44:997–1002.
7. Lazarus R, Colditz G, Berkey CS, et al. Effects of body fat on ventilatory function in children and adolescents: cross-sectional findings from a random population sample of school children. *Pediatr Pulmonol* 1997; 24:187–194.
8. Inselma LS, Milanese A, Deurloo A. Effect of obesity on pulmonary function in children. *Pediatr Pulmonol* 1993; 16:130–137.
9. Chen Y, Rennie D, Cormier Y, et al. Waist circumference is associated with pulmonary function in normal-weight, overweight, and obese subjects. *Am J Clin Nutr* 2007; 85:35–39.
10. Statistics Canada. Canadian Health Measures Survey (CHMS) Data User Guide: Cycle 1. Available at: http://www23.statcan.gc.ca/imdb-bmdi/pub/document/5071_D3_T9_V2-eng.htm (2014). Accessed April 20, 2014.
11. Millar MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J* 2005; 26:319–338.
12. Pellegrino R, Viegi G, Brusasco V, et al. Interpretative strategies for lung function tests. *Eur Respir J* 2005; 26:948–968.
13. Fung KP, Lau SP, Chow OK, et al. Effects of overweight on lung function. *Arch Dis Child* 1990; 65:512–515.
14. Tantisira KG, Litonjua AA, Weiss ST, et al. Association of body mass with pulmonary function in the Childhood Asthma Management Program (CAMP). *Thorax* 2003; 58:1036–1041.
15. Chen Y, Rennie D, Cormier Y, et al. Waist circumference associated with pulmonary function in children. *Pediatr Pulmonol* 2009; 44:216–221.
16. Perez-Padilla R, Rojas R, Torres V, et al. Obesity among children residing in Mexico City and its impact on lung function: a comparison with Mexican-Americans. *Arch Med Res* 2006; 37:165–171.

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