

OBESITY AND PULMONARY FUNCTION IN NAVAJO AND HOPI CHILDREN

Background: Although several reports have shown an adverse cardiovascular and metabolic risk profile associated with childhood obesity, few reports have examined the effects of childhood obesity on pulmonary function.

Objective: The purpose of this study was to examine the influence of obesity on pulmonary function in Navajo and Hopi children.

Methods: Subjects included 256 (110 males, 146 females) Hopi children 6–12 years of age and 557 (274 males, 283 females) Navajo children 6–12 years of age ($N=813$). The body mass index was used to classify subjects as normal weight, overweight, or obese on the basis of international reference values. Forced vital capacity (FVC), forced expired volume in one second (FEV_1), $FEV_1\%$ (FEV_1 to FVC ratio; FEV_1/FVC), and forced expiratory flow between 25%–75% of vital capacity (FEF_{25-75}) were determined according to the American Thoracic Society recommendations.

Results: Approximately 26% of Navajo and Hopi children were defined as overweight (26.0% of boys and 25.6% of girls) and an additional 16% (14.6% of boys and 17.7% of girls) were defined as obese. In general, the patterns showed an increase in pulmonary function between normal weight and overweight children and a decrease in pulmonary function of obese children. Significant differences among groups existed for $FEV_1\%$ and FEF_{25-75} in boys and FVC and FEV_1 in girls.

Conclusions: The results indicate the pulmonary consequences of obesity in children and provide further evidence of the adverse consequences of pediatric obesity among Native Americans. (*Ethn Dis.* 2007;17:14–18)

Key Words: BMI, Overweight, Native Americans, Lung Function, Ventilatory Function

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INTRODUCTION

Childhood obesity is a major public health issue.^{1–5} Results from the recent National Health and Nutrition Examination Survey (NHANES) indicate that $\approx 30\%$ of US youth 6–19 years of age are overweight or obese (ie, body mass index [BMI] higher than the age- and sex-specific 85th percentile).¹ The prevalence rates of overweight and obesity have also been published among Native Americans.^{6,7} Prevalence rates of $\approx 45\%$ for combined overweight and obesity in Navajo⁸ and Hopi⁹ children have been reported.

The public health concerns of obesity and related co-morbidities are well recognized.¹⁰ Obesity causes illness even early in life, and childhood overweight increases the risk of adult overweight, the clustering of cardiovascular disease risk factors, and all-cause and cardiovascular disease mortality.¹¹ The relationships between obesity and cardiovascular and metabolic risk factors have also been examined in Navajo adolescents.¹²

Although much attention has been given to the cardiovascular and metabolic consequences of pediatric obesity, relatively few studies have examined the functional consequences of obesity on lung function during childhood and adolescence.^{13–17} In 1846, Hutchinson observed that vital capacity increased with body weight for a given height up to a certain point and then decreased.¹⁸ This finding was also reported by Shoenberg¹⁷ and termed the “muscularity effect” and “obesity effect.” Others have found similar results in adults¹⁹ and children and adolescents.^{13–16}

Pulmonary disease is common among persons who live in the southwestern United States and particularly affects the Navajo and Hopi Native Americans who reside in the Colorado Plateau. This region covers thousands of square miles

in Arizona, New Mexico, Utah, and Colorado. It is characterized by a high desert plain landscape of windswept, sandy soils typically covered with sage brush, grasses, sparse wild flowers, and some trees. Most Navajo and Hopi have an agrarian lifestyle; Navajos are heavily involved with herding sheep, cattle, and horses, along with some farming, while the Hopi are largely involved in subsistence crop farming. The Navajo tend to live in dispersed communities over large tracts of land while the Hopi tend to aggregate around small villages.

Pulmonary disease is a major cause of morbidity and mortality for both tribes. Pulmonary diseases such as bronchitis, pneumonia, coccidioidomycosis (Valley Fever) and tuberculosis are common. Pulmonary disease can only successfully be diagnosed and treated if a pulmonary nomogram (normal table) is available to determine the upper and lower limits of normal lung volumes and capacities. Pulmonary normal tables are race-specific and cannot usually be used to diagnose pulmonary disease in other racial groups. No pulmonary nomograms are available for Navajo or Hopi children. Therefore, the larger intent of this research project was to develop pulmonary nomograms for these two tribes. However, before developing these nomograms, we had to determine if pulmonary function was reduced in overweight and obese children. Since we previously showed that obesity is highly prevalent in this sample,^{8,9} we sought to examine whether pulmonary function was also reduced in this sample.

METHODS

Subjects

Participants were volunteers enrolled in elementary schools on the Navajo

and Hopi reservations in northeastern Arizona. Navajo children were volunteers enrolled in three boarding schools and one public school from various regions of the Navajo reservation in northeastern Arizona. Boarding schools were selected from ≈ 50 boarding schools on the Navajo Reservation based on location and willingness to participate in the study. The public school was selected because it served a large area and was removed from the other school locations. The total Navajo sample ($N=557$, 274 boys and 283 girls) represented $\approx 3\%$ of the children in this age range on the Navajo reservation in Arizona ($\approx 18,000$ children 5–12 years of age).²⁰ Informed consent was obtained according to school policy. The protocol for data collection was approved by the Northern Arizona University Human Subjects Committee and the Navajo Nation Institutional Review Board.

Children from every elementary school on the Hopi reservation were tested. One of these schools was a private school, while the others were part of the Hopi tribal school system. The recruitment of subjects and the protocol for testing children was reviewed and approved by the institutional review board of Northern Arizona University and the Hopi Tribal Council. A representative from the Hopi Health Department was appointed to assist and guide the research team in contacting school principals. Approval from the Hopi elementary schools to test on the school campuses was first obtained from the individual school boards, and then approval from the school principal was obtained. Letters of information and a parent/guardian consent form were sent to each of the households within the school boundaries. Parents/guardians gave consent for their children to participate by sending the signed consent form back to the school. On the day of testing, the children signed an assent form acknowledging their willingness to participate in the study. The

sample of Hopi children included 256 subjects (110 boys and 146 girls) 6–12 years of age. The sample represents at least 18% of the children in this age range on the Hopi reservation in Arizona (≈ 1500 children, 5–14 years of age).²⁰

Before testing, every child was interviewed for recent respiratory disease involvement. Children were asked if they had asthma, bronchiolitis, or other respiratory diseases. They were also interviewed to determine whether they had any seasonal or permanent allergies to grasses, pollens, flowers, trees, bushes, dust, animal dander, or medications. No child reported any significant allergies to any of these substances.

A cardiopulmonary specialist gave a respiratory examination using auscultation to ensure that crackles (rales) or sibilant or sonorous rhonchi or wheezes were absent. In cases where a school nurse was present, we asked if any of those tested had reported any respiratory problems other than the common cold. If a child reported having a significant cold in the two weeks before testing or who had a cold at the time of testing, we returned to the site and tested two weeks after the child had recovered.

Anthropometry

Height and body mass were measured while children were not wearing shoes or excess clothing and accessories. Height was measured to the nearest 1/4 inch while the subject was standing erect and his or her head was in the Frankfort horizontal plane. Body mass was measured to the nearest pound by using a standard physician's scale. Both measures were converted to standard international (SI) units. The body mass index (BMI) was calculated (kg/m^2). The recently developed international reference values were used to classify overweight and obesity based on BMI.²¹ These standards were proposed by the Childhood Obesity Working Group of

the International Obesity Task Force and are based on the adult cut-points for overweight (BMI >25) and obesity (BMI >30), which are associated with adverse health outcomes.

Pulmonary Function

All pulmonary function testing followed the recommendations of the American Thoracic Society (ATS) Statement on the Standardization of Spirometry.²² Included in our quality control procedures were the following: equipment performance criteria and validation, subject maneuvers, measurement procedures, acceptability, and reproducibility. Testing was performed by using a Collins Medical Survey Tach that meets or exceeds all of the ATS criteria for approved spirometers.²² Routine equipment maintenance included cleaning, calibration checks, and verification. The spirometer was calibrated on-site by using a 3-L syringe at the beginning of testing and whenever the spirometer was moved to a new testing site. When the spirometer was at a testing station for >2.5 hours, it was recalibrated before additional pulmonary function tests were conducted.

Each subject performed the ventilatory maneuver in the standing position with noseclips, according to the recommendations of the ATS.^{22,23} To perform a ventilatory maneuver, subjects were asked to inhale as far as possible, then blow out through the spirometer as hard and as far as they could. During the maneuver they were encouraged by the investigator. The total amount of air exhaled was termed the forced vital capacity (FVC). Of that exhaled volume, the amount of air exhaled in the first second was defined as the forced expiratory volume in one second (FEV_1). At least three acceptable maneuvers were performed to ensure that a best effort was obtained. Expirations had to last longer than four seconds to be accepted. If individual trial results varied by $>5\%$ for either

FVC or FEV₁, the pulmonary function test was repeated until all three trials were within 5% variation. The largest FVC, FEV₁, and FEV₁% (FEV₁ to FVC ratio; FEV₁/FVC) for each subject was used for analysis. Forced expiratory flow from 25% to 75% of vital capacity (FEF₂₅₋₇₅) was derived from the single best test that produced the largest sum for FVC and FEV₁. The FVC is generally considered a good measure of lung volume and is influenced by diseases such as fibrosis and by obesity. The forced expiratory volume in one second (FEV₁) and FEF₂₅₋₇₅ are estimates of the patency of the airways and are often affected by lung diseases such as emphysema, bronchitis, and asthma.

Statistical Analysis

To examine differences in pulmonary function, analyses of covariance (ANCOVA), controlling for age, height, and weight, were conducted. Age and body size variables were statistically controlled since they influence pulmonary function during growth and maturation.²⁴ We have previously used this analysis to study physical activity and lung function,²⁵ and Lazurus et al¹³ used a similar approach in studying obesity and lung function in children and adolescents. This analysis essentially allowed us to determine the influence of weight status (ie, normal weight, overweight, or obese) on pulmonary function, independent of age and body size. Statistical

analysis was carried out with SPSS version 11.0.

Results

Descriptive statistics by sex are shown in Table 1. Relative to reference values, the mean height was relatively stable at the 50th percentiles. Mean weight was relatively stable at the 75th percentiles. As a result, age-specific means for the BMI fluctuate at or above the 85th percentiles in both sexes. Approximately 26% (26.0% of boys and 25.6% of girls) of Navajo and Hopi children are defined as overweight, and an additional 16% (14.6% of boys and 17.7% of girls) are defined as obese. We found significant differences in the mean BMI, prevalence of overweight and obesity, and pulmonary function between tribes. In general, Hopi boys and girls had higher mean BMI and lower mean values for lung function in comparison to their Navajo counterparts. Because the direction of the relationship was in the expected direction (ie, higher BMI and lower pulmonary function), the Navajo and Hopi children were combined in the analysis to conserve the sample size.

Age-, height-, and weight-adjusted values for pulmonary function variables are shown in Table 2. Significant differences among groups existed for FEV₁% and FEF₂₅₋₇₅ in boys and FVC and FEV₁ in girls. FEV₁ was also 80 mL lower in obese boys compared

Table 1. Descriptive characteristics of the sample, mean (SD)

	Males (n=384)	Females (n=429)
Age (years)	9.6 (2.0)	9.5 (1.9)
Height (m)	1.36 (.13)	1.36 (.13)
Weight (kg)	37.0 (12.8)	37.5 (13.7)
BMI (kg/m ²)	19.5 (4.0)	19.8 (4.5)
% Overweight	26.0	25.6
% Obese	14.6	17.7
FVC (L)	2.59 (.70)	2.41 (.65)
FEV ₁ (L)	2.20 (.59)	2.09 (.55)
FEV ₁ %	.85 (.06)	.87 (.07)
FEF ₂₅₋₇₅ (L/s)	2.53 (.79)	2.56 (.80)

BMI= body mass index; FVC, forced vital capacity; FEV₁= forced expiratory volume in 1 second; FEV₁%= ratio of FEV₁ to FVC; FEF₂₅₋₇₅= forced expiratory flow from 25% to 75% of vital capacity.

to normal-weight boys, but this difference did not reach statistical significance.

DISCUSSION

The main findings of this study show decreased lung function in obese children, which supports findings from previous studies.¹³⁻¹⁷ In Australian children and adolescents, Lazurus et al¹³ found that increasing percent body fat was inversely related to height- and weight-adjusted FVC and FEV₁. Other reports of small samples (n=13-42) of obese children or adolescents have found either lower lung volumes^{14,26-28} or “normal” lung volumes and capacities.¹⁶ Although not measured in the present study, decreased expiratory reserve volume, maximal vol-

Table 2. Age-, height-, and weight-adjusted means (SE) for pulmonary function by weight status in Navajo and Hopi children

	Boys			Girls		
	Normal	Overweight	Obese	Normal	Overweight	Obese
FVC (L)	2.573 (.023)	2.621 (.028)	2.585 (.058)	2.436 (.020)	2.427 (.024)	2.311 (.042)*
FEV ₁ (L)	2.211 (.022)	2.220 (.026)	2.130 (.054)	2.089 (.020)	2.132 (.024)	2.035 (.041)*
FEV ₁ %	.864 (.054)	.848 (.059)	.829 (.061)*	.868 (.005)	.880 (.006)	.870 (.110)
FEF ₂₅₋₇₅ (L/s)	2.594 (.053)	2.547 (.063)	2.228 (.131)*	2.527 (.050)	2.659 (.061)	2.509 (.106)

* P<.05 for trend.

FVC, forced vital capacity; FEV₁= forced expiratory volume in 1 second; FEV₁%= ratio of FEV₁ to FVC; FEF₂₅₋₇₅= forced expiratory flow from 25% to 75% of vital capacity.

untary ventilation, and increased residual volume have been observed in obese children.^{14,15} Recent work has also shown that childhood obesity may be related to the development of asthma.²⁹⁻³¹ In relation to this study, the reduced pulmonary function may be a diagnostic sign for the development of asthma among Navajo and Hopi children.

The decreased pulmonary function in obese children could be due to several mechanisms including respiratory or chest wall mechanics (work of breathing, compliance, elastic recoil), resistance within the respiratory system, respiratory muscle function, and airway structure or function.^{32,33} Obesity may change airway function by increasing bronchial hyperresponsiveness.³³ An alternative explanation may be related to the inflammatory response shown in obese individuals. As suggested by Gilliland et al,³⁰ adipose tissue is a source of proinflammatory cytokines and chemokines, and their increase in the obese state may have the potential to enhance pulmonary inflammation.

Obesity also acts like a restrictive pulmonary disease in that it provides an external load on the chest wall.^{30,36} Such a restrictive effect is characterized by decreases in both FVC and FEV₁, with variable effects on FEV₁%, and is shown with many types of external loads.³⁴ This effect may provide a direct link with the decreases seen in pulmonary function that might even precede the previously mentioned airway effects.

The results show a sex-specific pattern in the decreased lung function of obese children, which may reflect the earlier initiation of the adolescent growth spurt in girls and dysanaptic lung growth. Dysanaptic lung growth refers to the mismatch between lung and airway size due to a disproportionately larger growth in the airspace compared to the airway system.^{35,36} Further study is warranted to determine the consequences of obesity on lung function and morphology and airway

dynamics during growth and maturation.

The limitations of BMI as a proxy for overweight have previously been addressed.³⁷ Since BMI is a measure of not only fat tissue but also fat-free mass (ie, bone and muscle), this proxy for overweight assumes that at a given stature, variation in body mass is due to variation in body fat content. During childhood and adolescence, changes associated with normal growth and maturation confound this indicator, especially rates of growth in stature and mass during the adolescent spurt. An important note with regard to the utility of BMI in this study is that Navajo children have greater skinfold thicknesses than other US youth.^{38,39} In addition, results from the Pathways study of 11-year-old Native Americans found that the estimated body fat was 36% in boys and 39% in girls.³⁹ These results suggest a greater contribution of subcutaneous fat to overall mass in the Native American pediatric population. Unfortunately, we did not measure an index of relative fat distribution or central adiposity (eg, waist circumference or trunk-to-extremity skinfold thickness ratio). Central obesity adversely affects pulmonary function in adults because stress on the chest wall and diaphragm is greater.⁴⁰

The results of this study were consistent with previous findings in adults and children, and these results have clinical and public health implications. First, given the relative strong tracking of obesity into adulthood, childhood obesity may develop into morbid obesity in adulthood, which is associated with pulmonary insufficiency, risk of aspiration pneumonia, pulmonary thromboembolism, and respiratory failure.³³ Second, the results of this study provide further evidence of the consequences of obesity beyond cardiovascular and metabolic complications in Navajo and Hopi children. Finally, the results further highlight the importance of establishing effective pre-

vention and treatment strategies for obesity during childhood. In this regard, culturally appropriate primary prevention and treatment programs for obesity during childhood, such as those recently initiated in Native American communities,^{7,41-46} should be established.

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