

# Effects of Body Position on Resting Lung Volume in Overweight and Mildly to Moderately Obese Subjects

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**INTRODUCTION:** A partial sitting position has been reported to increase functional residual capacity (FRC) in lean subjects, whereas FRC does not change with position in the morbidly obese. The effects of positioning in the subgroup of overweight and mildly to moderately obese subjects have not been examined. We hypothesized that a change in FRC may be related to adipose tissue distribution. **METHODS:** We investigated the hypotheses that a 30° Fowler's position would increase the FRC and decrease the closing-capacity-to-FRC ratio in subjects with a body mass index in the 25.0–39.9 kg/m<sup>2</sup> range. We tested whether body fat distribution, measured by waist circumference and waist-to-hip ratio, correlated with the lung-volume changes. **RESULTS:** The 30° Fowler's position did not improve the FRC, when compared to the supine position ( $n = 32$ ). The closing-capacity-to-FRC ratio was  $> 1$  in 5 of 7 subjects while sitting, and in all 7 subjects while supine or in the 30° Fowler's position. The waist-to-hip ratio was correlated with closing capacity in all positions, and correlated with closing-capacity-to-FRC ratio in the supine position. **CONCLUSIONS:** Standard position changes purported to increase FRC are ineffective in the overweight and mildly to moderately obese, a subpopulation represented by almost 67% of Americans. Bedside caregivers may need to modify current practices when the clinical goal is to improve resting lung volumes in sedentary patients. *Key words:* functional residual capacity, closing capacity, positioning, obesity. [Respir Care 2009;54(3):334–339. © 2009 Daedalus Enterprises]

## Introduction

The use of a partial sitting position to increase the functional residual capacity (FRC) is conventional practice in hospitalized patients, particularly when recovering from general anesthesia and surgery. Lean individuals (body mass index [BMI]  $< 25$  kg/m<sup>2</sup>) may ameliorate the loss of

FRC when moving from a supine to a partial sitting position.<sup>1,2</sup> Alternatively, there is evidence that in the morbidly obese (BMI  $\geq 40$  kg/m<sup>2</sup>) the FRC is so substantially decreased that it changes minimally when moving between sitting and supine.<sup>3,4</sup> Among the adult American population, morbid obesity has a prevalence of only 4.8%, while the combined prevalence of overweight (BMI 25.0–29.9 kg/m<sup>2</sup>) and mild (BMI 30.0–34.9 kg/m<sup>2</sup>) and moderate (BMI 35.0–39.9 kg/m<sup>2</sup>) obesity is 61.5%,<sup>5</sup> and this group may compose

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over 60% of the critical care population.<sup>6</sup> We hypothesized that a 30° Fowler's position would improve the FRC and closing-capacity-to-FRC ratio in healthy, overweight and mildly to moderately obese subjects. We also evaluated if, and to what extent, relative BMI and body fat distribution, indicated by waist circumference or waist-to-hip ratio, correlated with the effects of position on resting lung volume.

## Methods

This was a quasi-experimental study with a repeated-measures, within-subjects design. The study was conducted in the pulmonary function laboratory at the University of Texas MD Anderson Cancer Center in Houston, Texas. All subjects gave written informed consent according to the University of Texas Health Science Center Committee on the Protection of Human Subjects and the MD Anderson Cancer Center Institutional Review Board.

The sample comprised healthy volunteers with a BMI range from 27.0 kg/m<sup>2</sup> to 39.9 kg/m<sup>2</sup>, recruited from the general population of Houston, Texas. Inclusion criteria included age 18–75 years, English speaking, and able to understand and follow instructions in regard to pulmonary function tests. Exclusion criteria included weight over 180 kg, known abdominal pathology, pregnancy, presence of known chronic pulmonary disease requiring daily pharmacologic treatment, and presence of acute lung disease currently requiring medication. A sample size of 34 for repeated-measures analysis of variance (ANOVA) was calculated (N-Query Advisor, Statistical Solutions, Saugus, Massachusetts), with interim analysis at 6, 17, 25, and 30 subjects. The assumptions,  $\alpha = 0.05$ , mean FRC values 2.3 L, 1.95 L, and 2.06 L (sitting, supine, and 30° Fowler's, respectively), and common standard deviation = 0.51, yielded power = 0.90. Data on resting lung volumes, specifically in obese subjects while in various body positions, are sparse. The sitting and supine FRC values are based on a rather dated report from Tucker and Seiker, and represent the most conservative effect size from available data.<sup>7</sup>

## Measurements

Anthropometric measurements (height, weight, waist and hip circumference) were made according to the National Heart, Lung, and Blood Institute anthropometry manual, with attention to the privacy of the subject.<sup>8</sup>

Pulmonary function tests were done in a hospital-based laboratory, according to the 2005 American Thoracic Society/European Respiratory Society recommendations.<sup>9,10</sup> The spirometry system and analyzers, including flow, volume, and gases, were calibrated prior to each test run, according to the manufacturer's specifications.

**Spirometry.** Spirometric values were measured with a spirometry system (MasterScreen, Jaeger, Hoechberg, Germany, technical specifications available in Appendix). Inspiratory capacity and expiratory reserve volume (ERV) were determined by the spirometry system, based on the end-expiratory level determined during tidal breathing and the vital capacity.

**Functional Residual Capacity.** FRC, residual volume, and total lung capacity were measured with the multiple-

breath helium-dilution technique. FRC measurements represented the mean of at least 2 reproducible trials that agreed within 10%. A minimum 5-min interval occurred between each run of FRC measurements, to ensure adequate helium washout. Both the end-expiratory volume and helium concentrations were evaluated in real time; baseline deviations or evidence of system leaks terminated the run, and the test was repeated according to protocol. All subjects were able to perform a "linked" ERV and inspiratory capacity vital capacity maneuver without the patient removing the mouthpiece, as recommended.

**Closing Capacity.** The closing volume was measured with the single-breath nitrogen-washout technique (Vmax Spectra, SensorMedics, Yorba Linda, California, technical specifications available in Appendix). The onset of stage IV was identified by visual examination of the tracing and the instrument's software. The instrument's screen was positioned in view of the subjects, who were coached to maintain expiratory flow at the targeted rate (0.3–0.5 L/s). Closing-volume measurements were repeated until the mean of at least 2 trials were reproducible within 10%. A minimum 5-min interval occurred between each run of closing-volume measurements, to ensure adequate oxygen washout. Complete closing-volume measurements were limited to 7 subjects, due to technical problems with the instrumentation (see Appendix for a full description). Residual-volume measurements obtained from the helium-dilution test were added to the closing-volume measurement to determine the closing capacity.

**Pulse Oximetry.** Pulse oximetry (Onyx 9500, Nonin, Plymouth, Minnesota, technical specifications available in Appendix) was used to measure blood oxygen saturation (S<sub>pO<sub>2</sub></sub>). Pulse oximetry readings were taken after the subject had been in the research posture for a minimum of 5 min.

**Positioning.** The sitting, 30° Fowler's, and supine positions were measured with a universal inclinometer and maintained with standard operating room stretcher and pillows. All test runs began with the sitting position, to establish a standard baseline measurement. The research postures (30° Fowler's to supine, or supine to 30°Fowler's) were randomized with a random number table. The subject was placed in the research posture for a minimum of 5 min before each test run, and remained in the research posture between runs for the same position, until reproducible results were obtained for each variable.

## Data Analysis

Data were analyzed with statistics software (SPSS 12.0, SPSS, Chicago, Illinois). The mean values and standard

Table 1. Study Subjects (*n* = 32)

Female ( <i>n</i> , %)	19 (59)
Male ( <i>n</i> , %)	13 (41)
Asian ( <i>n</i> , %)	4 (12)
African American ( <i>n</i> , %)	5 (16)
White ( <i>n</i> , %)	15 (47)
Hispanic ( <i>n</i> , %)	8 (25)
Overweight ( <i>n</i> , %)	9 (28)
Mildly to moderately obese ( <i>n</i> , %)	23 (72)
Weight (mean ± SD kg)	89.4 ± 11.6
Height (mean ± SD cm)	165 ± 9
BMI (mean ± SD kg/m <sup>2</sup> )	32.7 ± 3.5
Waist circumference (mean ± SD cm)	105 ± 11
Hip circumference (mean ± SD cm)	115 ± 7
Waist-to-hip ratio (mean ± SD)	0.91 ± 0.08
FVC (mean ± SD % predicted)	103 ± 18
FEV <sub>1</sub> /FVC (mean ± SD)	80.2 ± 5.7
FRC (mean ± SD % predicted)	90 ± 2
RV (mean ± SD % predicted)	90 ± 2
TLC (mean ± SD % predicted)	97 ± 13

BMI = body mass index  
 FVC = forced vital capacity  
 FEV<sub>1</sub> = forced expiratory volume in the first second  
 FRC = functional residual capacity  
 RV = residual volume  
 TLC = total lung capacity

deviation were computed for all relevant variables. All subgroup variables were defined prospectively. Pearson correlation coefficients were used to assess the relationship among the independent and dependent variables. Repeated-measures ANOVA was used to evaluate the effects of 3 positions (sitting, supine, 30° Fowler's) on the dependent variables, FRC, and closing-capacity-to-FRC ratio. Differences were considered to be significant when *P* < .05. Repeated-measures ANOVA depends on an assumption of sphericity, meaning that the variances of the differences are equal. We used Mauchly's test to determine sphericity. When Mauchly's test indicated a violation of sphericity, the Greenhouse-Geisser correction was applied. Univariate and multiple regression were calculated to determine whether any indices of body habitus predicted the FRC or closing-capacity-to-FRC ratio.

## Results

### Subjects

The study sample comprised 32 subjects, whose demographics and descriptive data are depicted in Table 1.

### Effects of Position on FRC and Closing-Capacity-to-FRC Ratio

The overall mean FRC in the supine and 30° Fowler's position were very similar, with the mean FRC higher in

the sitting position (Table 2). Supine and 30° Fowler's FRC were 77.5% and 79.3% of sitting FRC, respectively; supine and 30° Fowler's ERV were 22.2% and 27.7% of sitting ERV, respectively. There was no interaction between position and sex in the difference between supine, 30° Fowler's, and sitting FRC (*P* = .16). The overall mean closing-capacity-to-FRC ratio in the supine and 30° Fowler's positions were very similar, with mean closing-capacity-to-FRC ratio lower in the sitting position (see Table 2). The closing-capacity-to-FRC ratio was > 1 in 5 of 7 subjects while sitting, and all 7 subjects while supine or in the 30° Fowler's position (Table 3).

Changes in S<sub>pO<sub>2</sub></sub> for sitting, supine, and 30° Fowler's positions (97.3%, 96.9%, and 96.4%, respectively) were statistically significant; however, the differences were within the instrumentation variance. In addition, the changes in S<sub>pO<sub>2</sub></sub> did not appear to be clinically relevant.

### Effects of Body Fat Distribution

Subgroup analysis in overweight (BMI 25.0–29.9 kg/m<sup>2</sup>), mildly to moderately obese (BMI 30.0–39.9 kg/m<sup>2</sup>), waist-to-hip ratio < 0.95, and waist-to-hip ratio ≥ 0.95 subjects revealed that neither relative body mass nor the distribution of mass influenced the effect of a 30° Fowler's position on the FRC. Neither waist-to-hip ratio nor waist circumference correlated to FRC in any position (data not shown). However, waist-to-hip ratio was correlated to closing capacity in all positions (sitting *r* = 0.831, *P* = .02; supine *r* = 0.877, *P* = .01; 30° Fowler's *r* = 0.790, *P* = .035).

Univariate and multiple regression of BMI, waist circumference, and waist-to-hip ratio on the difference between the supine and 30° Fowler's position for FRC, closing-capacity-to-FRC ratio, and S<sub>pO<sub>2</sub></sub> revealed no statistically significant explanation of the variability (data not shown).

## Discussion

This pilot study investigated the effect of a 30° Fowler's position on resting lung volumes in a sample of overweight and mildly to moderately obese subjects. The findings revealed that FRC did not increase when overweight and mildly to moderate obese subjects were moved from the supine to a 30° Fowler's position. These data suggest that a historical principle of pulmonary physiology may not apply to a large proportion of the American population. The effects of posture on FRC are described in the classic texts of pulmonary physiology used in medical and graduate education.<sup>1,2</sup> These effects are generally interpreted as supine positioning reducing the FRC by approximately 1.0 L, whereas about half of that loss is regained in a 30° head-elevated position. This schema is not supported by the results in this sample. However, the histor-

## BODY POSITION AND LUNG VOLUME IN OVERWEIGHT AND OBESE SUBJECTS

Table 2. Body Mass Index, Body Fat Distribution, and Patient Position Versus Functional Residual Capacity

	No. Subjects	Supine	30° Fowler's	Sitting	P*
FRC (mean ± SD L)					
Entire cohort	32	1.65 ± 0.43	1.69 ± 0.45	2.13 ± 0.56	<.001
BMI 25–29.9 kg/m <sup>2</sup>	9	1.92 ± 0.49	1.98 ± 0.54	2.52 ± 0.63	.002
BMI 30–39.9 kg/m <sup>2</sup>	23	1.55 ± 0.37	1.57 ± 0.36	1.98 ± 0.45	<.001
Waist-to-hip ratio < 0.95	19	1.67 ± 0.45	1.72 ± 0.51	2.15 ± 0.63	<.001
Waist-to-hip ratio ≥ 0.95	13	1.64 ± 0.43	1.64 ± 0.37	2.10 ± 0.45	<.001
Ratio of closing capacity to FRC (mean ± SD)	7	1.30 ± 0.09	1.33 ± 0.15	1.06 ± 0.09	.005
S <sub>pO<sub>2</sub></sub> (%)	32	96.9	96.4	97.3	.001†

\*For sitting vs supine and 30° Fowler's.

†For 30° Fowlers vs supine and sitting.

FRC = functional residual capacity

BMI = body mass index

S<sub>pO<sub>2</sub></sub> = oxygen saturation measured via pulse oximetry

Table 3. Ratio of Closing Capacity to FRC in 7 of the Subjects

Sex	BMI (kg/m <sup>2</sup> )	Waist-to-Hip Ratio	Ratio of Closing Capacity to FRC		
			Supine	30° Fowler's	Sitting
M	27.0	0.93	1.32	1.15	0.90
M	28.9	0.98	1.45	1.47	1.05
F	31.0	0.85	1.22	1.16	1.10
M	34.2	0.88	1.33	1.34	1.05
F	34.9	0.85	1.17	1.34	1.11
F	36.0	0.90	1.34	1.54	1.20
F	39.9	0.81	1.25	1.30	0.99

BMI = body mass index

FRC = functional residual capacity

ical data are based on a British sample from the 1950s, when the prevalence of obesity was < 10%.<sup>11</sup> Our sample comprised subjects with a BMI from 25 kg/m<sup>2</sup> to 39.9 kg/m<sup>2</sup>, which currently represents almost two thirds of the American population.

Persons with upper-body obesity have significantly lower lung volumes than persons with lower-body obesity.<sup>12,13</sup> In this study, a higher waist-to-hip ratio was associated with higher closing capacity in all positions, and a higher closing-capacity-to-FRC ratio when supine. This suggests that relative abdominal adiposity engenders unfavorable static lung function. In our study, static lung volume measurements were prioritized because of their clinical importance in the sedentary, hospitalized patient.

Complete closing-volume measurements were only available for 7 subjects in this study. Despite the small sample size, both statistical and clinical importance were found in the relationship between waist-to-hip ratio and closing capacity in all body positions. Previous research demonstrated closing-capacity-to-FRC ratios > 1 in su-

pine, anesthetized patients, without controlling for body mass and body fat distribution.<sup>14-16</sup> We were surprised to find detrimental closing-capacity-to-FRC ratios in healthy awake subjects who were sitting, partially reclining, and supine. These conditions may lead to airway closure within tidal breathing and the potential for intrapulmonary shunt and impaired oxygenation. Despite the lack of precision in pulse oximetry readings, it was unexpected to find that the lowest S<sub>pO<sub>2</sub></sub> readings were identified for subjects in the 30° Fowler's position. This suggests that the partial sitting position impedes oxygenation in the overweight and obese beyond its effects on FRC. Our results indicate the need for further research on methods to maintain FRC and reduce the closing-capacity-to-FRC ratio in the overweight and mildly to moderately obese population.

### Limitations

The total sample size in this study was small; although both sexes and multiple ethnicities were represented, none of the subgroup sizes is large enough to warrant generalizations to specific groups. Despite statistical significance, the small sample size of the closing capacity group was problematic. The closing-volume maneuver was difficult for some subjects; several required multiple tests for reproducible results. The software limited the number of closing-volume maneuvers that could be recorded, which may explain the rare use of this technique in current research.

The S<sub>pO<sub>2</sub></sub> differences between the 3 positions were within the precision of the pulse oximeter. The differences reported were not judged to be clinically important. Because of the shape of the oxyhemoglobin dissociation curve, changes in the P<sub>O<sub>2</sub></sub> could have occurred with very small to nondetectable changes in S<sub>pO<sub>2</sub></sub>. Arterial blood gas analysis would be a more precise method to describe subtle changes in oxygenation and ventilation.



Conceptually, all gas-dilution techniques underestimate lung volume to some degree; they are somewhat limiting in the context of airway obstruction and small-airways closure. Body plethysmography accounts for trapped, or noncommunicating, gases; however, it was not a feasible choice for this study because of the positional interventions. In addition, the intent of the study was to measure communicating lung volumes. It has been speculated that one reason for the decrease in FRC that occurs from a sitting to a supine posture may be small-airway closure in the dependent lung regions. Once those airways are closed, they are no longer available as a reservoir for inhaled gases and contribute little to physiologic gas exchange. This research specifically targeted the change in functional lung volume during positioning: that is, the volume reservoir that serves the subject physiologically. Measurement of noncommunicating lung volume in this context might have confounded the findings.

This pilot study was performed with healthy subjects; the effect of a partial Fowler's position on FRC and closing capacity in patients with acute or chronic cardiac or pulmonary disease is not known. In addition, the effect of a partial sitting posture on FRC in medically sedated or post-anesthesia patients is not known. Both the physiologic and pathophysiologic effects of the above conditions on resting lung volumes deserve further study. Therefore, these results cannot be generalized to awake postoperative, critically ill, medically sedated or anesthetized patients.

### Conclusion

Obesity has well documented effects on lung function: in particular, it reduces FRC and respiratory-system compliance.<sup>17,18</sup> Increased fat in the chest wall and abdomen alters respiratory excursion and decreases lung volume: effects that are exaggerated when the morbidly obese person lies supine.<sup>19</sup> More recent research has demonstrated that even overweight and mild obesity engender decreased resting lung volumes.<sup>20</sup> Our study duplicated these findings, demonstrating not only that increases in BMI are negatively associated with FRC and ERV in erect subjects, but also that the substantial fall in resting lung volume that occurs while supine does not improve when the head of the bed is elevated to 30° in overweight and mildly to moderately obese healthy subjects. Many critically ill patients have a body mass and fat distribution within the ranges tested here. Based on our results in healthy sub-

jects, further research on hospitalized and sedentary patients in these BMI ranges is warranted.

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## Appendix

## Technical Specifications of the Instruments

## Jaeger MasterScreen

Pneumotachograph: flow range 0–20 L/s, accuracy 0.2–12 L/s  $\pm$  2%, resistance to flow  $<$  0.5 cm H<sub>2</sub>O/L/s at 10 L/s. Volume measurement accuracy  $\pm$  5 mL. Helium analyzer range 0–9.5%, accuracy  $\pm$  0.05%.

## SensorMedics Vmax Spectra

Flow/volume system: range 0–16 L/s, resolution 0.003 L/s in the range 0.20–16 L/s; flow accuracy  $\pm$  3% or 0.25 L/s, whichever is greater, in the range 0.2–14 L/s; volume accuracy  $\pm$  3% or 0.050 L, whichever is greater. Oxygen analyzer: range 0–100%, resolution 0.01%, accuracy  $\pm$  0.02%.

Carbon dioxide analyzer: range 0–16%, resolution 0.01%, accuracy  $\pm$  0.02% in the range 0–10%.

Despite acceptable calibration results immediately prior to a test, the Vmax did not complete a single subject runs without a technical failure. The problems were not solved by changing the flow sensor and/or by recalibrating the Vmax. We believe the repeated runs required by the protocol taxed the instrument's capabilities. The protocol required closing-volume measurement in each of 3 positions, with reproducibility, so a minimum of 6 runs was required. Most subjects required at least 10 runs before reproducible results were obtained. Despite extensive consultation with the SensorMedics technical-support staff, we did not resolve these issues. Because these technical problems were impeding the study, we calculated whether the within-subject changes in closing volume due to position were statistically significant. Repeated-measures analysis of variance on the closing volume data ( $n = 7$ ) revealed that  $F = 0.596$  ( $P = .56$ ). Extrapolating this small data set to 24 subjects and 32 subjects, respectively, yielded  $F = 1.959$  ( $P = .15$ ) and  $F = 2.641$  ( $P = .08$ ). In theory, and in lean subjects, closing volume should not change significantly with position change, although there was a trend in that direction in our sample. It is possible that a larger sample of overweight and mildly and moderately obese subjects might show a change in closing volume with position.

## Nonin Onyx 9500

Pulse range 18–300 beats/min, accuracy  $\pm$  3% in the blood oxygen saturation range 70–100%,  $\pm$  2 digits.