The causes of childhood and adolescent obesity are manifold that include lack of regular exercise, sedentary habits, overconsumption of high-calorie foods, and genetic, perinatal, and early life factors.

Co-morbidities of adolescent obesity encompass both short- and long-term health concerns. Because 80% of adolescent obese become obese adults, adolescent obesity is associated with a greater long-term risk of hypertension and type 2 diabetes mellitus in adulthood. In addition, orthopedic issues such as slipped capital femoral epiphysis and gastrointestinal complications like cholelithiasis are far more common in the obese child. Obesity complicates the common adolescent problem of low self-esteem.

Impairment of pulmonary function is associated with both adolescent and adult obesity. Studies have revealed a significant reduction in forced vital capacity (FVC), forced expiratory volume in the 1st second (FEV₁), flow rates (peak expiratory flow rate (PEFR) and forced expiratory...
flow (FEF25–75%), maximum voluntary ventilation (MVV), expiratory reserve volume (ERV), and functional residual capacity (FRC) in the morbidly obese.\textsuperscript{10} Reductions in pulmonary function in relation to the waist-to-hip ratio have been observed in the adult obese.\textsuperscript{10} Significant decrease in FRC, ERV, flow rates, and MVV has been found in obese children and adolescents.\textsuperscript{10,11} However, studies investigating pulmonary functions in obese children in India are few.\textsuperscript{12} Hence, the present study was aimed to investigate pulmonary function variables in the adolescent obese in Baroda city, Gujarat.

**MATERIALS AND METHODS**

Subjects were randomly selected from Rosary High School, Pratapgunj, Baroda. Boys in the age group of 12–17 years were screened to identify the obese by recording their weight (in kilograms) and height (in centimeters). The protocol of the study was approved by the Institutional Ethics Committee. Body mass index (BMI) was calculated as per the following formula:

\[
\text{body mass index} = \frac{\text{weight (kilograms)}}{\text{height}^2 \text{ (meter}^2)\text{)}
\]

Boys having BMI greater than the 95th percentile for age were classified as obese.\textsuperscript{13} A total of 30 such obese boys were identified. An identical number of age-matched non-obese boys were taken as controls. Boys with symptoms of illness like fever, cough, abdominal pain, etc., and anxious, apprehensive, and uncooperative ones were excluded from the study. All subjects were explained about the procedures to be undertaken and written informed consent was obtained as per Helsinki Declaration, modified according to the test protocol. Informed consent forms were signed by parents/guardians as the children were minors. The following measurements/tests were performed.

**Clinical Assessment**

A detailed personal history was elicited. A brief questionnaire was administered regarding the subjects’ perception of obesity, any influence of obesity on their self-esteem, parental history of obesity, any complication in the perinatal period, weight at 5–7 years, habits like hours of watching television, daily physical activity, diet, etc. A complete physical examination was performed. Pulse and blood pressure were recorded observing the standard procedure. Systemic examination was carried out.

**Anthropometric Measurements**

Weight (in kilograms) and height (in centimeters) were recorded on a beam balance. Waist circumference was measured as the smallest circumference between the ribs and the iliac crest to the nearest 0.1 cm, while the participant was standing with the abdomen relaxed, at the end of normal expiration. Hip circumference was recorded as the maximum circumference between the iliac crest and the pubic symphysis. Skinfold thicknesses were measured at four sites by vernier calipers – triceps, chest, subscapular, and superior iliac crest thickness.

**Pulmonary Function Testing**

The subjects were demonstrated the maneuvers of the pulmonary function tests. Computerized spirometry was carried out using MEDI:SPIRO (Maestros Mediline Systems Ltd., Navi Mumbai, India) observing the guidelines laid down by the American Thoracic Society and European Respiratory Society\textsuperscript{[14]} with the subject seated. Calibration of the spirometer was carried out daily using a 3-L calibration syringe as recommended by the American Thoracic Society. For the FVC maneuver, the subjects were asked to take a deep inspiration and breathe out as rapidly as and as long as possible into the mouth of the spirometer. Flow volume curve was plotted with the best of three acceptable maneuvers being taken as the final reading. In addition, maximum voluntary ventilation was recorded by asking the subject to breathe as rapidly and as deeply as possible for a period of 12 s. Possible chronic obstructive pulmonary disease was defined on the basis of “GOLD” criteria.\textsuperscript{15} The following pulmonary functions were recorded: \(FEV_1\), \(FVC\), \(FEF_{25–75\%}\), \(PEFR\), \(PEF\), \(PEFR\), \(FEF_25–75\%).

**STATISTICAL ANALYSIS**

The data of the obese and control groups were compared using Student’s \(t\)-test. The following comparisons were made:

- Age, BMI, waist/hip ratio, skinfold thicknesses
- Pulmonary function parameters of the obese and control groups

Correlation co-efficient was calculated to determine the relationship between various measures of adiposity (weight, BMI, waist circumference, hip circumference, and waist-to-hip ratio) and pulmonary function parameters.

**RESULTS**

Table 1 compares the age and anthropometric variables of the obese and control groups. The average BMI of the obese group was 29.4 ± 4.12 kg/m\(^2\) compared to the control group’s 19.51 ± 1.23 kg/m\(^2\). The average age of the obese and control groups were 15.8 ± 1.37 and 15.9 ± 1.4 years, respectively.

Table 2 compares the pulmonary function parameters of the obese and control groups [Figures 1 and 2]. \(FEV_1\) (% predicted) was significantly decreased in the obese group \((P < 0.01)\) [Figure 1] \(FEV_1/FVC\) (both observed and percent predicted) was also significantly less in the obese group [Figure 3]. However, no obstructive impairment was detected in any subject of the obese group. In addition, MVV (both observed and percent predicted) was significantly decreased in the obese group \((P < 0.001)\) [Figure 3]. The other parameters, viz. \(FVC\) and flow rates \((PEFR\text{ and } FEF_{25–75\%}\), were not significantly different in the obese and control groups.

Table 3 presents the correlation matrix between various
anthropometric variables and pulmonary function parameters. Weight, BMI, waist circumference, and hip circumference were strongly negatively correlated with FEV/FVC, MVV, and FEF 25–75% (P < 0.01). Waist-to-hip ratio was strongly negatively correlated with MVV (P < 0.01) and FEF 25–75% (P < 0.05), but not with FEV/FVC [Figures 4-6].

**DISCUSSION**

The predominant pulmonary function abnormality detected in the obese subjects was a reduction in the FEV/FVC ratio and MVV. FEV, and FEV/FVC were significantly decreased in the obese subjects. A decrease in the FEV/FVC was also observed by Inselman et al. and Mallory et al. However, no significant reduction was detected by Bossisio et al. and Chaussain et al. A reduction in the FEV/FVC ratio indicates airway narrowing, the severity of which is indicated by the absolute value of FEV. Because no obstructive impairment was detected in any of the obese, results are indicative of airflow limitation without significant obstruction.

A significant finding of the study is a decrease in the MVV in the obese group. MVV depends on the movement of air into and out of the lungs during continued maximal effort throughout a preset interval. The MVV is a simple, informative test that provides an overall assessment of the effort, co-ordination, and flow-resistive properties of the respiratory system. A similar decrease in MVV was observed by Ho et al. and Inselman et al. in children, and Sahebjami et al. in adults. They hypothesized that some obese subjects manifest peripheral airway abnormalities, suggested by reduced maximum expiratory flow rates at low lung volumes and air trapping. As a result of air trapping, inspiratory muscles are placed at a mechanical disadvantage leading to lower inspiratory pressure and flow, and reduced respiratory muscle strength, causing low MVV. Alternatively, in some obese subjects, diaphragmatic muscle weakness due to a variety of causes could lead to a decreased MVV. In addition, a decreased MVV may reflect extrinsic mechanical compression on the lung and the thorax.

In our study, across the spectrum of normal weight and obese boys, FEV/FVC, MVV, and FEF 25–75% were strongly negatively correlated with body weight, BMI, waist circumference, hip circumference, and waist-to-hip ratio. This suggests that pulmonary function may be impaired, though not sufficiently to cause clinical abnormality with increasing adiposity as suggested by these indices. The strongest negative correlation was with BMI (P < 0.001). Similar negative correlation between BMI and pulmonary function was observed by Sri Nageswari et al. in a group of obese children of mixed socioeconomic status from Punjab, India. They hypothesized that obesity is characterized by decrease in chest wall compliance due to increased amount of adipose tissue around the chest and abdomen, which decreases pulmonary functions in these children.

With increasing waist circumference and hip circumference, values of pulmonary function have decreased. Waist-to-hip ratio was negatively correlated with MVV (P < 0.01) and FEF 25–75% (P < 0.05). A number of studies have revealed a negative correlation between measures of abdominal adiposity and pulmonary function parameters. Ochs-

**Table 1: Standard anthropometric measurements of the control and obese groups**

| Parameters          | Control (n = 30) | Obese (n = 30) |
|---------------------|-----------------|----------------|
| Age (years)         | 15.9 ± 1.4      | 15.8 ± 1.37    |
| Height (cm)         | 164.6 ± 6.43    | 166.77 ± 9.49  |
| Weight (kg)         | 51.92 ± 4.53    | 81.3 ± 13.9*** |
| Waist (cm)          | 65.6 ± 7.51     | 89.5 ± 13.35** |
| Hip (cm)            | 72.23 ± 5.68    | 96.63 ± 11.48**|
| Waist/hip           | 0.91 ± 0.05     | 0.96 ± 0.09    |
| Body surface area (m²)| 1.53 ± 0.09    | 1.99 ± 0.18*** |
| Body mass index (kg/m²)| 19.51 ± 1.23  | 29.4 ± 4.12*** |
| Skinfold thicknesses|                 |                |
| Triceps(cm)         | 2.34 ± 0.96     | 4.34 ± 0.85*** |
| Subscapular(cm)     | 2.7 ± 0.79      | 5.48 ± 1.55*** |
| Sub. iliacs(cm)     | 2.02 ± 0.63     | 4.43 ± 1.47*** |
|                      | 4.95 ± 1.37     | 9.15 ± 1.92*** |

**Table 2: Measurements of pulmonary function tests in control and obese adolescents**

| Parameters          | Control (n = 30) | Obese (n = 30) |
|---------------------|-----------------|----------------|
| FVC (L)             | 3.43 ± 0.52     | 3.66 ± 0.65    |
| FEV₁ (% of predicted values) | 105.7 ± 13.73 | 102.4 ± 15.88 |
| FEV₁ (% of predicted values) | 3.2 ± 0.42     | 3.01 ± 0.57   |
| FEV₁/FVC (% of predicted values) | 107.5 ± 12.51 | 93.27 ± 15.74** |
| PEFR (L/s)          | 6.82 ± 1.53     | 6.87 ± 1.56    |
| FEF25–75% (L/s)     | 4.76 ± 1.35     | 3.56 ± 1.02    |
| MVV (Lts.)          | 148.96 ± 29.04  | 108.45 ± 22.6*** |

0 = observed values, P = predicted values, **P < 0.01; ***P < 0.001
Paralikar, et al.: Pulmonary functions in obese adolescents

Table 3: Correlation of various anthropometric variables and pulmonary function parameters in adolescent boys (values are correlation co-efficient $r$)

|                  | FEV$_1$ | FVC  | FEV$_1$/FVC | MVV  | PEFR | FEF$_{25-75}$%
|------------------|---------|-------|-------------|------|------|------------------|
| Wt (kg)          | 0.05    | 0.29* | −0.48***    | −0.38** | 0.24 | −0.31*          |
| Ht (cm)          | 0.54*** | 0.60*** | −0.09      | 0.09  | 0.45*** | 0.14            |
| BMI (kg/m$^2$)   | −0.19   | 0.88*** | −0.52***    | −0.50*** | 0.06 | −0.43***        |
| Waist circumference (cm) | 0.00 | 0.19 | −0.37***    | −0.38*** | 0.14 | −0.37***        |
| Hip circumference (cm) | −0.04 | 0.20 | −0.45***    | −0.41*** | 0.08 | −0.37***        |
| Waist/hip ratio  | −0.01   | 0.13  | −0.24       | −0.33** | 0.04 | −0.31*          |

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Balcom et al.$^{[22]}$ found inverse associations of abdominal height and waist circumference with pulmonary function in men and women with BMI values of $\geq 25$ kg/m$^2$. Canoy et al.$^{[23]}$ analyzed the association of waist-to-hip ratio and pulmonary function in the European Prospective Investigation into Cancer and Nutrition (EPIC-Norfolk) study and reported an inverse relation. Harik-Khan et al.$^{[24]}$ investigated the association of fat distribution and pulmonary function using waist/hip ratio. They reported an inverse association of FEV$_1$ and waist/hip ratio in men only. Lazarus et al.$^{[25]}$ reported an inverse association of abdominal girth/hip breadth ratio with pulmonary function after adjustment for BMI in men over a narrow range in

the Normative Aging Study. Collins et al.$^{[26]}$ examined normal to mildly obese firefighters and found decreased pulmonary function in men with a waist/hip ratio of $>0.95$. A number of hypotheses have been proposed to explain the negative correlation between pulmonary function parameters and measures of visceral adiposity. One possible mechanism is a mechanical limitation of chest expansion during the FVC maneuver. Increased abdominal mass may impede the descent of the diaphragm and increase the thoracic pressure. Also, abdominal adiposity is likely to reduce ERV via compressing the lungs and diaphragm.$^{[22]}$
In addition, visceral adipose tissue influences circulating concentrations of interleukin-6, tumor necrosis factor-alpha, leptin, and adiponectin, which are cytokines that may act via systemic inflammation to negatively affect pulmonary function.\textsuperscript{12\textsuperscript{–}15} Investigators reported an inverse study population (Figure 6: Bhave S, Bavdekar A, Otiv M. IAP national task force for childhood obesity and pulmonary function. Arch Dis Child 2003;88:361-3).

To conclude, pulmonary functions are decreased (as compared to normal weight subjects) in our group of obese adolescent boys. This study unravels yet another health hazard associated with obesity and highlights the need to aggressively reduce weight at a younger age. However, no clinical abnormality, viz. obstructive or restrictive deficit, has been detected in any of the obese children. Also, the small sample size makes it necessary to view the results with caution. In addition, it would be interesting to conduct longitudinal studies to better assess the relationship between increasing body weight and pulmonary functions in obese.

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*Figure 6: Correlation between waist/hip ratio and MVV in the entire study population (N = 60)*