The Difference Between Slow and Forced Vital Capacity Increases With Increasing Body Mass Index: A Paradoxical Difference in Low and Normal Body Mass Indices

Spyridon Fortis MD, Edward O Corazalla MSc RPFT, Qi Wang MSc, and Hyun J Kim MD

BACKGROUND: Obesity reduces FVC, the most commonly used measurement of vital capacity (VC) and slow VC (SVC). It is unknown whether the difference between SVC and FVC is constant in different body mass indices (BMIs). We hypothesized that the difference between SVC and FVC increases as a function of BMI. METHODS: We retrospectively reviewed pulmonary function tests (PFTs) that included spirometry and plethysmography and were performed in adults from January 2013 to August 2013. A total of 1,805 PFTs were enrolled. The non-parametric Wilcoxon signed-rank test was used to compare FVC with SVC, and to compare FEV_1/FVC with FEV_1/SVC ratio. Spearman correlation analysis was used to determine whether BMI has an effect on the discordance between FVC and SVC. Finally, we used the McNemar test for paired binary data to compare the prevalence rate of obstruction when using different measurements of VC. RESULTS: In individuals with BMI < 25 kg/m^2 and no evidence of obstruction in the PFTs, FVC was larger than SVC ($P = .03$), whereas in overweight and obese individuals, SVC was significantly larger than FVC. The difference between SVC and FVC was positively correlated with BMI ($P < .001$). One hundred thirty-one patients had a normal FEV_1/FVC but low FEV_1/SVC ratio. Fifty of these 131 individuals also had a normal FVC; the majority of them (46 of 50) had the PFTs for investigation of respiratory symptoms and had BMI > 25 kg/m^2 (42 of 50). CONCLUSIONS: Our results indicate that FVC is larger than SVC in patients with low and normal BMI and no evidence of obstruction in the PFTs, whereas FVC is smaller than SVC in overweight and obese individual. Our findings add to the existing literature that use of FEV_1/FVC may lead to underdiagnosis of obstructive airway disease in overweight and obese individuals. *Key words: BMI; forced vital capacity; obesity; obstruction; pulmonary function; slow vital capacity; spirometry.* [Respir Care 2015;60(1):113–118. © 2015 Daedalus Enterprises]

Introduction

Obstructive airway disease (OAD) is diagnosed when an obstructive ventilatory defect is present in the pulmonary function test (PFT). Obstruction is defined as the ratio of FEV_1 to vital capacity (VC) below the lower limit of normal (LLN).[1] A potential issue complicating this diagnostic approach is that VC can be measured in multiple ways: as FVC, inspiratory VC, or slow VC (SVC). FVC is usually smaller than SVC[2] because intrathoracic pressure increases during a forced expiration, diminishing air flow.[3] In OAD, FEV_1 sometimes decreases concomitantly with FVC; in this instance, the FEV_1/VC ratio appears normal, underestimating the patient's degree of obstruction.[1] For this reason, the American Thoracic Society and European Respiratory Society (ATS/ERS) recommends the use of the largest VC to calculate the FEV_1/VC ratio.[1] Despite these recommendations, FEV_1/FVC ratio remains the most commonly used measurement in the United States for diagnosing OAD.[4]

Drs Fortis and Kim are affiliated with the Pulmonary and Critical Care Division, Department of Medicine, University of Minnesota; Mr Corazalla and Dr Kim are affiliated with the Pulmonary Function Test Laboratory, University of Minnesota Medical Center; Ms Wang is affiliated with the Clinical and Translational Science Institute, University of Minnesota, Minneapolis, Minnesota.

Correspondence: Spyridon Fortis MD, 420 Delaware Street SE, MMC 276, Minneapolis, MN 55455. E-mail: forti042@umn.edu.

Obesity can decrease a patient's vital capacity, as reflected in both FVC and SVC measurements.[5-7] To our knowledge, however, it is not known whether body mass index (BMI) affects FVC more than SVC. If obesity reduces FVC more than SVC, the FEV_1/FVC ratio may be artificially low in obese individuals, leading to underdiagnosis of OAD. We hypothesized that the difference between FVC and SVC increases as a function of BMI. To test our hypothesis, we analyzed pulmonary function tests (PFTs) that included both spirometry and plethysmography, as the SVC maneuver is performed only during plethysmography. We compared FVC to SVC, FEV_1/FVC ratio to FEV_1/SVC, and examined whether BMI has an effect on the discordance between FVC and SVC. We also examined the prevalence of obstruction when using different measurements of VC.

Methods

The study protocol was reviewed and approved (exempt status, study 1311E45941) by the University of Minnesota institutional review board, in accordance with the Code of Federal Regulations, 45 CFR 46.101(b).

Data Collection

To construct our study dataset, we retrieved data from the University of Minnesota Medical Center PFT Laboratory electronic database for all PFTs performed between January 1, 2013 and August 15, 2013 across 5 clinical sites: Fairview Maple Grove Clinic (Maple Grove, Minnesota), Fairview Princeton Clinic (Princeton, Minnesota), Fairview Ridges Hospital (Burnsville, Minnesota), Fairview Southdale Hospital (Edina, Minnesota), and University of Minnesota Medical Center (Minneapolis, Minnesota). We included PFTs for adults 18 y of age or older that included both spirometry and plethysmography results. We excluded PFTs that were not performed according to ATS/ERS guidelines and did not meet the ATS/ERS standards for acceptability and repeatability.[8-10] If several PFTs were recorded in the database for the same individual, we included only the first test.

PFTs were performed using Medical Graphics Diagnostics Corporation equipment and BreezeSuite 7.1 software. Predicted values were computed by the software using equations derived from Hankinson.[11] We extracted the following data for each PFT record: patient age, race, height, sex, weight, FEV_1 (L), FEV_1 % predicted, FVC (L), FVC percentage predicted, SVC (L), and SVC percentage.

Analysis

PFT records were categorized by patient BMI (BMI < 25, BMI 25–30, BMI 30–35, and BMI ≥ 35 kg/m²), then sub-

QUICK LOOK

Current knowledge

FVC is reduced with obesity as part of the pattern of restrictive lung dysfunction. The impact of body mass index (BMI) on measures of FVC and slow vital capacity (SVC) are not well described.

What this paper contributes to our knowledge

In this retrospective study, FVC was larger than SVC in individuals with BMI < 25 kg/m² and no evidence of obstructive airway disease (OAD) but smaller than SVC in overweight and obese subjects. The difference between SVC and FVC increased with increasing BMI. The use of FEV_1/FVC may lead to underdiagnosis of OAD in overweight and obese subjects.

categorized further based on the presence or absence of obstruction. Obstruction was defined as a FEV_1/VC ratio below LLN.[1,11] Because the data were not normally distributed, we used the non-parametric Wilcoxon signed-rank test to compare FVC with SVC, and to compare FEV_1/FVC ratio with FEV_1/SVC ratios.

To determine whether BMI had an effect on the discordance between FVC and SVC, we conducted a Spearman correlation analysis of the change in BMI with the change in the difference between SVC and FVC.

We used the McNemar test for paired binary data to compare the prevalence rate of obstruction diagnosis when using different measurements of VC. Because there are no available FEV_1/SVC predicted values, we defined obstruction as a ratio lower than the LLN of the predicted FEV_1/FVC.[11]

Finally, we reviewed the electronic medical records of those patients who had a normal FEV_1/FVC but abnormally low FEV_1/SVC to find out whether they had respiratory symptoms.

Results

Over the 7.5 months examined, 6,882 spirometries were performed, of which 2,534 had SVC measurements (plethysmography). Of these 2,534 PFTs, 99 were not included because they were performed in pediatric patients. One hundred fifty-five PFTs were also excluded for being performed in a laboratory that did not use ATS standards. Another 116 PFTs were excluded because they had incomplete data or were performed for testing/calibration of the equipment, and 159 were excluded because they were performed in the same individuals. From the remaining 2,005 tests, 200 did not meet the ATS standards for ac-

Table 1.   Subject Characteristics

Characteristics	Values
Age, y	58.3 ± 15.6
Race, *n* (%)	
African-American	17 (0.9)
White	372 (20.6)
Unspecified	1,416 (78.4)
Female, *n* (%)	891 (49.4)
BMI, kg/m^2	29.5 ± 7
Height, cm	169.8 ± 10.5

The total number of subjects was 1,805. Age, body mass index (BMI), and height are presented as mean ± SD.

ceptability and reproducibility and were excluded. The remaining 1,805 PFTs were included in our final dataset. The demographics of our sample and their pulmonary function results are shown in Tables 1 and 2, respectively.

Table 3 compares PFT parameters within specific BMI and obstruction categories. FVC was significantly smaller than SVC, and FEV_1/FVC ratio was significantly higher than FEV_1/SVC in overweight and obese individuals (BMI > 25 kg/m^2). In contrast, in individuals with a BMI < 25 kg/m^2 who did not have obstruction (based on FEV_1/FVC ratio), FVC was larger than SVC ($P = .03$), and FEV_1/FVC ratio was significantly lower than FEV_1/SVC ($P = .04$). The difference between SVC and FVC (SVC-FVC) was significantly positively correlated with BMI, both in individuals with ($r = 0.2$, $P < .001$) and without obstruction ($r = 0.23$, $P < .001$) (Fig. 1).

As shown in Table 4, the prevalence of obstruction was significantly lower when using the FEV_1/FVC ratio (23.3%, 421 of 1,805) than when using FEV_1/SVC ratio (28.8%, 520 of 1,805, $P < .001$). Notably, 131 subjects had a normal FEV_1/FVC but abnormally low FEV_1/SVC. Fifty of these 131 subjects had a normal FVC; 42 of these 50 individuals had a BMI > 25 kg/m^2; the majority (46 of 50) had the PFTs for investigation of respiratory symptoms. In contrast, 32 subjects with a normal FEV_1/SVC ratio had an abnormally low FEV_1/FVC. Sixteen of these 32 subjects had a BMI < 25 kg/m^2; 9 were overweight.

Discussion

Our study reveals that the difference between FVC and other measurements of VC depends on BMI. In individuals with a BMI < 25 kg/m^2 who do not have obstruction (defined as FEV_1/FVC ratio lower than LLN), FVC is larger than SVC. In contrast, in overweight and obese individuals, SVC is larger than FVC, and the SVC-FVC difference is positively correlated with BMI. To our knowledge, this is the first report of BMI influencing the difference between SVC and FVC. This discordance could

lead to a falsely lower rate of OAD diagnosis when using FEV_1/FVC in overweight and obese individuals.

The discordance between FVC and other measurements of VC has been reported previously.[12] It has been suggested that the difference between VC (measured either as SVC or inspiratory VC) and FVC reflects small airway obstruction.[13,14] Individuals with OAD may have a substantially reduced FVC compared with SVC (the accepted standard measurement of VC). This difference could result in a falsely normal FEV_1/FVC ratio, leading to underdiagnosis of OAD.[2] For this reason, the ATS/ERS task force recommends the use of FEV_1/SVC instead of FEV_1/FVC.[1]

Several authorities have reported the effect of weight on VC.[5,6] The VC decreases with increasing BMI. Obesity reduces lung compliance,[15] and, as a consequence, it decreases VC. Its effect on chest wall compliance varies in different studies,[16-18] and some authors have reported normal chest wall compliance.[16,17,19] Moreover, it results in airway closure, pulmonary gas trapping, diffuse microatelectasis, and relatively increased intrathoracic blood volume and, thereby, an increase in respiratory system elastance.[7] In addition, reduced VC may result from OAD in obese individuals.[20] Several studies report that obesity is associated with OAD, but such an association is still unclear.[21,22]

FVC may be also reduced more than SVC in obesity due to airway closure and this discrepancy increases further in OAD.[2] In our cohort, the SVC was always larger than FVC in subjects with obstruction based on a FEV_1/FVC ratio lower than the LLN. In subjects without obstruction using the same criteria, SVC was larger than FVC only in BMI > 25 kg/m^2, and their difference increases as a function of BMI (Fig. 1). Surprisingly, the FVC was larger than SVC in individuals with BMI < 25 kg/m^2 and no evidence of obstruction in their PFTs. Similarly, the FEV_1/FVC ratio was smaller than FEV_1/SVC in these individuals. To our knowledge, this paradoxical difference has not been reported previously and is most likely due to the use of different maneuvers. FVC requires not only a forced expiration but also a forced inspiration.[9] A force inspiratory maneuver may lead to a larger inspiratory reserve volume only in normal weight individuals who have larger respiratory compliance compared with the overweight and obese.[7] On the other hand, the SVC maneuver requires a slow inspiration.[9] Another explanation could be that more individuals with OAD are in the category of BMI < 25 kg/m^2 in our cohort, as we did not have clinical information for these individuals. However, this is less likely, as the numbers in each category are large and we subcategorized the subjects based on the presence or absence of obstruction defined by FEV_1/FVC < LLN.

The fact that FVC is larger in BMI < 25 kg/m^2 and smaller than SVC in BMI > 25 kg/m^2 adds to the existing literature regarding the limitation of FEV_1/FVC to diag-

Table 2.   Pulmonary Function Test Results for Total Sample and by BMI Category

Test Parameter	Total (N = 1,805)	BMI < 25 (n = 438)	BMI 25–30 (n = 579)	BMI 30–35 (n = 418)	BMI ≥ 35 (n = 370)
FEV_1, L	2.33 ± 0.95	2.31 ± 1.03	2.34 ± 0.95	2.45 ± 0.97	2.21 ± 0.78
FEV_1, %	76.1 ± 22.5	74.3 ± 24.1	77 ± 23.1	78.8 ± 21.8	73.5 ± 19.9
FVC, L	3.17 ± 1.15	3.24 ± 1.23	3.21 ± 1.13	3.27 ± 1.19	2.92 ± 0.98
FVC, %	79.7 ± 19.5	81.5 ± 20.6	81.1 ± 19.8	80.3 ± 18.4	74.5 ± 18.1
SVC, L	3.24 ± 1.13	3.25 ± 1.22	3.27 ± 1.11	3.35 ± 1.18	3.03 ± 0.96
SVC, %	81.5 ± 19.1	81.8 ± 20.1	82.9 ± 19.2	82.5 ± 18.4	77.5 ± 18
FEV_1/FVC, %	73.2 ± 12.9	70.6 ± 15.3	72.4 ± 13.3	74.6 ± 11.2	75.9 ± 10

BMI = body mass index
SVC = slow vital capacity

Table 3.   FVC, SVC, FEV_1/FVC, and FEV_1/SVC Categorized by BMI for Total Sample

	FVC (L)	SVC (L)	FEV_1/FVC (%)	FEV_1/SVC (%)
Total (N = 1,805)				
Obstruction (n = 421)	3.06 ± 1.2	3.21 ± 1.18*	54.9 ± 11.5	52.6 ± 13.4*
No obstruction (n = 1384)	3.21 ± 1.13	3.25 ± 1.11*	78.7 ± 6.7	77.7 ± 8.8*
BMI < 25 (n = 438)				
Obstruction (n = 156)	3.09 ± 1.22	3.18 ± 1.22*	54.7 ± 12.3	53.7 ± 14.3‡
No obstruction (n = 282)	3.32 ± 1.23	3.29 ± 1.22†	79.4 ± 7.8	80.2 ± 10.3†
BMI 25–30 (n = 579)				
Obstruction (n = 138)	3.05 ± 1.14	3.22 ± 1.09*	53.2 ± 11.3	50.6 ± 13.6*
No obstruction (n = 441)	3.26 ± 1.13	3.29 ± 1.12*	78.4 ± 6.5	77.6 ± 8.6*
BMI 30–35 (n = 418)				
Obstruction (n = 74)	3.13 ± 1.32	3.34 ± 1.34*	56.6 ± 11.1	53.1 ± 12.2*
No obstruction (n = 344)	3.30 ± 1.16	3.36 ± 1.15*	78.5 ± 6.5	77.1 ± 8.1*
BMI ≥ 35 (n = 370)				
Obstruction (n = 53)	2.87 ± 1.13	3.07 ± 1.09*	57.9 ± 9.4	53.8 ± 11.5*
No obstruction (n = 317)	2.93 ± 0.95	3.02 ± 0.94*	78.9 ± 6.2	76.3 ± 8.2*

Obstruction is defined as FEV_1/FVC ratio lower than the lower normal of limit. BMI is expressed in kg/m^2. Values are presented as mean ± SD. Wilcoxon signed-rank test was used to compare FVC with SVC and FEV_1/FVC with FEV_1/SVC ratio.
* $P < .001$ vs FVC or FEV_1/FVC ratio.
† $P < .05$ vs FVC or FEV_1/FVC ratio.
‡ $P < .005$ vs FVC or FEV_1/FVC ratio.
SVC = slow vital capacity
BMI = body mass index

nose OAD in overweight and obese individuals.[2] Two people of the same age, sex, race, and height with different BMIs also have different FVC and FEV_1/FVC values, although they have the same predicted values based on Hankinson equations.[11] Because there are no available FEV_1/SVC predicted values, we computed the observed FEV_1/SVC percentage values based on the FEV_1/FVC predicted values.[11] Although we cannot conclude with certainty, as there are no predicted FEV_1/SVC values, our findings indicate that potentially 1 out of 10 patients (50 of 520, given that 520 individuals had obstruction based on FEV_1/SVC ratio) with normal FVC, most of them overweight or obese, might be erroneously diagnosed as "normal" despite their symptoms. Interestingly, 32 sub-

jects with a normal FEV_1/SVC had an abnormally low FEV_1/FVC ratio; 16 of these subjects had a BMI < 25 $kg/m,^2$ whereas 9 were overweight.

The subject sample was racially homogenous (predominantly white), which limits the generalizability of our results to other racial and ethnic groups. Race was unspecified for a large number (1,416) of our subjects, although race was self-identified. The staff in our PFT laboratories performed the data entry in the PFT software. Our PFT software calculates the predicted values for unspecified using data for whites. Our staff know this information and often use unspecified instead of white. In some occasions, our staff may even prefer unspecified over white, as some of the patients have different racial origins. We have no
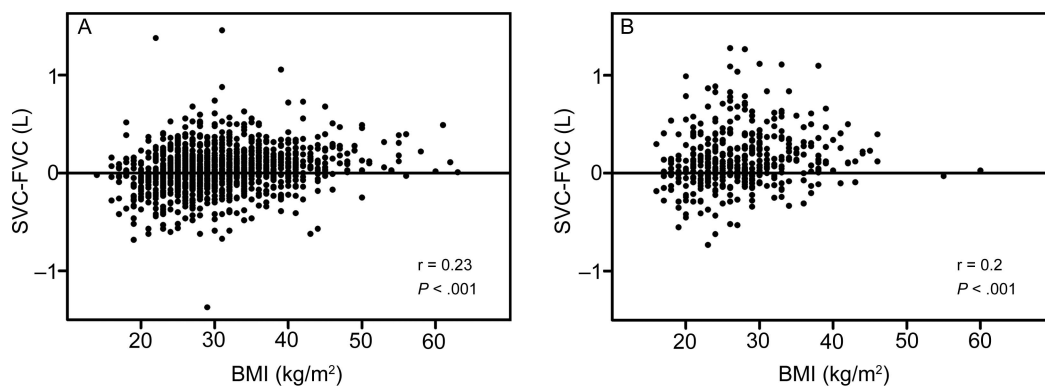
Fig. 1. Relationship of the difference between slow vital capacity (SVC) and FVC with BMI in subjects with A: no obstruction and B: obstruction. Obstruction is defined as FEV_1/FVC lower than the lower limit of normal.

Table 4. Rate of Obstruction Using FEV_1/FVC and FEV_1/SVC

	FEV_1/SVC Obstruction, n (%)	FEV_1/SVC No Obstruction, n (%)	Total, n (%)
FEV_1/FVC obstruction	389 (21.6)	32 (1.8)	421 (23.3)
FEV_1/FVC no obstruction	131 (7.3)	1,253 (69.4)	1,384 (76.7)
Total	520 (28.8)	1,285 (71.2)	1,805 (100)
P	< .001		

The McNemar test was used to compare the prevalence rate of obstructive airway disease diagnosis using FEV_1/FVC vs FEV_1/SVC.
SVC = slow vital capacity

way to identify in which cases the race was truly unspecified, but we assume that would be a small minority. Nevertheless, 85.3% of the local population is "white alone" according to 2010 American Census Bureau.[23] Another limitation of our study is that we did not have clinical data to correlate with the PFTs for all the subjects in our cohort.

Our findings lead us to question whether equations for predicted values of FVC and FEV_1/FVC should include BMI. This potentially is clinically relevant, as the obese and overweight constitute 69.2% of the total United States population.[24] Mannino et al[25] reported that individuals who have normal FEV_1/FVC ratio using the LLN criteria are at risk for early respiratory death if they have FEV_1/FVC ratio lower than 0.7. We suggest comparison of SVC with FVC should be used when there is doubt until equations of FEV_1/FVC that include BMI or FEV_1/SVC predicted values become available for the United States population.

Conclusions

Our retrospective study demonstrates that FVC is larger than SVC in subjects with BMI lower than 25 kg/m² and no evidence of obstruction in the PFTs, but smaller than SVC in overweight and obese people. The difference between SVC and FVC increases with increasing BMI. Our findings add to the existing literature that use of FEV_1/FVC may lead to underdiagnosis of OAD in overweight and obese individuals.

REFERENCES

1. Pellegrino R, Viegi G, Brusasco V, Crapo RO, Burgos F, Casaburi R, et al. Interpretative strategies for lung function tests. Eur Respir J 2005;26(5):948-968.
2. Hyatt RE, Cowl CT, Bjoraker JA, Scanlon PD. Conditions associated with an abnormal nonspecific pattern of pulmonary function tests. Chest 2009;135(2):419-424.
3. Ferretti A, Giampiccolo P, Cavalli A, Milic-Emili J, Tantucci C. Expiratory flow limitation and orthopnea in massively obese subjects. Chest 2001;119(5):1401-1408.
4. Mohanka MR, McCarthy K, Xu M, Stoller JK. A survey of practices of pulmonary function interpretation in laboratories in Northeast Ohio. Chest 2012;141(4):1040-1046.
5. Jones RL, Nzekwu MM. The effects of body mass index on lung volumes. Chest 2006;130(3):827-833.
6. Pistelli F, Bottai M, Viegi G, Di Pede F, Carrozzi L, Baldacci S, et al. Smooth reference equations for slow vital capacity and flow-volume curve indexes. Am J Respir Crit Care Med 2000;161(3 Pt 1):899-905.
7. O'Donnell DE, Ciavaglia CE, Neder JA. When obesity and chronic obstructive pulmonary disease collide: physiological and clinical consequences. Ann Am Thorac Soc 2014;11(4):635-644.
8. Miller MR, Crapo R, Hankinson J, Brusasco V, Burgos F, Casaburi R, et al. General considerations for lung function testing. Eur Respir J 2005;26(1):153-161.
9. Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, et al. Standardisation of spirometry. Eur Respir J 2005;26(2):319-338.
10. Wanger J, Clausen JL, Coates A, Pedersen OF, Brusasco V, Burgos F, et al. Standardisation of the measurement of lung volumes. Eur Respir J 2005;26(3):511-522.
11. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. Am J Respir Crit Care Med 1999;159(1):179-187.

12. Cohen J, Postma DS, Vink-Klooster K, van der Bij W, Verschuuren E, Ten Hacken NH, et al. FVC to slow inspiratory vital capacity ratio: a potential marker for small airways obstruction. Chest 2007; 132(4):1198-1203.

13. Chan ED, Irvin CG. The detection of collapsible airways contributing to airflow limitation. Chest 1995;107(3):856-859.

14. Chhabra SK. Forced vital capacity, slow vital capacity, or inspiratory vital capacity: which is the best measure of vital capacity? J Asthma 1998;35(4):361-365.

15. Salome CM, King GG, Berend N. Physiology of obesity and effects on lung function. J Appl Physiol 2010;108(1):206-211.

16. Sharp JT, Henry JP, Sweany SK, Meadows WR, Pietras RJ. Effects of mass loading the respiratory system in man. J Appl Physiol 1964; 19:959-966.

17. Suratt PM, Wilhoit SC, Hsiao HS, Atkinson RL, Rochester DF. Compliance of chest wall in obese subjects. J Appl Physiol Respir Environ Exerc Physiol 1984;57(2):403-407.

18. Naimark A, Cherniack RM. Compliance of the respiratory system and its components in health and obesity. J Appl Physiol 1960;15: 377-382.

19. Sharp JT, Henry JP, Sweany SK, Meadows WR, Pietras RJ. The total work of breathing in normal and obese men. J Clin Invest 1964;43: 728-739.

20. Beuther DA, Sutherland ER. Overweight, obesity, and incident asthma: a meta-analysis of prospective epidemiologic studies. Am J Respir Crit Care Med 2007;175(7):661-666.

21. Chinn S. Asthma and obesity: where are we now? Thorax 2003; 58(12):1008-1010.

22. Pistelli F, Bottai M, Carrozzi L, Pede FD, Baldacci S, Maio S, et al. Changes in obesity status and lung function decline in a general population sample. Respir Med 2008;102(5):674-680.

23. 2010 United States Census Bureau. http://www.census.gov/ compendia/statab/cats/population/estimates_and_projections– states_metropolitan_areas_cities.html. *Accessed October 6, 2014.*

24. Centers for Disease Control and Prevention. Obesity and overweight. http://www.cdc.gov/nchs/fastats/obesity-overweight.htm. *Accessed September 15, 2014.*

25. Mannino DM, Diaz-Guzman E. Interpreting lung function data using 80% predicted and fixed thresholds identifies patients at increased risk of mortality. Chest 2012;141(1):73-80.