CHANGES IN THE SHAPE OF THE MAXIMAL EXPIRATORY FLOW-VOLUME CURVE FOLLOWING WEIGHT LOSS IN OBESE FEMALES

By

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Abstract

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Introduction: Obesity is one of the most prevalent issues throughout the world. In 2012, 34.9%
of adults in the United States population were classified as obese (Ogden, 2014). Though the
effects of obesity on cardiovascular health are well-studied (Van Gaal, 2006; Eckel, 1998; Lavie,
2009), less is known in regards to the effect of obesity on the respiratory system. The buildup of
fat around the respiratory muscles in obese individuals leads to greatly decreased chest wall
compliance and increased airway resistance, both of which are determinants to expiratory air
flow. Thus, it seems reasonable that following weight loss, including fat from the chest wall, the
shape of the maximal expiratory flow-volume (MEFV) curve will be altered, indicating an
improvement in respiratory function. **Purpose:** This project examined the shape of the MEFV
curve in obese females before and after completing a weight loss program. **Hypothesis:** We
hypothesized that the shape of the MEFV curve in obese females would be altered, as assessed
using the beta angle ($\beta°$), flow ratio (FR), slope ratio (FR), and area-under-the-curve (AUC)
techniques, following weight loss. **Methods:** Obese females were recruited to perform a
pulmonary function test (PFT) before and after completing a weight loss program. Following
measurements of height and weight, PFTs were conducted according to American Thoracic

Society standards (Miller et al., 2005). Subjects were counseled by a registered dietitian to assist with weight loss. Following completion of the 12-week program, subjects returned to repeat all testing procedures. Data obtained during the spirometry tests before and after the weight loss program were processed using a custom program to quantify the shape of the MEFV curve using four techniques. The techniques utilized were $\beta°$, FR, SR, and AUC. These different techniques were used in order to examine the shape of the curve throughout the entire maneuver. Data were compared before and after the weight loss program using paired t-tests. Significance was set at $\alpha = 0.05$. These data were part of a larger study investigating the effect of weight loss on respiratory limitations and exercise tolerance in obese females. **Results:** A total of 36 (N=36) females completed the study. The age of the participants was 31.7 ± 7.2 years and the height was 162.7 ± 6.9 cm. The participants had a BMI of 36.2 ± 3.6 kg/m^2. A significant difference was observed between pre- and post-weight loss for body mass, fat mass, and fat-free mass. Significant differences were observed in several pulmonary function parameters, including peak expiratory flow (PEF), maximum voluntary ventilation, total lung capacity, and functional residual capacity. There was no significant difference observed in $\beta°$ and FR from before to after the weight loss. However, significant differences were observed in SR at 80% and 75% of forced vital capacity, as well as in certain AUC segments (TLC to PEF, forced expiratory flow at 75% FVC (FEF$_{75\%}$) to FEF$_{50\%}$, and FEF$_{50\%}$ to FEF$_{25\%}$). **Conclusion:** A change in the shape of the MEFV curve occurs following weight loss, as evidenced by the SR and AUC methods. These data suggest that obese females may improve their ventilatory reserve for increasing ventilation during exercise as a result of weight loss.
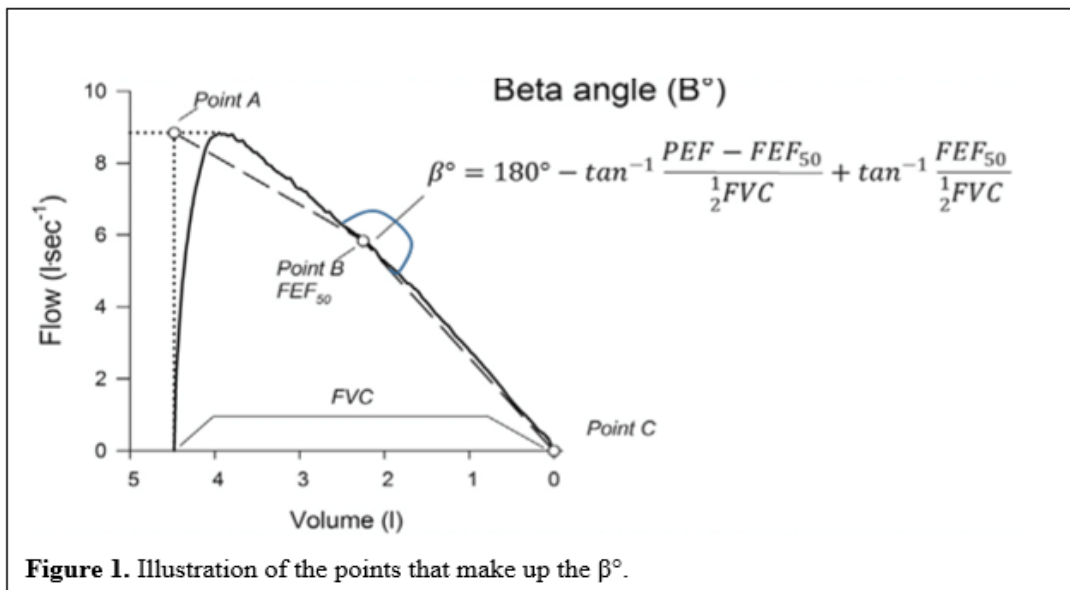
INTRODUCTION

Over the last few decades, obesity has become one of the most prevalent issues in the world (Sturm, R., & Hattori, A., 2013). Global obesity prevalence has been reported as high as 14% (Ng et al., 2014). In 2012, 34.9% of adults in the United States were classified as obese (Ogden, 2014). The National Institutes of Health has defined obesity as having a body mass index (BMI) ≥ 30 kg/m^2 (National Institutes of Health, 1998). The accumulation of fat around the chest wall and respiratory muscles causes a decrease in chest wall compliance, which is contributory to the decrease in the total respiratory compliance (Naimark, A., & Cherniack, R.M., 1960). In addition to a lower respiratory compliance, obese individuals also may face increased airway resistance throughout their respiratory system. Studies have linked a positive relationship between the increase in BMI and increase in airway resistance (Zerah, 1993).

The function of the respiratory system is evaluated during completion of a pulmonary function test (PFT). Notable expiratory flow and lung volume parameters commonly recorded include forced vital capacity (FVC), forced expiratory volume in the first second (FEV$_1$), peak expiratory flow (PEF), and expiratory reserve volume (ERV). In obese individuals, FVC, FEV$_1$, and PEF are not typically below predicted values (Thomas et al., 1989). However, ERV is significantly reduced in obese individuals but will increase as a result of weight loss (Thomas et al., 1989).
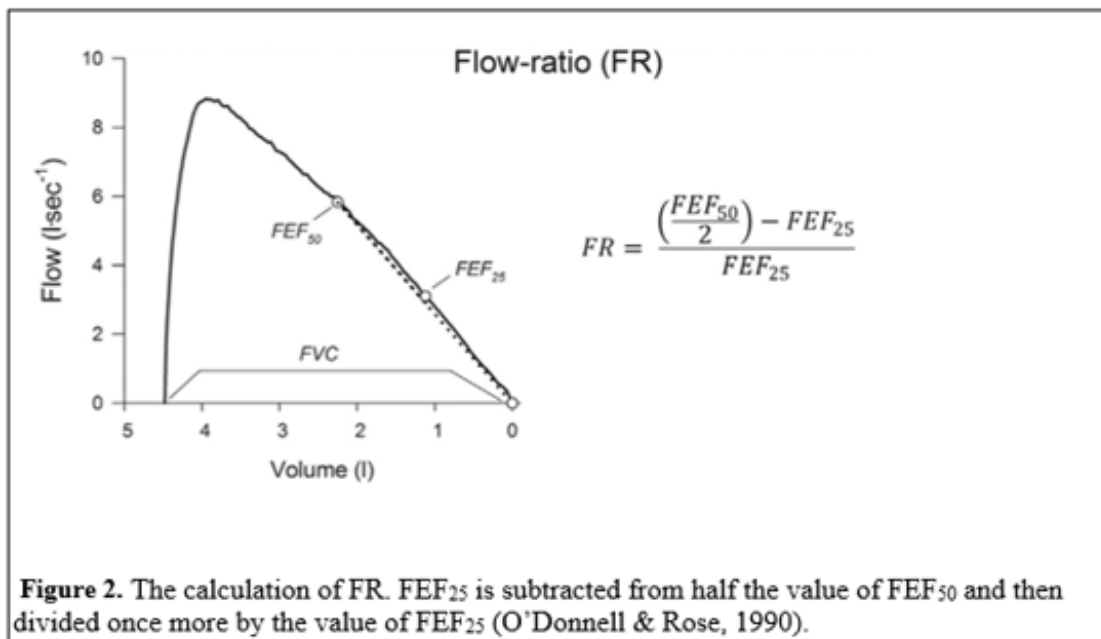
In addition to PFT parameters, maximal expiratory flow volume (MEFV) curves themselves can be utilized to examine lung function in individuals (Green, Mead, & Turner, 1974; Cochrane, Prieto, & Clark, 1977). MEFV curves are produced during a PFT, and the shape of the curve can be quantified using several methods. The methods most commonly used to quantify the shape of the MEFV curve are beta angle ($\beta°$), flow ratio (FR), slope ratio (SR),

and area under the curve (AUC) (Dominelli et al., 2015; Struthers, A. D., & Addis, G. J., 1988). The influence of body fat on these measurements, and in particular the loss of body fat in obese individuals, are not known.
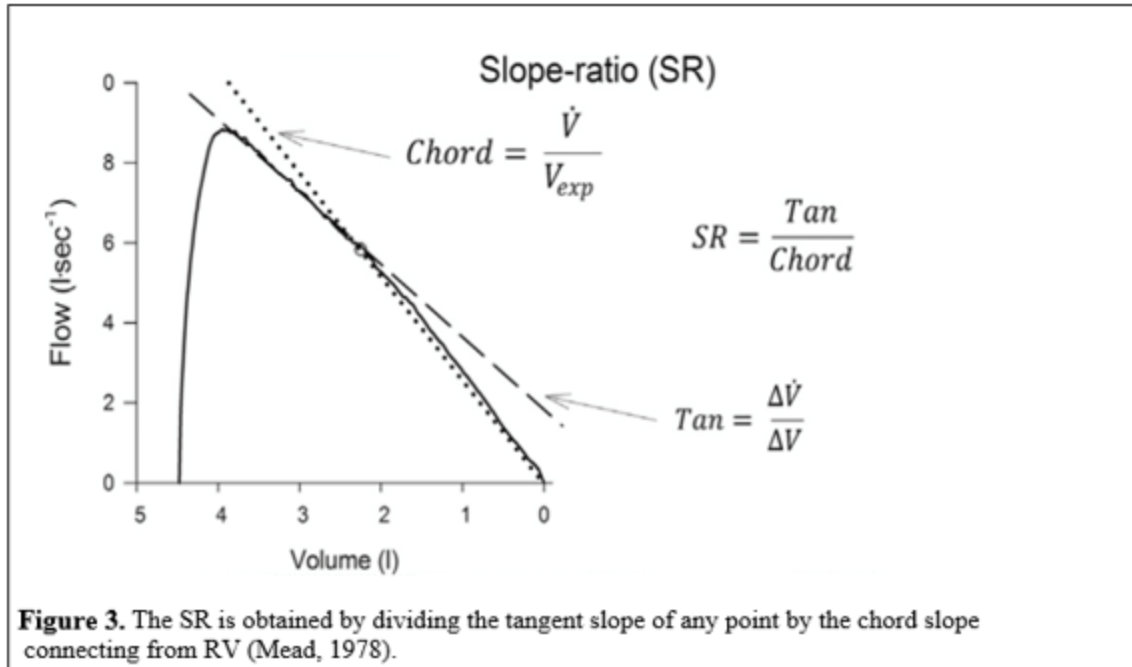
The β° is defined by the concavity or convexity formed between the slope of three points. These three points are flow at PEF as point A, $FEF_{50\%}$ as point B, and the point at residual volume (RV) as point C (Kapp et al., 1988). These points can be seen in Figure 1. A β° of approximately 180° is classified as normal. At 180°, the lungs can be described as having homogenous emptying. However, a β° less than 180° is an indicator of heterogeneous emptying of the lungs and may indicate some airway obstruction (Dominelli et al., 2015).

Figure 1. Illustration of the points that make up the β°.

$$\beta° = 180° - tan^{-1} \frac{PEF - FEF_{50}}{\frac{1}{2}FVC} + tan^{-1} \frac{FEF_{50}}{\frac{1}{2}FVC}$$

The FR examines the final 25% of a forceful expiration. FR can be calculated by subtracting the value of flow at $FEF_{25\%}$ from half of $FEF_{50\%}$ and then dividing by $FEF_{25\%}$ (O'Donnell & Rose, 1990). This calculation can be seen in Figure 2. There is, however, an assumption being made through this equation: the MEFV curve produced by a healthy individual should be a straight line in the last 50% of the maneuver. Any deviation from this straight line can be used to describe some form of lung dysfunction (O'Donnell & Rose, 1990).

Figure 2. The calculation of FR. FEF_{25} is subtracted from half the value of FEF_{50} and then divided once more by the value of FEF_{25} (O'Donnell & Rose, 1990).

SR is used to describe the change of the slope during exhalation. The SR is defined as the division of the slope of the tangent at any point on the MEFV curve by the slope of the chord between that point and RV, as can be seen in Figure 3 (Mead, 1978). The SR, much like the $\beta°$, also has a value that can be classified as normal. This value would be 1.0, which would indicate homogenous emptying of the lungs. A range that would be acceptable as normal would be from 0.5-2.5, while a SR of greater than 2.5 is indicative of disease (Dominelli et al., 2015).

Figure 3. The SR is obtained by dividing the tangent slope of any point by the chord slope connecting from RV (Mead, 1978).

The AUC is another technique of examining the shape of the MEFV curve. AUC observes the area of the curve in five segments: TLC to PEF, PEF to $FEF_{75\%}$, $FEF_{75\%}$ to $FEF_{50\%}$, $FEF_{50\%}$ to $FEF_{25\%}$, and $FEF_{25\%}$ to RV. The advantage of using AUC as opposed to the other methods is that it analyzes the entire curve from the start of the maneuver to the end in segments, as well as being much more sensitive to change in the shape of the curve (Struthers, A. D., & Addis, G. J., 1988). While one segment may not be different following weight loss, another section may be significantly different.

The aim of this study was to examine whether or not a change in the shape of the MEFV curve can be observed in obese individuals following, as compared with before, weight loss. Due to the buildup of fat around the chest and respiratory muscles, it was hypothesized that a loss in weight would alter chest wall compliance and change the shape of the MEFV curve.

METHODS

Participants

The participants for this study were females with an age of 20 to 45 years. The females must have had a BMI of 30 kg/m^2 to 50 kg/m^2. The females were required to not be taking part in vigorous exercise (exercise more than 2 times/week) over the previous six months. Exclusion from the study included a history of smoking or diseases such as asthma, cardiovascular disease, or sleep disorders. Prior to participating in the weight loss program, participants signed an informed consent form.

Study Design

Participants visited the laboratory on two occasions to complete body composition and pulmonary function testing. The two visits were separated by a 12-week diet and resistance training program with the goal of inducing weight loss.

Body Composition

Anthropometric measurements, such as height, body mass (BM), and percent body fat were measured using standard techniques. Percent body fat was estimated via the underwater weighing technique. Fat mass (FM) was calculated by multiplying BM and percent body fat. FM was subtracted from BM to yield fat-free mass (FFM).

Pulmonary Function Testing

Participants were required to perform breathing maneuvers while in a body plethysmograph (Carefusion Vmax Auto Box, Yorba Linda, CA) according to ATS guidelines in order to measure forced expiratory flow and lung volumes (Miller et al., 2005). The participants performed spirometry procedures while seated and breathing room air with nasal breathing occluded by a nose clip. Participants were instructed to inhale as much air as possible and then to exhale it

forcefully to RV in order to measure MEF at all lung volumes. The measured parameters produced by these maneuvers included FVC, FEV_1, FVC/FEV_1, PEF, maximal voluntary ventilation (MVV), TLC, FRC, and RV. Each subject was required to perform three acceptable spirograms. Flow was continuously measured throughout the performance of each maneuver in order to yield the expired mouth volume. A plot of MEF vs expired mouth volume was then constructed and the best curve was determined by the largest $FVC + FEV_1 + PEF$ values. The best curve was used in the shape analysis of the MEFV curve.

Quantifying the Shape of the MEFV Curve

In order to quantify the shape of the MEFV curves, four main techniques were used: $\beta°$, FR, SR, and AUC. The best MEFV curve was analyzed using a custom program (LabView, Biopac Systems, Inc., Goleta, CA). The program automatically calculated the $\beta°$, FR, SR, and AUC at several segments of each curve. Each technique was used to evaluate the shape of the curve at specific points. The $\beta°$ was used to examine the shape of the curve at $FEF_{50\%}$, while FR was used to examine the shape of the curve at $FEF_{25\%}$. The shape of the curve was analyzed through the entire maneuver using the other two methods, SR and AUC. The SR was used to analyze the curve in increments of 5% FVC, while AUC was used to analyze the curve in segments of 25% of the total curve.

Weight Loss Program

Each participant underwent a supervised 12-week diet and resistance exercise program. A registered dietitian met with each participant and issued dietary counseling along with an individualized diet plan. During three days per week, the participants took part in resistance exercises (i.e., weight-lifting) while under the guidance of a personal trainer. These exercises

were used as means to prevent loss of muscle mass and increase caloric expenditure while enrolled in the program. One to two pounds per week was the encouraged amount of weight loss.

Statistical Analyses

Paired Student's *t*-tests were performed to examine significant differences between pre- and post- weight loss for $\beta°$, FR, SR, and AUC. A significance value of $p<0.05$ was used as a mark of significance. Data are expressed as mean $\pm$ standard deviation (SD).

RESULTS

A total of 36 (N=36) participants completed the study, of which 12 were Caucasian, 11 African American, 10 Hispanic, 2 Asian, and 1 Mixed. The age of the participants was 31.7 ± 7.2 years and the height was 162.7 ± 6.9 cm. The participants had a BMI of 36.2 ± 3.6 kg/m^2. A significant difference was found post weight loss in BM ($p < 0.01$), FM ($p < 0.01$), and FFM ($p < 0.01$) (Figure 4). However, the reduction in BM was due primarily to the loss of FM.
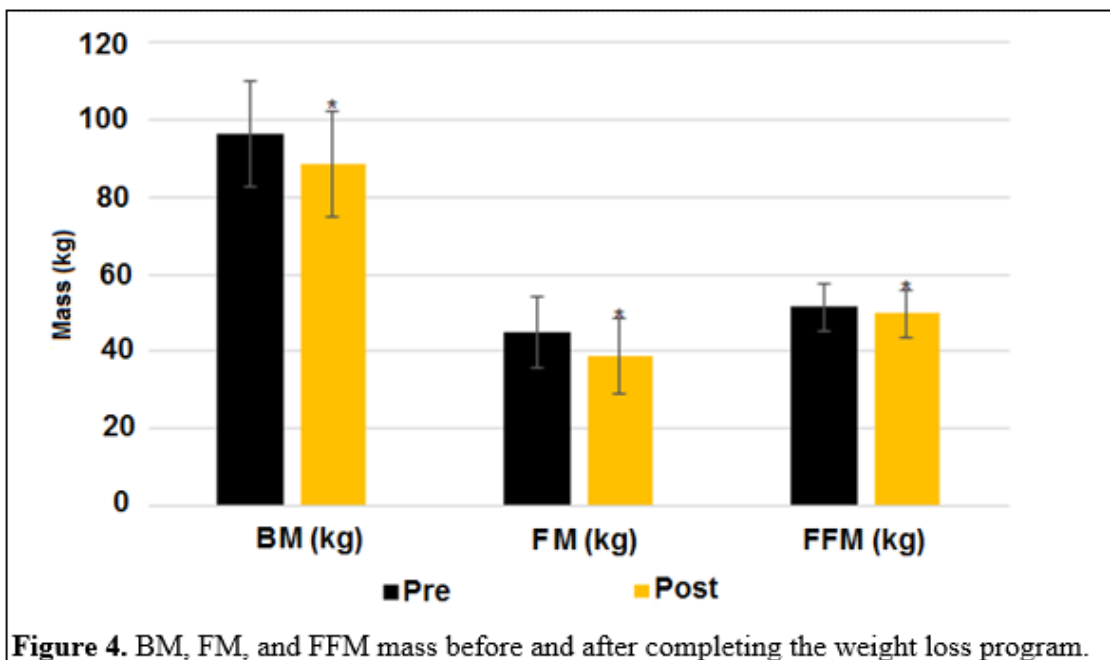

Figure 4. BM, FM, and FFM mass before and after completing the weight loss program.

The pulmonary function data had several values that were significantly different following weight loss. Those values include PEF ($p = 0.01$), MVV ($p < 0.01$), TLC ($p = 0.01$), and FRC ($p < 0.01$) (Table 1).

Table 1. Pulmonary function testing values before and after completing the weight loss program.

	Pre	Post
FVC (L)	3.72 ± 0.57	3.72 ± 0.59
FEV_1 (L)	2.99 ± 0.46	2.99 ± 0.44
$FVC/FEV_{1\ (\%)}$	81 ± 6	81 ± 6
PEF (L $\cdot$ s^{-1})	7.39 ± 1.01	7.73 ± 1.25 *
MVV (L $\cdot$ min^{-1})	119 ± 18	126 ± 18 *
TLC (L)	4.80 ± 0.69	4.85 ± 0.70 *
FRC (L)	1.96 ± 0.42	2.19 ± 0.48 *
RV (L)	1.04 ± 0.30	1.06 ± 0.28

A significant difference in PEF was observed between the best curve trials pre- and post-weight loss, as can be seen in table 2. All other values not different.

Table 2. Pre- and post-weight loss changes in the selected curve trial data.

|	Pre	Post
FVC (L)	3.71 ± 0.55	3.73 ± 0.58
PEF (L $\cdot$ s^{-1})	7.31 ± 1.06	7.65 ± 1.30*
$FEF_{50\%}$ (L $\cdot$ s^{-1})	3.62 ± 0.97	3.64 ± 0.95
$FEF_{25\%}$ (L $\cdot$ s^{-1})	1.24 ± 0.44	1.26 ± 0.42

Figure 5 indicates that the β° between pre- and post-weight loss had no significant difference (p= 0.33). This was also true of pre- and post-weight loss in FR (p= 0.33) in figure 6.

Figure 5. Pre- and post-weight loss changes in β°.

Figure 6. Pre- and post-weight loss changes in FR.
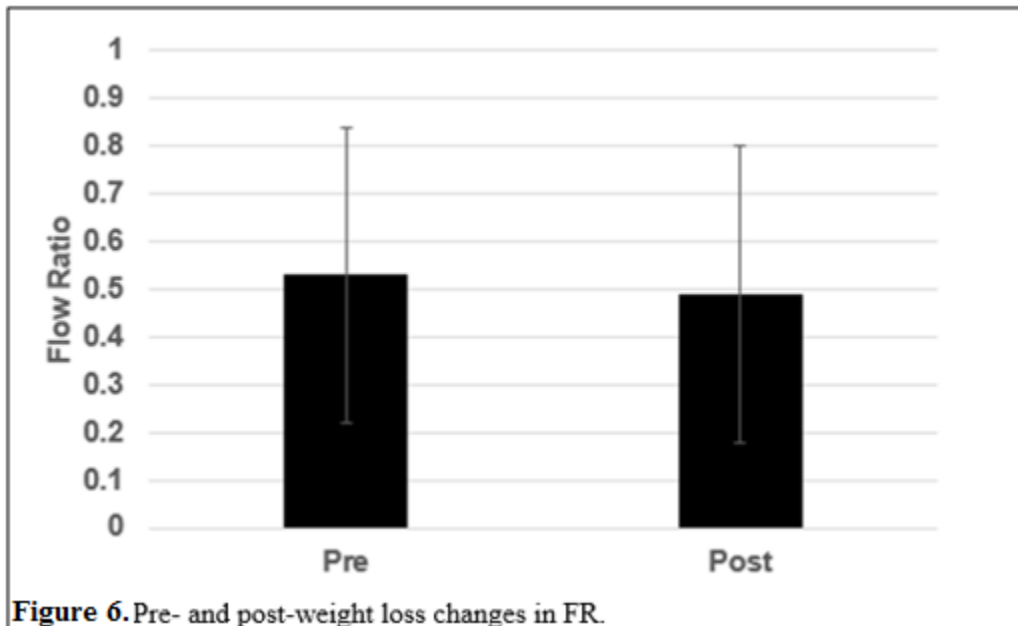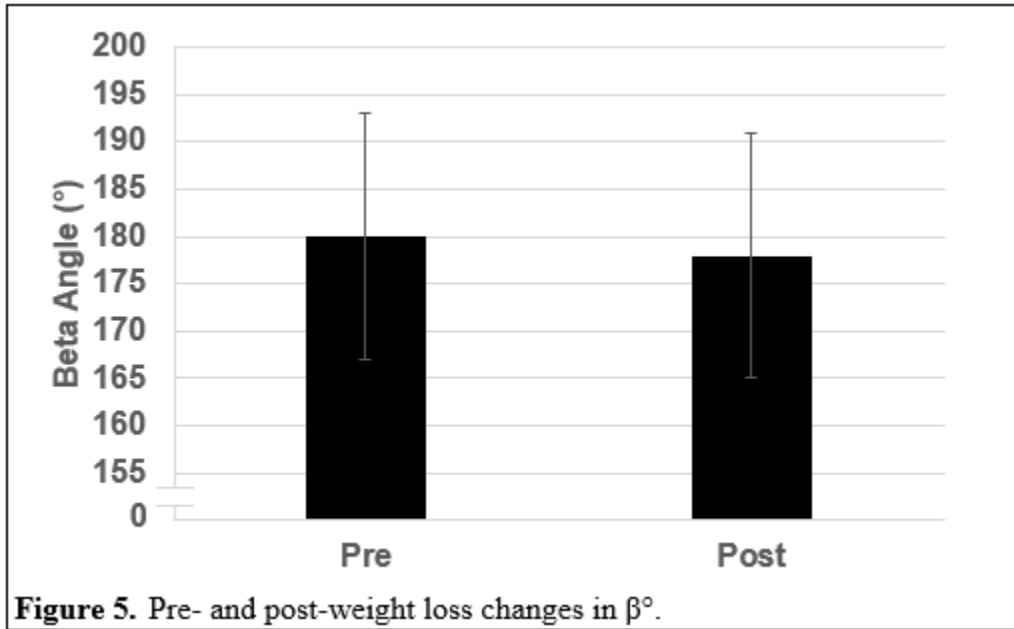
SR was determined to have a significant difference at SR at 80% FVC (p= 0.01) as well as SR at 75% FVC (p= 0.04) (Figure 7).

Figure 7. Pre- and post-weight loss changes in SR.
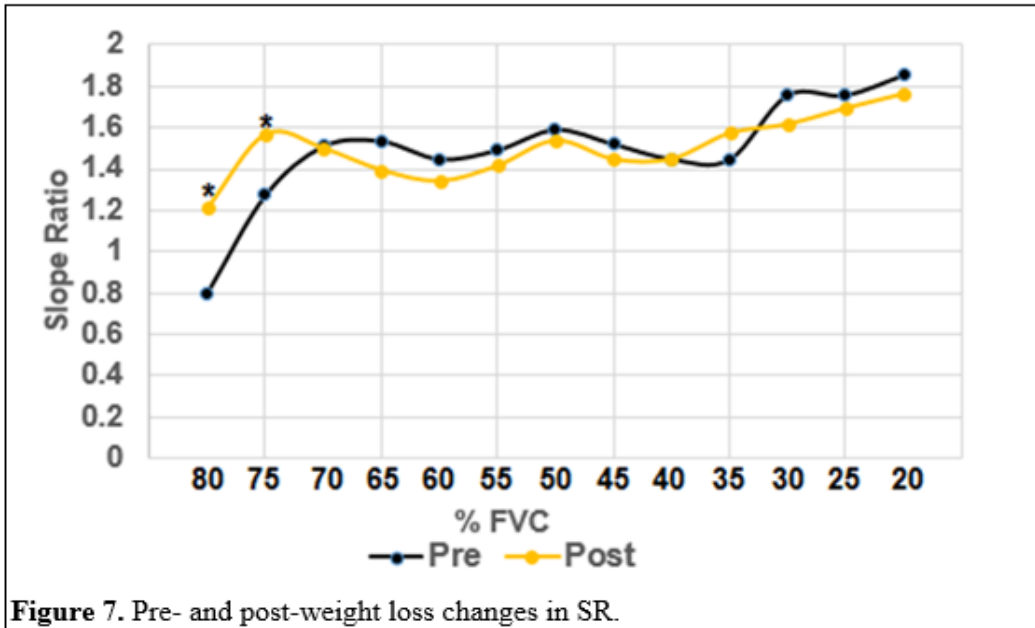
As figure 8 displays, the AUC had several segments that were observed to be significantly different. The segments that were found to be significantly different were: TLC to PEF (p= 0.04), FEF75 to $FEF_{50\%}$ (p= 0.002), and $FEF_{50\%}$ to $FEF_{25\%}$ (p= 0.01). The total AUC (i.e., the sum of all segments) was not different between pre- and post-weight loss.

Figure 8. Pre- and post-weight loss changes in AUC.
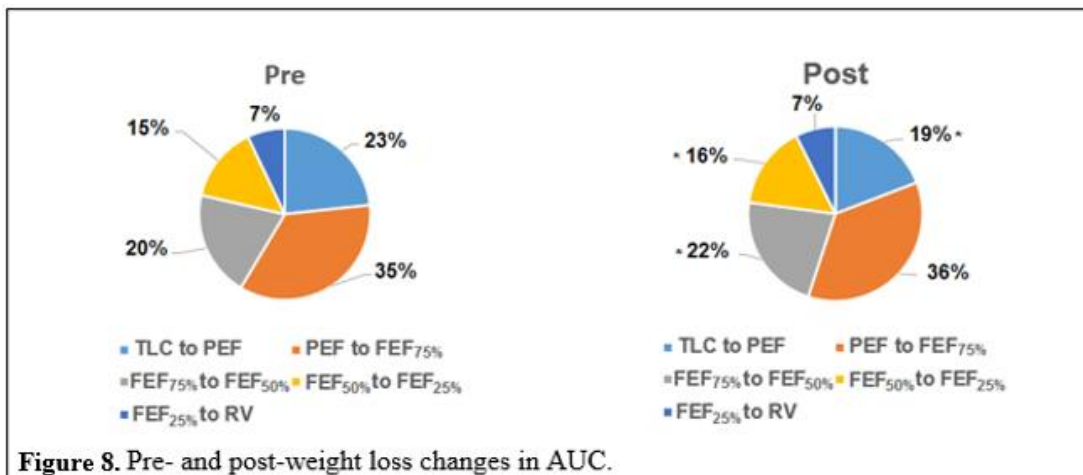
DISCUSSION

An improvement in lung function can be observed through the values that were significantly different following weight loss, such as PEF, SR at 80% and 75% SR, and segments of AUC. As there was a significant difference observed between two methods, SR and AUC, at multiple points in the curve, a change in the shape of the MEFV curve did occur following weight loss. This change in the shape occurs at the earlier aspects of the curve, due to the parameters that underwent a significant difference (PEF, SR at 80% and 75% of FVC, and AUC from TLC to PEF) between pre- and post-weight loss. These findings are important due to their implication on other aspects of respiratory physiology.

The increase in PEF may potentially have been due to other changes that occur with weight loss, namely a decrease in airway resistance and chest-wall compliance. As these are determinants of flow, it is reasonable to expect that those changes were the cause behind the change in PEF (Koenig, 2001). This elevation in PEF may have also had an effect on the SR, which was found to have a significant difference earlier in the curve. As SR at 80% and 75% of FVC are relatively close to PEF, the rise in PEF may have caused those two values to increase as well.

The changes in AUC have a significant impact on other aspects of respiratory physiology. While total AUC did not change, several segments of the AUC were significantly different. Total AUC was not observed as significantly different potentially due to the other segments decreasing to balance out the total AUC. As discussed in previous studies, flow limitation is typically observed around 75% FVC to 25% FVC (Hyatt, 1983). This range, 75% FVC to 25% FVC, is the range of AUC segments that was found to be significantly different following weight loss.

The implications behind this are that following weight loss, it is possible that flow limitation may be less likely due to the increased AUC in these segments.

Though the results showed an expected change in PEF, several of the other pulmonary function values that had not been reported in other studies were found to be significantly different. These values included MVV, TLC, and FRC. While these values were not reported as being significantly different in other studies, it is plausible that these changes did occur following weight loss.

Participants

The criteria for participants to take part in this study were consistent with other studies involved with obese individuals (Torchio et al., 2009; Aaron et al., 2004). The BMI range of 30 kg/m^2 to 50 kg/m^2 is consistent with other studies on obese individuals (Aaron et al., 2004). In relation to studies on normal weight individuals, the participants in this study were all above normal value ranges for BM, FM, and percent body fat. The methods were also consistent with other studies by following the ATS guidelines while performing spirometry.

Limitations

While many of the methods of this study were followed according to guidelines, there are some limitations. A potential measurement for this study was airway resistance. Airway resistance is known to increase in obese individuals (Zeah, 1993). This study did not measure airway resistance before or after the 12-week weight loss program, however, it could have been beneficial to analyze the changes in airway resistance. The study could have analyzed different amounts of weight loss and changes in airway resistance.

Finally, chest wall compliance was another measurement that was not recorded but could have presented significant findings. Much like airway resistance, obesity is known to have a

negative effect on chest wall compliance (Naimark, A., & Cherniack, R.M., 1960). Due to the participants in the study losing differing amounts of weight, recording the change in chest wall compliance may have led to observing a threshold that is required for chest wall compliance to change.

Further Research

The findings in this study, namely the change in the segments of AUC, can be used in further research. As the range of AUC that is observed to be significantly different falls into the range of flow limitation, future studies may wish to analyze the change in flow limitation following weight loss in obese individuals. Future studies may also look at pulmonary function values through the use of the techniques used in this study ($\beta°$, FR, SR, and AUC) to examine if values other than PEF are observed to be significantly different.

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