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Association between obesity and lung function in South African adolescents of African Ancestry

Godwill Azeh Engwa¹, Chungag Anye² and Benedicta Ngwenchi Nkeh-Chungag^{1*}

Abstract

Background: There is a growing body of literature on the increasing prevalence of obesity in adolescents of Sub-Saharan African ancestry. However, limited data is available on the impact of obesity on pulmonary function. This study assessed the relationship between obesity and lung function in South African adolescents of African ancestry.

Methods: This was a cross-sectional study involving 10–14 year old adolescents recruited from middle schools of the Eastern Cape Province of South Africa. Anthropometric measurements were performed. Body mass index (BMI) was converted to percentiles for age and sex and used to classified obesity. Spirometry was performed to assess lung function. Chi-square test of association and binary regression analysis were used to assess the relationship between obesity and airway obstruction. Adjusted linear regression was used to determine the relationship between obesity and lung function parameters.

Results: A total of 540 adolescents were recruited for the study among which 77 (14.3%) were obese. Lung function parameters: forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV₁) were higher ($p < 0.001$) in obese than in non-obese adolescents while peak expiratory flow (PEF) % and FEV₁/FVC ratio were lower ($p < 0.05$) in obese than non-obese adolescents. Obesity was associated ($\chi^2 = 9.614$; $p < 0.01$) with airway obstruction and obese adolescents were over 1.5 times more likely to have pulmonary obstruction (OR: 1.57; $p < 0.05$) than their non-obese counterparts. Anthropometric measures were positively associated ($p < 0.05$) with FVC, FEV₁, PEF and/or FEV₂₅₋₇₅ but negatively associated with FEV₁/FVC ratio.

Conclusions: Obesity was associated with airway obstruction in South Africa adolescents of African ancestry.

Keywords: Obesity, Lung function, Airway obstruction, Adolescent

Background

Obesity is a global epidemic known to increase the risk of cardiovascular diseases (CVDs), hypertension, type 2 diabetes, and certain forms of cancer [1]. The prevalence of obesity and overweight is continuously on the rise and almost doubling since 1980 with 1.9 billion obese and 609

million overweight adults in 2015. This translates to over a third (39%) of the world's population affected [2]. The world has equally observed a drastic rise in the prevalence of obesity in children. Recent reports suggest over 40 million children below 5 years of age and more than 330 million children and adolescents aged 5–19 years were either obese or overweight in 2016 [3, 4]. Global analyses show that a vast majority of obese children aged between 5 and 19 years are within the African region with the largest population in the Southern African region [5].

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Obesity is a chronic disease characterized by abnormal or excessive body fat accumulation that may impair health. It is commonly assessed by measuring body mass index (BMI), which highly correlates with body fat and is therefore a useful measure in routine clinical assessment and epidemiological studies [6]. BMI percentile (pBMI) which is relative to gender and age is the recommended measure to assess obesity in children of all ages [7].

Obesity is known to be associated with respiratory diseases such as asthma and chronic obstructive pulmonary disease (COPD) [8, 9]. Excess adipose tissue as a result of obesity exerts a mechanical effect on the lung and affects the respiratory well-being of affected persons since it increases the consumption of oxygen and production of carbon dioxide, while at the same time it increases the mechanical workload for breathing and stiffens the respiratory system [10]. Excess adipose tissue in the chest wall and abdominal cavity compresses the lungs, diaphragm, and thoracic cage, thus reducing the diaphragm's capacity to move downward limiting inflation of the lung [11]. Also, adipose tissue in the thoracic region reduces the volume of the chest cavity and limits movements in the chest wall. A decrease in chest and lung wall compliance coupled with a decrease in diaphragm displacement, and a corresponding increase in elastic recoil results in an overall decrease in lung volume which overloads the inspiratory muscles of the chest [12]. Thus, increase in fat in the thoracic region can affect respiratory function such as decrease in the strength and endurance of the respiratory muscle, alterations in respiratory mechanics, lower control of breathing, decrease in pulmonary gas exchange and airway obstruction [13, 14]. These pulmonary changes are exacerbated by increases in the BMI [15]. The common physiological abnormalities due to obstructive mechanics of the lungs are manifested as changes in the force expiratory volume (FEV) and forced vital capacity (FVC) of the lungs which are commonly assessed by spirometry, a primary screening tool for lung function [16].

Reports in South Africa have shown a high prevalence of obesity in adolescents [17, 18] with some studies by our group in children of African ancestry showing between 30 and 40% prevalence of obesity/overweight [19–21]. Although obesity is highly prevalent in South African adolescents, little is known about its impact on pulmonary function. Several studies in children have shown an inverse association between obesity and respiratory function impairment [22, 23], while others failed to show any relationship [24]. Therefore, this study aimed to assess the relationship between obesity and pulmonary function in South African adolescents.

Methods

Ethics consideration

This study was conducted in accordance with the Helsinki Declaration guidelines (2008 revised version). Ethical approval was obtained from the Walter Sisulu University Health Sciences Ethics Committee (Ref No: 112/2018). Study objectives and procedures were explained after which written informed consent was obtained from parents/legal guardians of participants as well as the relevant school authorities before enrolment into the study. Participation was voluntary and participants could freely withdraw from the study at any point. The study was in accordance with the National Data Protection Act and adhered to the standards of reporting clinical data wherein participants were assigned specific codes, and their data/samples were stored anonymously. No important changes were made in the study methods after commencement.

Study design

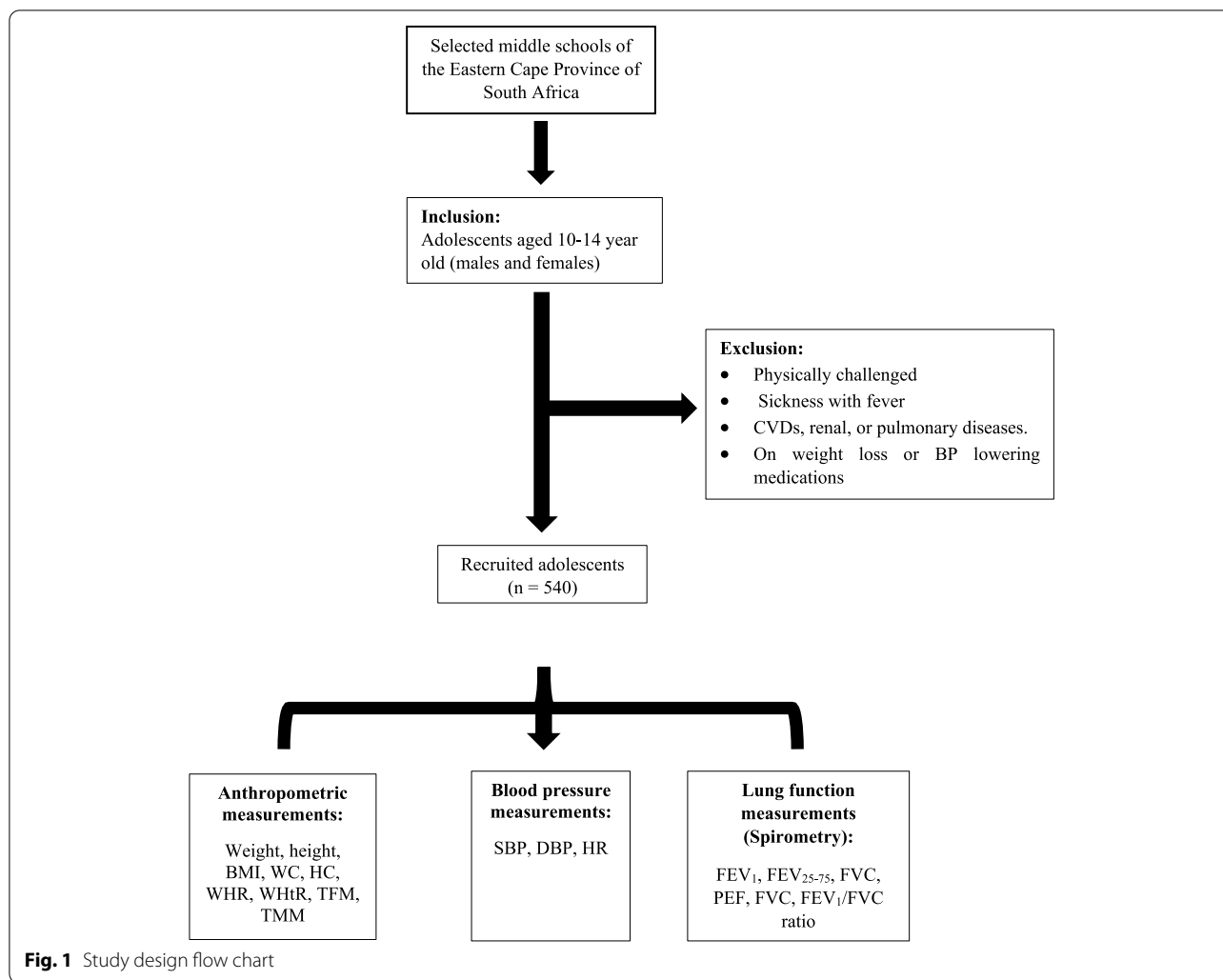
This was a cross-sectional study that recruited adolescents aged 10–14 years from some selected middle schools of the Eastern Cape Province of South Africa.

Inclusion/exclusion criteria

Adolescents aged 10–14 years (males or females) who were free from any CVDs, renal, or pulmonary diseases were enrolled into the study. Physically challenged and sick individuals with fever as well as individuals on weight loss therapy or blood pressure lowering medication were excluded from the study.

Anthropometric measurements

Anthropometric measurements were performed in accordance with the guidelines of the International Standards for Anthropometric Assessments [25] and as previously reported by us [26]. Participants were requested to stand upright with feet together and their waist circumference (WC) and hip circumference (HC) were measured with a measuring tape in centimeters (cm). The WC and HC were used to calculate waist to hip ratio (WHR). Participants were requested to take off their shoes and socks and to step on the wall-mounted stadiometer (Electronic Body Scale TCS-200-RT) platform, close to the stadiometer rod. A movable bar on the stadiometer was lowered to just touch their head and their height was measured to the nearest cm. Weight, total fat mass (TFM) and total muscle mass (TMM) were measured using an Omron body composition monitor (BR511). Participants personal data including age, height, and sex were entered into the Omron monitor to calculate the body mass index (BMI) expressed as weight/height² (kg/m²). The BMI was converted to percentiles



(pBMI) for sex and age according to the CDC criteria and a pBMI $\geq 95^{\text{th}}$ percentile was categorised as obesity [27]. The weight and height were used to calculate the weight to height ratio (WHtR).

Blood pressure measurements

Blood pressure (BP) was measured using appropriate arm cuff fitted on the left arm of participants using the Omron (Hem 7120) automated blood pressure machine after resting for ten minutes in a seated position. Measurements were done in triplicates at three-minute intervals. The mean of three readings of the diastolic blood pressure (DBP), systolic blood pressure (SBP) and heart rate (HR) were calculated.

Pulmonary function test

Lung function test was performed in accordance with the ATS/ERS guidelines [28] using a Contec hand-held spirometer SP10 (Contec Medical Systems Co., Ltd,

Qinhuangdao, China). Prior to the testing, participants' age, weight and height were computed into the device. After participants sat in an upright position and rested for at least 5 min, a nose clip was worn and the test was conducted as per device protocol. The parameters that were assessed by the device included the forced expiratory volume in 1 s (FEV₁), forced vital capacity (FVC), the peak expiratory flow (PEF), forced expiratory volume 25–75% interquartile (FEV₂₅₋₇₅) and ratio of FEV₁ to FVC (FEV₁/FVC) calculated. After measurement, the best three acceptable readings were recorded and the mean calculated. The device was disinfected after every participant and the mouthpiece replaced. The study design flow chart is summarised in Fig. 1.

Statistical analysis

Data were analysed using Statistical Package for Social Sciences (SPSS) Version 20 (IBM. Inc, 1 New Orchard Road Armonk, New York, USA). Data were summarised

in tables as mean ± standard deviation. Independent sample t-test was used to compare mean differences of quantitative variables between males and females as well as between obese and non-obese participants. Chi-square test of association and binary regression analysis were used to assess the relationship between obesity and airway obstruction. Linear regression was employed to assess the association between obesity and lung function parameters after adjusting for age and sex. Differences with a *p*-value ≤ 0.05 were considered significant.

Results

Characteristics of study population

Five hundred and forty (540) adolescents were recruited for the study: 290 (53.7%) were females and 240 (44.3%) were males. Females were heavier than males (*p* < 0.001) and all the anthropometric measurements and ratios (WC, HC, WHtR, BMI, pBMI, TFM and TMM) except for WHR were higher in females than in males (*p* < 0.01). Among the 540 participants, 77 (14.3%) were obese: 44 (8.1%) females and 33 (6.2) males. Blood pressure parameters (SBP, DBP and HR) were different between males and females (*p* < 0.005). On the other hand, only the

PEF% for lung function was different between males and females (*p* < 0.05) (Table 1).

Obesity and lung function

Lung function parameters (FVC and FEV₁) were higher (*p* < 0.001) in obese than in non-obese adolescents while PEF% and FEV₁/FVC ratio were lower (*p* < 0.05) in obese than non-obese adolescents (Table 2).

Obesity and airway obstruction

As shown in Table 3, the proportion of obese adolescents with airway obstruction (7.8%) was higher than the prevalence in non-obese adolescents (1.7%) translating to an association between obesity and airway obstruction ($\chi^2=9.614$; *p* < 0.01). Obese adolescents were over 1.5 times more likely to have pulmonary airway obstruction (OR: 1.57; *p* < 0.05) than their non-obese counterparts.

Relationship between lung function and anthropometric measures

The relationship between anthropometric indices and lung function parameters showed increased HC, WC, WHtR, pBMI, TFM and TMM to associate (*p* < 0.05) positively with FVC. Increasing HC, WC, pBMI, TFM and TMM were associated (*p* < 0.05) with an increase in FEV₁. Increased PEF was associated (*p* < 0.05) with an increase in HC, WC, pBMI, and TMM. Increase in WC, pBMI and TMM were associated (*p* < 0.05) with an increase in

Table 1 Characteristics of study population

	Female	Male	<i>p</i> -value
Weight	46.99 ± 17.33	41.94 ± 15.32	< 0.001
Height	148.11 ± 16.47	145.62 ± 16.43	0.081
WC	68.96 ± 12.42	65.18 ± 10.62	< 0.001
HC	85.03 ± 14.11	79.55 ± 12.27	< 0.001
WHR	0.81 ± 0.06	0.82 ± 0.09	0.119
WHtR	0.46 ± 0.07	0.44 ± 0.07	0.001
BMI	20.33 ± 5.22	18.96 ± 4.13	0.001
pBMI	57.79 ± 31.76	49.74 ± 32.61	0.004
TFM	23.97 ± 10.02	19.11 ± 8.96	< 0.001
TMM	32.64 ± 3.01	34.95 ± 3.59	< 0.001
SBP	112.63 ± 10.28	110.11 ± 10.36	0.005
DBP	73.14 ± 7.64	70.57 ± 7.28	< 0.001
HR	90.04 ± 11.84	84.26 ± 12.54	< 0.001
FVC	2.01 ± 0.43	2.06 ± 0.52	0.207
FVC%	76.95 ± 11.96	75.02 ± 12.23	0.066
FEV ₁	1.79 ± 0.35	1.81 ± 0.43	0.616
FEV ₁ %	74.35 ± 11.43	76.52 ± 11.67	0.030
PEF	4.25 ± 1.31	4.09 ± 1.26	0.152
PEF%	93.30 ± 23.45	84.22 ± 21.95	< 0.001
FEV ₁ /FVC	0.90 ± 0.08	0.89 ± 0.08	0.130
FEV ₂₅₋₇₅	2.48 ± 0.71	2.34 ± 0.69	0.016

Legend: HC Hip circumference, WC Waist circumference, WHR Waist to hip ratio, TMM Total muscle mass, TFM Total fat mass, BMI Body mass index, pBMI Body mass index percentile, WHtR Weight to height ratio, SBP Systolic blood pressure, DBP Diastolic blood pressure, HR Heart rate, FEV₂₅₋₇₅ Forced expiratory volume 25–75% Interquartile, FEV₁ Forced expiratory volume in 1 s, FVC Forced vital capacity, PEF Peak expiratory flow

Table 2 Lung function parameters between obese and non-obese adolescents

	Non-obese	Obese	<i>p</i> -value
FVC	2.00 ± 0.45	2.24 ± 0.56	< 0.001
FVC%	75.77 ± 12.00	78.79 ± 12.73	0.176
FEV ₁	1.78 ± 0.37	1.95 ± 0.47	< 0.001
FEV ₁ %	75.21 ± 11.34	76.21 ± 13.03	0.486
PEF	4.19 ± 1.29	4.09 ± 1.28	0.534
PEF%	90.14 ± 23.35	82.91 ± 21.35	0.011
FEV ₁ /FVC	0.90 ± 0.08	0.88 ± 0.09	0.050
FEV ₂₅₋₇₅	2.40 ± 0.70	2.47 ± 0.75	0.431

Legend: FEV₂₅₋₇₅ Forced expiratory volume 25–75% interquartile, FEV₁ Forced expiratory volume in 1 s, FVC Forced vital capacity, PEF Peak expiratory flow

Table 3 Relationship between obesity and airway obstruction

	Non-obese	Obese	Total	χ^2	<i>p</i> -value
AO	8 (1.7)	6 (7.8)	14 (2.6)	9.614	0.008
Normal	455 (98.3)	71 (92.2)	526 (97.4)	OR	<i>p</i>-value
Total	463	77	540	1.57	0.05

AO Airway obstruction, χ^2 Chi-square test, OR Odd ratio

FEV₂₅₋₇₅. Moreover, increased HC, WC, pBMI and TMM were associated ($p < 0.05$) with reduced FEV₁/FVC ratio (Table 4).

Discussion

In this study we assessed the cross-sectional association between obesity and lung function. The main finding showed that obesity was associated with a decrease in FEV₁/FVC ratio (airway obstruction) and increase in FVC and FEV₁ in 10–14 year old adolescents. This finding corroborates with some previous spirometry studies in children and adolescent [29–31].

Obesity has been reported to affect lung function and promote the development of respiratory diseases [10]. In obesity, excess fat is deposited in the mediastinum, chest, and abdominal cavity which affects the mechanical properties of the chest and lung wall thus, reduce the compliance of the chest and lung wall, and the entire respiratory system [32]. This may result in airway closure and narrowing with increased resistance in the respiratory system due to the restricted outward movement of the chest wall and downward movement of the diaphragm. This results in restricted expansion of the lung. On the other hand, airway obstruction which is commonly characterised by an FEV₁/FVC less than 70% [33] is strongly associated with obesity in children [34]. Most studies in adults have shown that obese individuals (with or without asthma) have a reduced FEV₁ and FVC but present a normal FEV₁/FVC ratio which is suggestive of a restrictive ventilatory deficit [15, 35]. However, although the relationship between obesity and pulmonary function in children and adolescent remains inconclusive [16] several studies have shown obesity to be associated with reduced FEV₁/FVC (an obstructive deficit) [36, 37]. Findings in this study showed that FEV₁/FVC was significantly lower in obese adolescents. Moreover, a negative association was observed between obesity parameters (WC, HC and pBMI) and FEV₁/FVC ratio in these adolescents. Also, there was an association between obesity

and airway obstruction as obese adolescents were over 1.5 times more likely to have airway obstruction. These findings suggest that obesity was associated with airway obstruction in adolescents. Previous studies have equally reported airway obstruction in obese children and adolescents [38, 39].

Although obese individuals have been reported to have a reduction in FEV₁ and FVC [15, 35], studies in children have reported an increase in FEV₁ and FVC and a reduction in FEV₁/FVC in obese children [31, 40]. In fact, Lazarus et al. showed that even after adjusting for height, an increased FEV₁ and FVC, and a lower FEV₁/FVC ratio was associated with obesity in children [40]. Findings in this study showed FEV₁ and FVC to be increased in obese adolescents and there was a positive association between obesity parameters (WC, HC, WHtR, BMI, TFM) and lung function parameters (FEV₁, FEV₂₅₋₇₅, FVC and PEF) in these adolescents. These findings suggest that childhood obesity is associated with increased FEV₁ and FVC in this population. This finding is in accordance with some previous studies that have shown increased FVC and FEV₁ and reduced in FEV₁/FVC in obese children [31, 41]. This increase in FVC and FEV₁ in obese adolescents which is unexpected has been suggested by previous studies to be due to airway dysanapsis [42, 43], a condition characterised by disproportionate relationship between airways and lungs. Airway dysanapsis is a condition which results from an incongruence of a faster growth in airway length and lung volume relative to a slower rate of increase in airway caliber [42]. Thus, children with obesity experience an accelerated pace of lung growth resulting in airway dysanapsis evident by a disproportionate increase in FVC compared to FEV₁. This incongruence may be a natural physiological process which originated early in life. A meta-analysis study of 24 birth cohorts which recruited over 25,000 children by den Dekker and colleagues found that greater weight at birth and weight gain at infancy were associated with higher FVC and FEV₁ at school age irrespective of the

Table 4 Predictors of lung function parameters in children

Regression coefficient	HC	WC	WHR	WHtR	pBMI	TFM	TMM
FVC	0.013***	0.012***	-0.236	0.703*	0.004***	0.004*	0.03***
FEV ₁	0.009***	0.009***	-0.284	0.382	0.003**	0.004*	0.023***
PEF	0.015**	0.017***	-1.036	-0.319	0.005**	0.003	0.061***
FEV ₁ /FVC	-0.001**	0.001**	0.025	0.088	-0.002*	0.001	-0.001
FEV ₂₅₋₇₅	0.008	0.009***	-0.733	0.118	0.003**	0.005	0.023**

Legend: *significant difference at $p < 0.05$; **significant difference at $p < 0.01$; ***significant difference at $p < 0.001$. HC Hip circumference, WC Waist circumference, WHR Waist to hip ratio, TMM Total muscle mass, TFM Total fat mass, pBMI Body mass index percentile, WHtR Weight to height ratio, FEV₂₅₋₇₅ Forced expiratory volume 25–75% interquartile, FEV₁ Forced expiratory volume in 1 s, FVC Forced vital capacity, PEF Peak expiratory flow

gestational age of the children [44]. Moreover, lower FEV₁/FVC and FEV₂₅₋₇₅ were associated with infant weight gain. Thus, these changes observed may have originated early in life following increased weight after birth.

The strength of this study is that it utilised a relatively sufficient sample size to assess the relationship between obesity and lung function in adolescents of African ancestry. Thus, the findings of this study are reliable and dependable. Further, this is one of the first reports on the relationship between obesity and pulmonary function in South African adolescents of African ancestry.

Despite these strengths, this study was limited to spirometry analysis. Other parameters of lung function assessment including total lung capacity (TLC), functional residual capacity (FRC), and expiratory residual volume (ERV) were not assessed due to the lack of whole-body plethysmography [45, 46]. This was a cross-sectional study and thus did not selectively isolate adolescents with airway obstruction or presenting clinical signs and symptoms for dysanapsis to further confirm the impact of obesity on respiratory function. From a public health perspective, the findings of this study have shown associations between obesity and airway obstruction in South African adolescents of African ancestry which is of public health concern and therefore, identifying some modifiable risk factors such as obesity is of importance for the prevention of potential respiratory diseases. Though the sample size was large, the proportion of obese adolescents was relatively small. As such, it will be interesting to have an increased population of obese children to assess the observed finding. Thus, further studies with a larger sample size using longitudinal models will be important to better assess the impact of obesity on lung function indicators including airway obstruction and dysanapsis with associated clinical manifestations.

Conclusion

This study revealed that obesity was associated with airway obstruction in South African adolescents of African ancestry. This is the first report on the relationship between obesity and lung function in South African children of African ancestry. Being a cross-sectional study, it is therefore necessary for further studies using longitudinal models to ascertain this finding.

Abbreviations

BMI: Body mass index; BP: Blood pressure; DBP: Diastolic blood pressure; COPD: Chronic obstructive pulmonary disease; CVDs: Cardiovascular diseases; ERV: Expiratory residual volume; FEV: Force expiratory volume; FEV₁: Forced expiratory volume in 1 s; FEV₂₅₋₇₅: Forced expiratory volume 25–75% interquartile; FRC: Functional residual capacity; FVC: Forced vital capacity; HC: Hip circumference; HR: Heart rate; pBMI: BMI percentile; PEF: Peak expiratory flow; SBP: Systolic blood pressure; SPSS: Statistical Package for Social Sciences; TFM: Total fat mass; TLC: Total lung capacity; TMM: Total muscle mass; WC: Waist circumference; WHR: Waist to hip ratio; WHtR: Weight to height ratio.

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Authors' contributions

"B.N.N.–C. developed the concept, designed and funded the study. B.N.N.–C., G.A.E. and C.A. performed the field work and collection of data. G.A.E., C.A. and B.N.N.–C. analysed and interpreted the data. G.A.E. wrote the first draft of the manuscript. B.N.N.–C. and G.A.E. reviewed and revised the manuscript. All authors proofread and approved the final manuscript".

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Availability of data and materials

All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate

All methods were performed in accordance with the study protocol of relevant institutional, national, and international guidelines, regulations and legislation required for human studies. Ethical approval was obtained from the Health Sciences Ethics Committee of Walter Sisulu University (Ref No: 112/2018). After careful explanation of the study objectives and protocol, written informed consent was obtained from the parents and/or legal guardians of children before recruitment into the study. Participation was voluntary and participants were free to withdraw from the study at any point.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

1. WHO. Obesity and overweight. 2019. Available: [http:// who. int/ media-centre/ factsheets/ fs311/ en/](http://who.int/media-centre/factsheets/fs311/en/) 2016
2. Chooi YC, Ding C, Magkos F. The epidemiology of obesity. *Met Clin Exp*. 2019;92:6–10.
3. Development Initiatives. 2018 Global Nutrition Report: Shining a Light to Spur Action on Nutrition. Bristol: Development Initiatives Poverty Research Ltd; 2018. <https://globalnutritionreport.org/>. Accessed 2 Apr 2019.
4. Di Cesare M, Sorić M, Bovet P, Miranda JJ, Bhutta Z, Stevens GA, et al. The epidemiological burden of obesity in childhood: a worldwide epidemic requiring urgent action. *BMC Med*. 2019;17:212.
5. Abarca-Gómez L, Abdeen ZA, Hamid ZA, Abu-Rmeileh NM, Acosta-Cazares B, Acuin C, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: A pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*. 2017;390:2627–42.
6. Akindele MO, Phillips JS, Igumbor EU. The relationship between body fat percentage and body mass index in overweight and obese individuals in an Urban African Setting. *J Public Health Afr*. 2016;7(1):515.

7. Krebs NF, Himes JH, Jacobson D, Nicklas TA, Guilday P, Styne D. Assessment of child and adolescent overweight and obesity. *Pediatrics*. 2007;120:5193–222.
8. di Palmo E, Filice E, Cavallo A, Caffarelli C, Maltoni G, Miniaci A, et al. Childhood obesity and respiratory diseases: which link? *Children*. 2021;8:177.
9. Zammit C, Liddicoat H, Moonsie I, Makker H. Obesity and respiratory diseases. *Int J General Med*. 2010;3:335–43.
10. Salome CM, King GG, Berend N. Physiology of obesity and effects on lung function. *J Appl Physiol*. 2010;108:206–2011.
11. Parameswaran K, Todd DC, Soth M. Altered respiratory physiology in obesity. *Can Respir J*. 2006;13(4):203–10.
12. Franssen FME, O'Donnell DE, Goossens GH, Blaak EE, Schols AMWJ. Obesity and the lung: 5? Obesity and COPD *Thorax*. 2008;63:1110–7.
13. Peters U, Dixon AE. The effect of obesity on lung function. *Expert Rev Respir Med*. 2018;12:755–67.
14. Melo LC, Silva MA, Calles AC. Obesity and lung function: a systematic review. *Einstein (São Paulo)*. 2014;12(1):120–5.
15. Jones RL, Nzekwu MMU. The effects of body mass index on lung volumes. *Chest*. 2006;130:827–33.
16. Ferreira MS, Marson MAL, Wolf VL, Ribeiro JD, Mendes RT. Lung function in obese children and adolescents without respiratory disease: a systematic review. *BMC Pulmonary Med*. 2020;20:281.
17. Farrag NS, Cheskin LJ, Farag MK. A systematic review of childhood obesity in the Middle East and North Africa (Mena) region: prevalence and risk factors meta-analysis. *Adv Pediatr Res*. 2017;4:8.
18. Kimani-Murage EW, Kahn K, Pettifor JM, Tollman SM, Dunger DB, Gómez-Olivé XF, et al. The prevalence of stunting, overweight and obesity, and metabolic disease risk in rural South African children. *BMC Public Health*. 2010;10:158.
19. Nkeh-Chungag BN, Sekokotla AM, Sewani-Rusike C, Namugowa A, Iputo JE. Prevalence of hypertension and pre-hypertension in 13–17 year old adolescents living in Mthatha - South Africa: a cross-sectional study. *Cent Eur J Public Health*. 2015;23:59–64.
20. Sekokotla MA, Goswami N, Sewani-Rusike CR, Iputo JE, Nkeh-Chungag BN. Prevalence of metabolic syndrome in adolescents living in Mthatha. *South Africa Ther Clin Risk Manag*. 2017;13:131–7.
21. Letswalo BP, Schmid-Zalaudek K, Brix B, Matjuda EN, Klosz F, Obernhumer N, et al. Cardiometabolic risk factors and early indicators of vascular dysfunction: a cross-sectional cohort study in South African adolescents. *BMJ Open*. 2021;11:e042955.
22. Davidson WJ, Mackenzie-Rife KA, Witmans MB, Montgomery MD, Ball GD, Egbogah S, et al. Obesity negatively impacts lung function in children and adolescents. *Pediatr Pulmonol*. 2014;49:1003–10010.
23. Köchli S, Endes K, Bartenstein T, Usemann J, Schmidt-Trucksäss A, Frey U, et al. Lung function, obesity and physical fitness in young children: The EXAMIN YOUTH study. *Respir Med*. 2019;159:105813.
24. Torun E, Cakir E, Özgüç F, Özgen IT. The Effect of Obesity Degree on Childhood Pulmonary Function Tests. *Balkan Med J*. 2014;31:235–8.
25. Stewart A, Marfell-Jones M, Olds T, Ridder H. International Standards for Anthropometric Assessment. Lower Hutt: ISAK; 2011.
26. Matjuda EN, Engwa GA, Anye SNC, Nkeh-Chungag BN, Goswami N. Cardiovascular risk factors and their relationship with vascular dysfunction in South African Children of African Ancestry. *J Clin Med*. 2021;10:354.
27. Centers for Disease Control and Prevention. A SAS Program for the 2000 CDC Growth Charts (Ages 0 to <20 Years); Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention: Atlanta. USA: GA; 2014.
28. Graham BL, Steenbruggen I, Miller MR, Barjaktarevic IZ, Cooper BG, Hall GL, et al. Standardization of spirometry 2019 update. An official American Thoracic Society and European Respiratory Society Technical Statement. *Am J Respir Crit Care Med*. 2019;200(8):e70–88.
29. Weinmayr G, Forastiere F, Büchele G, Jaensch A, Strachan DP, Nagel G, et al. Overweight/obesity and respiratory and allergic disease in children: international study of asthma and allergies in childhood (ISAAC) phase two. *PLoS One*. 2014;9:e113996.
30. Ekström S, Hallberg J, Kull I, Protudjer JLP, Thunqvist P, Bottai M, et al. Body mass index status and peripheral airway obstruction in school-age children: a population-based cohort study. *Thorax*. 2018;73:538–45.
31. Forno E, Han YY, Mullen J, Celedón JC. Overweight, obesity, and lung function in children and adults - a meta-analysis. *J Allergy Clin Immunol Pract*. 2018;6(2):570–581.e10.
32. Chapman D, King G, Forno E. Chapter 3 - Obesity and lung function: From childhood to adulthood. In: Johnston RA, Suratt BT, editors. *Mechanisms and Manifestations of Obesity in Lung Disease*. London: Academic Press; 2019. p. 45–65.
33. Moore VC. Spirometry: step by step. *Breathe-Eur Respir Soc*. 2012;8:232–40.
34. Hasan RA, Abuhammour W, Zureikat GY. The relationship between body weight and objective measures of airway obstruction in children. *The Open Pediatr Med J*. 2009;3:26–30.
35. King GG, Brown NJ, Diba C, Thorpe CW, Munoz P, Marks GB, Toelle B, et al. The effects of body weight on airway calibre. *Eur Respir J*. 2005;25:896–901.
36. Forno E, Acosta-Pérez E, Brehm JM, Han YY, Alvarez M, Colón-Semidey A, et al. Obesity and adiposity indicators, asthma, and atopy in Puerto Rican children. *J Allergy Clin Immunol*. 2014;133(5):1308–14 (e1-5).
37. Emil GE, Saad EBM, Mohammed AF, Mohamed HM. Effects of body weight and posture on pulmonary functions in asthmatic children. *Afri Health Sci*. 2020;20(4):1777–84.
38. Han YY, Forno E, Celedón JC. Adiposity, fractional exhaled nitric oxide, and asthma in U.S. children. *Am J Respir Crit Care Med*. 2014;190:32–9.
39. Chu YT, Chen WY, Wang TN, Tseng HI, Wu JR, Ko YC. Extreme BMI predicts higher asthma prevalence and is associated with lung function impairment in school-aged children. *Pediatr Pulmonol*. 2009;44:472–9.
40. Tantisira KG, Litonjua AA, Weiss ST, Fuhlbrigge AL. Association of body mass with pulmonary function in the Childhood Asthma Management Program (CAMP). *Thorax*. 2003;58(12):1036–41.
41. Lazarus R, Colditz G, Berkey CS, Speizer FE. 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(3):187–94.
42. Forno E, Weiner DJ, Mullen J, Sawicki G, Kurland G, Han YY, et al. Obesity and airway dysanapsis in children with and without asthma. *Am J Respir Crit Care Med*. 2017;195(3):314–23.
43. Forno E, Weiner D, Mullen J, Kurland G, Sawicki GS, Acosta-Perez E, et al. Obesity and airway dysanapsis in children and adolescents with and without asthma [abstract]. *Am J Respir Crit Care Med*. 2016;193:A3828.
44. den Dekker HT, Sonnenschein-van der Voort AM, de Jongste JC, Anessi-Maesano I, Arshad SH, Barros H, et al. Early growth characteristics and the risk of reduced lung function and asthma: a meta-analysis of 25,000 children. *J Allergy Clin Immunol*. 2016;137:1026–35.
45. Dempsey TM, Scanlon PD. Pulmonary function tests for the generalist: a brief review. *Mayo Clin Proc*. 2018;93(6):763–71.
46. Chu MW, Han JK. Introduction to Pulmonary Function. *Otolaryngol Clin N Am*. 2008;41:387–96.

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