Original Article

Sex Differences in Spirometric Measures and its Association with Basal Metabolic Rate in Obese and Healthy Normal Weight Middle-Aged Subjects

Afreen Begum H. Itagi, Ambrish Kalaskar[1], Pasang Tshering Dukpa[2], Dhruba Hari Chandi[3], G. Y. Yunus[4]

Department of Physiology, All India Institute of Medical Sciences, Mangalagiri, Andhra Pradesh, [1]Department of Physiology, Navodaya Medical College and Research Center, Raichur, [4]Department of Public Health Dentistry, ESIC Dental College, Kalaburagi, Karnataka, [2]Department of Physiology, A. B. N. Seal College, Cooch Behar, West Bengal, [3]Department of Microbiology, Datta Meghe Institute of Medical Sciences, Wardha, Maharashtra, India

Abstract

Context: Reduced basal metabolic rates (BMRs) are said to be common in obese or sedentary adults. Very few investigations have analyzed the BMR relationship with that of respiratory functions in middle-aged obese individuals. **Objectives:** We aimed to determine the sex differences in BMR and spirometric measures in obesity and evaluate the association of BMR with respiratory functions in middle-aged people. **Methods:** This analytical study was undertaken in healthy normal-weight and obese men and women (50 each) of age 35–55 years. Body mass index (BMI), percentage of body fat, fat mass, and fat-free mass were estimated and BMR was calculated using predicted equations. Spirometric measures such as forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1), FEV_1/FVC, peak expiratory flow rate, mean forced expiratory flow during the middle of FVC ($FEF_{25\%-75\%}$), and maximum voluntary ventilation were assessed in both sexes. Independent two-sample *t*-test and Pearson's correlation were used as tests of significance with $P \leq 0.05$ affirming the statistical significance. **Results:** BMR among men showed significantly higher mean scores than females. In obese group, most of the respiratory function parameters except FEV1/FVC ratio were significantly reduced in females compared to men. An inverse correlation existed between BMR and FEV1/FVC ratio, whereas BMR observed a positive correlation with all other respiratory function measures among both obese and nonobese. **Conclusions:** To study the early lung function alterations in the obese, it is necessary to take into account the sex differences, BMR, and body composition instead of BMI alone.

Keywords: Anthropometrics, basal metabolism, lung functions, obesity, sex differences

Introduction

Obesity being twenty-first century's worldwide and one of the most pressing public health concerns has approached epidemic proportions in India, with morbid obesity afflicting over 5% of the country's population.[1] The energy metabolism rate per day that an individual must endure in order to maintain the integrity of daily vital functions is referred to as the basal metabolic rate (BMR). It is a minimum required energy for sustenance of life in temperate environment neutrally when in a postabsorptive condition, taking into account the energy cost of physiological activities such as muscular contractions, breathing, and brain activity.[2] It is hypothesized that reduced BMRs are common in obese people and in sedentary adults, BMR accounts for 60% of total energy expenditure.[3] However, differential BMRs, on the other hand, are unlikely to be the cause of growing obesity rates.[4]

Access this article online

Quick Response Code:

Website: www.ijrc.in

DOI: 10.4103/ijrc.ijrc_116_21

Obesity impedes the mobility of diaphragm and the expansion of the thoracic cage, which reduces chest compliance. Its negative impacts on energy cost/effort of breathing, respiratory mechanics, respiratory resistance, respiratory volumes and muscle functioning, gaseous exchange in lungs, and breathing control can drastically change pulmonary function and cut down exercise capacity.[5,6] The mechanism that impacts respiratory function in obesity is still being disputed, and so is an appropriate indicator of fatness in connection to respiration in a dynamic state yet unclear.[7-9]

Address for correspondence: Dr. Afreen Begum H. Itagi, Department of Physiology, All India Institute of Medical Sciences, Mangalagiri, Andhra Pradesh, India. E-mail: afreen.itagi@gmail.com

How to cite this article: Itagi AB, Kalaskar A, Dukpa PT, Chandi DH, Yunus GY. Sex differences in spirometric measures and its association with basal metabolic rate in obese and healthy normal weight middle-aged subjects. Indian J Respir Care 2022;11:14-9.

Received: 06-09-2021 **Revised:** 27-10-2021
Accepted: 01-11-2021 **Published:** 04-01-2022

Multiple studies have found that obese persons had inferior lung volumes, with negative relation between lung functioning and numerous indicators of fat distribution and obesity.[5-10] Only a few investigations, however, have looked at the association between BMR and the components of ventilatory dysfunction.[11-14]

To our knowledge, the relationship between obesity and BMR as a risk factor for pulmonary dysfunction has not been thoroughly investigated and documented among South Indians, who are regarded to be at higher risk of obesity-related problems. Furthermore, there is a dearth of research evidence about sex differences in BMR, spirometric measures in obesity, and also the association between BMR and ventilatory dysfunction in middle-aged people. Hence, the study aimed at investigating the BMR and its influence on spirometric measures among middle-aged obese and nonobese individuals with an emphasis on sex differences in the same.

Methods

This observational research was undertaken in an institute of medical sciences and research in southern India. The apparently healthy individuals between the ages of 35 and 55 years were taken as participants. Minimum required sample (N) was estimated using the equation $N = (Z/2)^2 s^2/d^2$; considering power of 80%, error rate of 5% and taking into account the standard deviation (SD) of 9 resulted from the pilot study undertaken on 8 middle-aged obese adults, the estimated sample size was 45. However, allowing for 10% nonrespondents, the corrected sample size required in each group was 49. Detailed history of extended exposure to drugs that can lead to altered lung functions, medical issues requiring drug therapy during the last 6 months, and current clinical/systemic examination findings were recorded. Subjects with physical chest wall abnormalities, established obstructive pulmonary illness, unstable coronary syndromes, presently smokers and alcoholics were excluded. The approval of research protocol was provided by the institutional scientific review board and ethical committee. Informed as well as written consent from all subjects was obtained after satisfactorily detailing about the objectives and procedures of the study.

After a minimum of 2 h of light breakfast and according to the specified guidelines, anthropometric measures were obtained in the physiology laboratory. All spirometric measurements were obtained from 10 a. m. to 12 noon to eliminate circadian variations.[15] The estimation of BMR was done using height, age, gender, and body weight. Measuring the weight to the nearest 0.5 kilogram (kg) was done using a digital personal weighing scale (Apollo Hospitals Enterprises Ltd), while the stature was recorded by means of 150 cm standard flexible poly-fiber tape for measuring to the nearest 0.2 cm, with the subject standing against a wall and head in Frankfort horizontal plane.[16] Body mass index (BMI) was calculated as weight/height^2, expressed in kilograms and square meters (m^2), respectively.[17] Percentage of body fat (BF%) was calculated based on physiological differences in the males and females by using Deurenberg formula, which accounts for factors such as age, BMI, and sex.[17] BF% estimation was followed by calculation of fat mass (FM) and fat-free mass (FFM) using the standard equations.[17-19] Eventually, Cunningham's equation is used to relate the FFM with the BMR, as mentioned in Table 1.

The pulmonary function tests were performed as per the Joint Indian Chest Society-National College of Chest Physicians (India) guidelines for spirometry. Subjects with history of forced expiration/cough-related syncope, thoracic (or) abdominal surgery in recent 4 weeks, atrial/ventricular arrhythmia, confirmed/suspected systemic or transmissible respiratory infection were excluded from participating in the study. "NDD – Easy on PC," a portable, computerized, precalibrated, electronic, dry-type spirometer from NDD Medical Technologies, was used for recording spirometric measures. Even though the sensor of NDD – Easy on PC is based on a principle of digital measurement technique, requires calibration only once, and does not change during the sensor's lifetime, daily calibration verification of the spirometer at low, medium, and high flow along with the visual inspection of the performance of each maneuver was also undertaken by the principal investigator for quality assurance.

Spirometric measurements were recorded in a vacant area with adequate sunlight, and the subjects were made to sit comfortably/relaxed in an armed chair with straight back and were explained about the forced expiratory maneuvers before the procedure. Disposable filter mouthpiece (spirette) was used to avoid cross-contamination, and face masks and gloves were used to protect the investigator/assistants. The participants were asked to inhale atmospheric air deeply, and the nose clip was placed immediately with the spirette inside the mouth, lips tightly sealed around it, followed by blowing out the air as hard and fast as possible. The blast out for a minimum of 6 s was followed by inhalation deeply with the spirette still inside the mouth (to form a loop). Similarly, at least three appropriate maneuvers of forced vital capacity (FVC), forced 1-s expiratory volume (FEV$_1$), mean forced expiratory flow during the middle of FVC (FEF$_{25\%–75\%}$), peak expiratory flow rate (PEFR), and maximum voluntary ventilation (MVV) have been performed. The highest volumes of three acceptable FVCs, FEV$_1$, PEFR, and FEV$_1$/FVC ratio percentage were recorded. MVV was assessed by asking the subject to inhale and exhale as deeply and rapidly as possible for 15 s.

Statistical analysis

The data were analyzed using version 20.0 Statistical Package for the Social Sciences software (SPSS Inc., IBM

Table 1: Measures and formulae used for calculation of basal metabolic rate

Measures	Formula
Percentage of BF	(1.2 × BMI) + (0.23 × age)−(Sex* × 10.8)−5.4
FM (kg)	Weight × BF%
FFM (kg)	Weight–FM
BMR (kcal/day)	501.6 + 21.6 (FFM)

*Male=1 and female=0. BF: Body fat, FM: Fat mass, FFM: Fat-free mass, BMR: Basal metabolic rate

Corporation, Chicago, Illinois, USA). Descriptive data presentation included expressing as mean ± SD or percentages. Independent two-sample *t*-test was used as an inferential test for measuring the difference between two measured variables. The degree of correlation was determined using the correlation coefficient (Pearson's "*r*"). Statistically significant was affirmed at $P \leq 0.05$.

Results

The estimated gender-wise mean age and anthropometric measurements of both the groups, i.e., obese (n = 50) and nonobese (n = 50), are presented in Table 2. In both obese and normal-weight individuals, BMR was higher in males than in females ($P < 0.05$). In comparison to nonobese middle-aged individuals, the BMR was significantly higher among obese group [Table 3].

The spirometric evaluation showed substantial sex difference in most of the respiratory measures among obese with significant reduction in females than in males. However, except for FEF and MVV, no other respiratory measures were significantly less in normal-weight females than in nonobese males [Table 2]. The PFT parameters FVC, FEV_1, and $FEF_{25-75\%}$ were substantially lower in obese group; however, FEV_1/FVC%, PEFR, and MVV were not significantly different in comparison to nonobese [Table 3]. Table 4 shows the sex differences in the correlation of BMR with spirometric parameters. In both the obese and nonobese groups studied, a significantly positive correlation of BMR was identified with FVC and FEV_1. In comparisons to obesity (r = +0.66 FVC and r = +0.62 for FEV1), the degree of correlation was higher for nonobese compared to obese (r = +0.57 FVC and r = +0.56 FEV_1) [Table 4 and Figure 1]. This positive association implies that whenever the BMR increases, the FVC and FEV_1 levels will increase significantly. An inverse correlation of BMR with FEV1/FVC was observed among both obese and nonobese subjects, which was showing comparatively higher strength of relationship in obese group (r = −0.02) than the nonobese middle-aged individuals (r = −0.002). A positive correlation of BMR with PEFR, $FEF_{25\%-75\%}$, and MVV was observed in both groups, with the strength of correlation being comparatively slightly high and significant in nonobese subjects, as shown in Table 4 and Figure 1.

Discussion

Obesity is linked to variation of lung volume and result in various patterns of alteration to the respiratory parameters; however, it is still unclear whether the gender difference exists. The BMR accounts for 44%–70% of total daily expended energy, subjected to age and lifestyle, and is largely determined by age, gender, body size, body composition, etc., and hence, BMR is the principal focus of development and treatment of obesity.[20,21] Spirometry is among the simplest of the tools to detect impairment in pulmonary function at an early stage so that preventive measures can be adopted. Our study evaluates the sex differences in respiratory function parameters and examines the relationship of BMR with spirometric measures among the obese and nonobese subjects of age group 35–55 years.

In the present study, BMR, $FEF_{25\%-75\%}$, and MVV measures were significantly higher for nonobese men than the

Table 2: Sex differences in anthropometric measures, basal metabolic rate, and spirometric measures among obese and nonobese subjects

	Nonobese (n = 50)			Obese (n = 50)		
	Mean±SD		*P*	Mean±SD		*P*
	Males (n = 25)	Females (n = 25)		Males (n = 25)	Females (n = 25)	
Age	44.8±6.25	45.4±6.39	0.705	45.3±6.36	44.6±6.49	0.710
Weight	63.8±6.21	61.2±5.84	0.128	84.7±7.36	74.28±9.6	0.000
Height	1.6±0.05	1.59±0.04	0.175	1.62±0.05	1.55±0.66	0.000
BMI	24.2±1.98	23.9±1.98	0.659	32.06±2.06	31.88±1.46	0.724
BF%	23.1±2.6	32.8±4.51	0.000	32.8±3.49	43.18±2.44	0.000
FM	14.8±2.64	20.2±4.11	0.000	27.8±5.09	33.40±3.63	0.000
FFM	48.9±4.29	41.0±3.71	0.000	56.8±4.04	43.93±4.26	0.000
FMI	5.97±1.3	8.94±3.08	0.000	13.6±3.58	14.36±2.44	0.386
BMR	1551.8±100	1404.9±104	0.000	1664.6±321	1440.4±89	0.002
FVC	3.21±0.61	3.08±0.41	0.365	4.17±0.63	2.97±0.59	0.000
FEV_1	2.99±0.64	2.92±0.37	0.642	3.89±0.81	2.77±0.41	0.000
FEV_1/FVC (%)	93.13±9.58	91.37±18.6	0.676	92.6±9.86	95.0±9.26	0.366
PEFR	7.86±1.53	7.59±1.76	0.556	6.83±1.93	7.88±1.73	0.049
$FEF_{25\%-75\%}$	4.48±1.3	3.70±0.73	0.012	3.57±0.98	3.13±0.53	0.053
MVV	131.2±30.8	94.8±12.6	0.000	144.2±26.1	91.44±13.9	0.000

Independent two-sample *t*-test used for analysis of the parameters; $P \leq 0.05$ = Significant. SD: Standard deviation, BMI: Body mass index, BF: Body fat, FM: Fat mass, FFM: Fat-free mass, BMR: Basal metabolic rate, FVC: Forced vital capacity, FEV_1: Forced expiratory volume in 1 s, PEFR: Peak expiratory flow rate, MVV: Maximal voluntary ventilation, FEF: Forced expiratory flow, FMI: Fat mass index

Table 3: Comparison of anthropometric measures, basal metabolic rate, and spirometric measures between obese and nonobese subjects

Pulmonary parameters (actual value)	Mean±SD		Significance	
	Obese ($n = 50$)	Nonobese ($n = 50$)	t	P
Age (years)	45.0±6.4	45.1±6.3	0.13	0.90 (NS)
Weight (kg)	79.5±9.98	62.56±6.12	10.23	<0.001 (HS)
Height (m)	1.59±0.07	1.61±0.05	1.15	0.251 (NS)
BMI (kg/m^2)	31.9±1.78	24.1±1.97	20.94	<0.001 (HS)
BF %	37.99±6.03	28.0±6.10	8.23	<0.001 (HS)
FM (kg)	30.65±5.19	17.57±4.36	13.65	<0.001 (HS)
FFM (kg)	50.37±7.69	45.00±5.66	3.98	<0.001 (HS)
FMI (kg/m^2)	13.99±3.06	7.46±2.78	11.15	<0.001 (HS)
BMR (kcal/day)	1584±169.2	1478±126.0	3.55	0.001* (HS)
FVC (L)	3.57±0.86	3.15±0.52	2.95	0.04* (S)
FEV_1 (L)	3.34±0.85	2.96±0.52	2.66	0.009* (S)
FEV_1/FVC (%)	93.8±9.6	93.9±8.2	0.06	0.95 (NS)
PEFR (L/sec)	7.36±1.90	7.73±1.64	1.05	0.30 (NS)
$FEF_{25\%-75\%}$ (L/sec)	3.35±0.81	4.10±1.12	3.80	<0.001** (HS)
MVV (L/min)	117.9±33.8	113.0±29.7	0.76	0.45 (NS)

Independent two-sample *t*-test used for analysis of the parameters. *P<0.05, S, **P<0.01, HS. HS: Highly significant, S: Significant, NS: Not significant, SD: Standard deviation, BMI: Body mass index, BF: Body fat, FM: Fat mass, FFM: Fat-free mass, BMR: Basal metabolic rate, FVC: Forced vital capacity, FEV_1: Forced expiratory volume in 1 s, PEFR: Peak expiratory flow rate, MVV: Maximal voluntary ventilation, FEF: Forced expiratory flow, FMI: Fat mass index

Table 4: Comparison of basal metabolic rate with relation to spirometric measures between obese and nonobese subjects

		r with BMR (kcal/day)					
Group	Correlation	FVC (L)	FEV_1 (L)	FEV_1/FVC (%)	PEFR (L/sec)	$FEF_{25\%-75\%}$ (L/sec)	MVV (L/min)
Nonobese males (n = 25)	r	0.778**	0.815**	0.285	0.776**	0.791**	0.739**
	P	0.000	0.000	0.168	0.000	0.000	0.000
Nonobese females (n = 25)	r	0.696**	0.634**	−0.079	0.724**	0.463*	0.599**
	P	0.000	0.001	0.708	0.000	0.020	0.002
Nonobese (n=50)	r	0.660**	0.618**	−0.002	0.652**	0.692**	0.769**
	P	0.000	0.000	0.99	0.000	0.000	0.000
Obese males (n = 25)	r	0.388	0.395	0.211	0.135	0.184	0.223
	P	0.056	0.051	0.310	0.519	0.377	0.284
Obese females (n = 25)	r	0.757**	0.609**	−0.586**	0.803**	0.654**	0.749**
	P	0.000	0.001	0.002	0.000	0.000	0.000
Obese (n= 50)	r	0.569**	0.567**	−0.020	0.086	0.324*	0.501**
	P	0.000	0.000	0.889	0.555	0.022	0.000

**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level. r: Pearson's correlation coefficient, FVC: Forced vital capacity, FEV_1: Forced expiratory volume in 1 s, PEFR: Peak expiratory flow rate, MVV: Maximal voluntary ventilation, FEF: Forced expiratory flow, BMR: Basal metabolic rate

corresponding values for normal-weight women. It was found that the BMR, FVC, FEV1, PEFR, FEF, and MVV measures in obese females were substantially lower than in obese men. These findings corroborate previous data of similar studies by Mihai *et al*., Wang *et al*., Merghani *et al*., and Lasser *et al*., where comparative analysis was undertaken between obese and normal-weight individuals.[11,20,22,23] In addition to smaller lung volumes and diffusion surfaces, the respiratory airways in women are usually with smaller diameter compared to their height-matched men. The lower lung function test values of female subjects in this study can be attributed to the above gender-related differences, which is evident from previous research.[24,25]

There existed a positive correlation of pulmonary functions with BMR, which implies the higher the BMR, the higher were the levels of FVC, FEV1, and $FEF_{25\%–75\%}$ in both normal-weight and obese subjects, however, the levels of PEFR showed a nonsignificant correlation in obese subjects only. These possibly indicate that respiratory functions are more directly related to fat distribution rather than the degree of obesity. Respiratory measure variables, such as forced FEV_1 and FVC, tend to decline with continuing increase in BMR.[11,12,21] The

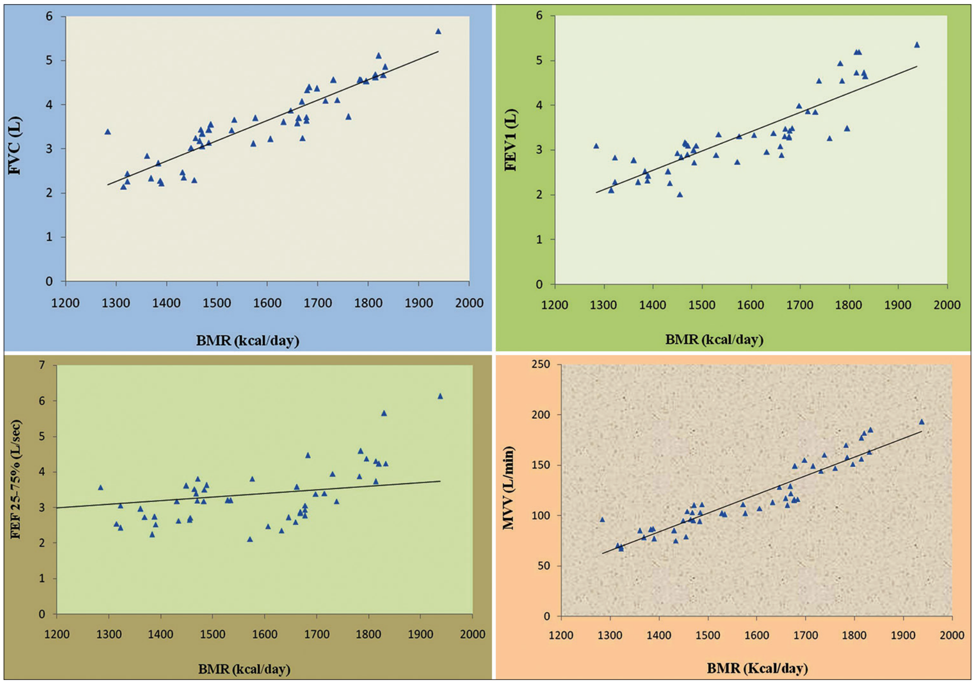

Figure 1: Relationship of basal metabolic rate with pulmonary functions in obese subjects

effect is, however, quite minimal, and in children, healthy adults, and obese individuals, FVC and FEV_1 are commonly within the normal range. The FEV_1-to-FVC ratio even in morbid obesity is either well maintained or increased, implying that both FEV1 and FVC are influenced equally. This outcome signifies that obesity has a substantial impact on lung volume but has no effect on airway obstruction directly.[11-14,26]

Our study shows that the level of $FEF_{25\%–75\%}$ was significantly higher in subjects with increased BMR reflecting a positive correlation. A study done on respiratory function in obese individuals with normal FEV1/FVC showed that pulmonary function is impaired only with higher degrees of obesity.[27] Similarly, other studies have shown obesity to modestly affect the total lung capacity and vital capacity.[5,28-30] Our investigation is consistent with the results of Ofuya *et al*. which reported a decrease in PEFR in obesity.[31]

Harik-Khan *et al*., Zeng *et al*., and others confirmed that deposition of fat minimizes the thoracic movements and also observed reduced maximal expiratory flow rates at lower lung volumes indicating impeded peripheral airflow and resistance in obese individuals.[13,32,33] The harmful influence of abnormal metabolism and obesity on lung function is also affirmed in many other studies.[30,34,35] In line with these observations, we found BMR significantly correlated with values of respiratory function indicators. There is, however, a considerable deviation in BMR between normal weight and individuals with obesity as its calculations are based directly on participants' weight.

Limitations

Among the limitations of the study, important ones to mention include the use of BMI as an obesity analysis parameter which rather cannot differentiate muscle mass from body fat. We did not investigate further the duration of obesity, potential association between changes in respiratory volumes, and obesity phenotype (i.e., central/abdominal obesity), which might account for the above sex differences. The moderate sample size of our study has limits, and it may be useful to assess maximal inspiratory and expiratory pressures, which are markers of diaphragm strength and abdominal/intercostal muscle strength, respectively, along with FVC and FEV1. FVC and FEV1 are the pulmonary variables most commonly utilized in clinical investigations and appear to be the most closely associated with fat distribution. To further validate the existence of this association, it is proposed that a more practical estimate of BMR based on direct oxygen consumption measurement be undertaken. Finally, the study population was confined to small geographical location in south India, and hence, it is uncertain whether our findings could be generalized to other populations.

Conclusions

We found a significant effect of BMR on spirometric measures, and gender difference existed in detrimental effects of obesity on lung functions. Females were more susceptible to the effects than males. To our knowledge, this is one of the few studies of its kind that has sought to determine and assess the association of BMR with respiratory functioning in obese and normal-weight individuals. Although our research is not thorough, it does give a glimpse into direct relationships of BMR with pulmonary functions in middle-aged healthy subjects with obesity. The study outcomes suggest that the BMR is a stronger predictor of pulmonary function changes in normal-weight and obese people; therefore, instead of looking at BMI, it is vital to look at BMR when identifying early changes in respiratory function.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Hruby A, Hu FB. The epidemiology of obesity: A big picture. Pharmacoeconomics 2015;33:673-89.
2. Foster GD, McGuckin BG. Estimating resting energy expenditure in obesity. Obes Res 2001;9 Suppl 5:367S-72.
3. Henry CJ. Basal metabolic rate studies in humans: Measurement and development of new equations. Public Health Nutr 2005;8:1133-52.
4. Bruen C. Variation of basal metabolic rate per unit surface area with age. J Gen Physiol 1930;13:607-16.
5. Bokov P, Delclaux C. The impact of obesity on respiratory function. Rev Mal Respir 2019;36:1057-63.
6. Nguyen LP, Nguyen BX, Ngo TT, Nguyen YH, Phan HT. Correlations between excessive body mass index, body perception, physical activity, and respiratory functions among youths in an urban setting of vietnam. Biomed Res Int 2020;2020:9627605.
7. Mafort TT, Rufino R, Costa CH, Lopes AJ. Obesity: Systemic and pulmonary complications, biochemical abnormalities, and impairment of lung function. Multidiscip Respir Med 2016;11:28.
8. Wannamethee SG, Shaper AG, Whincup PH. Body fat distribution, body composition, and respiratory function in elderly men. Am J Clin Nutr 2005;82:996-1003.
9. Leone N, Courbon D, Thomas F, Bean K, Jégo B, Leynaert B, *et al.* Lung function impairment and metabolic syndrome: The critical role of abdominal obesity. Am J Respir Crit Care Med 2009;179:509-16.
10. Dixon AE, Peters U. The effect of obesity on lung function. Expert Rev Respir Med 2018;12:755-67.
11. Merghani TH, Alawad AO, Ibrahim RM, Abdelmoniem AM. Prediction of basal metabolic rate in overweight/obese and non-obese subjects and its relation to pulmonary function tests. BMC Res Notes 2015;8:353.
12. Choi JW, Pai SH. Brief communication: Respiratory function is closely associated with basal metabolic rate in elderly persons. Ann Clin Lab Sci 2004;34:99-102.
13. Harik-Khan RI, Wise RA, Fleg JL. The effect of gender on the relationship between body fat distribution and lung function. J Clin Epidemiol 2001;54:399-406.
14. Lee YY, Tsao YC, Yang CK, Chuang CH, Yu W, Chen JC, *et al.* Association between risk factors of metabolic syndrome with lung function. Eur J Clin Nutr 2020;74:811-7.
15. Spengler CM, Cotes SA. Endogenous circadian rhythm of pulmonary function in healthy humans. Am J Respir Crit Care Med 2002;166:1005.
16. Norgan NG, Ferro-Luzzi A. Weight-height indices as estimators of fatness in men. Hum Nutr Clin Nutr 1982;36:363-72.
17. Lean ME, Han TS, Deurenberg P. Predicting body composition by densitometry from simple anthropometric measurements. Am J Clin Nutr 1996;63:4-14.
18. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: Age and sex-specific prediction formulas. Br J Nutr 1991;65:105-14.
19. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. Height-normalized indices of the body's fat-free mass and fat mass: Potentially useful indicators of nutritional status. Am J Clin Nutr 1990;52:953-9.
20. Lasser S, Bedogni G, Lafortuna CL, Marazzil N, Bustil C, Galli R, *et al*. Relationship between basal metabolic rate, gender, age and body composition in 8,780 white obese subjects. Obesity 2009;18:71-8.
21. Cunningham JJ. A reanalysis of the factors influencing basal metabolic rate in normal adults. Am J Clin Nutr 1980;33:2372-4.
22. Mihai A, Zetu C, Carniciu S, Picu A, Petcu L, Guja C, *et al.* Gender influence on resting metabolic rate and adipocytokines levels in newly diagnosed type 2 diabetic patients with metabolic syndrome. Rom J Diabetes Nutr Metab Dis 2014;21:193-202.
23. Wang Z, Ying Z, Bosy-Westphal A, Zhang J, Heller M, Later W, *et al.* Evaluation of specific metabolic rates of major organs and tissues: Comparison between men and women. Am J Hum Biol 2011;23:333-8.
24. Mead J. Dysanapsis in normal lungs assessed by the relationship between maximal flow, static recoil, and vital capacity. Am Rev Respir Dis 1980;121:339-42.
25. Thurlbeck WM. Postnatal human lung growth. Thorax 1982;37:564-71.
26. Bhammar DM, Babb TG. Effects of obesity on the oxygen cost of breathing in children. Respir Physiol Neurobiol 2021;285:103591.
27. Santana H, Zoico E, Turcato E, Tosoni P, Bissoli L, Olivieri M, *et al.* Relation between body composition, fat distribution, and lung function in elderly men. Am J Clin Nutr 2001;73:827-31.
28. Sathyaprabha TN. Basal metabolic rate and body composition in elderly Indian males. Indian J Physiol Pharmacol 2000;44:179-84.
29. Strachan DP. Ventilatory function, height, and mortality among abdominal obesity and respiratory function. Am J Epidemiol 2004;159:1140-9.
30. Gabrielsen AM, Lund MB, Kongerud J, Viken KE, Røislien J, Hjelmesæth J. The relationship between anthropometric measures, blood gases, and lung function in morbidly obese white subjects. Obes Surg 2011;21:485-91.
31. Ofuya ZM, Georgewill AA, Agu GO. A study of cardiovascular and respiratory parameters in obese and non-obese subjects resident in Port Harcourt. Afr J Appl Zool Environ Biol 2005;7:11-3.
32. Zeng X, Liu D, An Z, Li H, Song J, Wu W. Obesity parameters in relation to lung function levels in a large Chinese rural adult population. Epidemiol Health 2021;43:e2021047.
33. Hegewald MJ. Impact of obesity on pulmonary function: Current understanding and knowledge gaps. Curr Opin Pulm Med 2021;27:132-40.
34. Johnstone AM, Murison SD, Duncan JS, Rance KA, Speakman JR. Factors influencing variation in basal metabolic rate include fat-free mass, fat mass, age, and circulating thyroxine but not sex, circulating leptin, or triiodothyronine. Am J Clin Nutr 2005;82:941-8.
35. Wang S, Sun X, Hsia TC, Lin X, Li M. The effects of body mass index on spirometry tests among adults in Xi'an, China. Medicine (Baltimore) 2017;96:e6596.