Obesity, respiratory function and breathlessness

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Introductory articles

The impact of morbid obesity on oxygen cost of breathing ($\dot{V}O_{2RESP}$) at rest

JP Kress, AS Pohlman, J Alverdy, JB Hall

Oxygen consumption dedicated to respiratory work ($\dot{V}O_{2RESP}$) during quiet breathing is small in normal patients. In the morbidly obese, at high minute ventilations, $\dot{V}O_{2RESP}$ is greater than in normal patients, but $\dot{V}O_{2RESP}$ during quiet breathing in these patients is not known. We postulated that such patients have increased $\dot{V}O_{2RESP}$ at rest which may predispose them to respiratory failure when additional respiratory workloads are imposed. We measured baseline $\dot{V}O_2$ in morbidly obese patients immediately prior to gastric bypass surgery and again after intubation, mechanical ventilation, and paralysis, and compared their change in $\dot{V}O_2$ to nonobese patients scheduled for elective abdominal surgery. Baseline $\dot{V}O_2$ was higher in the obese patients compared with control patients (354.6 versus 221.4 ml/min; $p = 0.0001$) and the change in $\dot{V}O_2$ from spontaneous breathing to mechanical ventilation was significant in the obese patients (354.6 versus 297.2 ml/min; $p = 0.0002$) but not the control patients (221.4 versus 219.8 ml/min; $p = 0.86$). We conclude that morbidly obese patients dedicate a disproportionately high percentage of total $\dot{V}O_2$ to conduct respiratory work, even during quiet breathing. This relative inefficiency suggests a decreased ventilatory reserve and a predisposition to respiratory failure in the setting of even mild pulmonary or systemic insults. (*Am J Respir Crit Care Med* 1999;**160**:883–6)

Dyspnea in obese healthy men

H Sahebjami

Study objectives. *To determine whether obese, apparently healthy individuals experience dyspnea at rest and, if so, whether their pulmonary function test (PFT) profile and maximal respiratory pressures are different from obese, healthy subjects without dyspnea.* ***Design.*** *Prospective, open.* ***Setting.*** *Pulmonary function test laboratory, Veterans Administration Medical Center.* ***Patients.*** *Twenty-three obese male subjects (each with a body mass index [BMI] of >28 kg/m^2) with an FEV_1 level and an FEV_1/FVC ratio $\geq$80% of predicted and no coexisting conditions. Fifteen complained of dyspnea, where eight denied having it, at rest.* ***Measurements and results.*** *Standard PFT parameters and maximum static inspiratory (PImax) and expiratory (PEmax) mouth pressures were determined. Subjects with dyspnea had similar age and height but larger body weight (113.9$\pm$5.0 vs 97.4$\pm$2.6 kg, $p = 0.03$) and BMI (37.4$\pm$1.6 vs 31.8$\pm$0.7 kg/m^2, $p = 0.02$) than subjects without dyspnea, and a greater number of them were current or previous smokers. Forced expiratory flow at 75% vital capacity (54.9$\pm$6 vs 75.5$\pm$7% predicted, $p = 0.05$), maximum voluntary ventilation (MVV; 90.2$\pm$3.8 vs 107.8$\pm$9.3% predicted, $p = 0.05$), and PEmax (77$\pm$2 vs 97.8% predicted, $p = 0.007$) were significantly reduced in the group of subjects with dyspnea. Large airway function (FVC, FEV_1, and FEV_1/FVC ratio), lung volumes, and gas exchange parameters were similar between the two groups.* ***Conclusions.*** *Some obese, but otherwise healthy, individuals experience dyspnea at rest. Reduced PEmax and MVV combined with greater body mass and peripheral airway disease are most likely responsible for the sensation of dyspnea in these individuals.* (*Chest* 1998;**114**:1373–7)

The prevalence of obesity is increasing in many countries and consequently its contribution to morbidity and mortality is also likely to increase. A recent estimate in the USA indicated that 97.1 million adults (55% of the total adult population) are either overweight (body mass index (BMI) 25.0–29.9) or obese (BMI $\geq$30.0).[1] In

the respiratory literature most recent interest in obesity has related to its role as a major risk factor for the obstructive sleep apnoea syndrome. This understandable emphasis on a relatively "new" condition may have distracted attention from the important consequences of obesity on breathing when awake. The two featured articles[2 3] and other recent publications highlight the important effects of obesity on the oxygen cost of breathing and the symptomatic consequences. The magnitude of these effects is underestimated if only conventional measurements of respiratory function are considered.

Obesity, metabolism and work of breathing

The basal metabolic rate and consequently the rate of total body oxygen consumption ($\dot{V}O_2$) increases as weight increases. However, since adipose tissue has a lower metabolic rate than other tissues, the increase in $\dot{V}O_2$ is proportionally less than the increase in weight. Consequently, if $\dot{V}O_2$ is standardised by expressing it per kilogram body weight, lower than normal values are obtained in obese individuals.[4]

A small proportion of the oxygen consumed is due to the work of the respiratory muscles. In healthy non-obese individuals at rest this proportion is very small, with earlier studies suggesting 3% or less of the total. Kress *et al*[2] have estimated respiratory muscle work during quiet breathing and have assessed how much this is likely to be increased by obesity. To this end, they investigated very obese patients (average BMI 53.4) undergoing weight reduction (bariatric) surgery and compared them with non-obese subjects undergoing other elective abdominal procedures. Patients were studied preoperatively under sedation and during subsequent anaesthesia when they were intubated and mechanically ventilated. The difference in $\dot{V}O_2$ in the two situations was attributed to respiratory muscle work. The obese patients showed a remarkable 16% reduction in $\dot{V}O_2$ while the control patients showed a surprisingly small reduction of <1%. The study might be criticised on the grounds that the intraoperative measurements were compared with those obtained in the sedated awake state rather than the anaesthetised spontaneously breathing state. The authors justify the comparison by pointing out that the preoperative measurements were made after "aggressive anxiolysis" and the very marked difference from the control subjects is reassuring. The data are valuable in giving more direct estimates of respiratory muscle $\dot{V}O_2$ than earlier studies which mainly used experimental animals. The study shows an effect of obesity on respiratory muscle work which is larger than might have been predicted, and the authors argue very reasonably that the increase is likely to be even greater when ventilation is increased above basal levels, either during exercise or with the added stress of intercurrent illness, which might predispose such patients to respiratory failure.

Obesity and respiratory function

Studies of conventional respiratory function tests in obesity have generally shown relatively minor effects unless obesity is extreme.[5–10] The most consistent finding is a reduction in functional residual capacity (FRC) due to the effect of the abdominal contents on the position of the diaphragm. This implies a reduction in expiratory reserve volume (ERV), which is often so marked that FRC approaches residual volume (RV). In consequence, ventilation at the lung bases is reduced, especially in those with the smallest ERV, leading to arterial hypoxaemia.[11] In comparison with reference values, other lung volumes are usually within normal limits, albeit less than average. Although the volume restriction is mild, vital capacity (VC) in obese subjects is related inversely to BMI.[12] On the other hand, in non-obese individuals VC increases with BMI. Consequently, in large populations the relation of VC to BMI shows an initial increase and subsequent fall due to opposing influences as BMI (or body weight) fails to distinguish fat mass and fat-free mass (FFM).[13] When VC is related to FFM there is a consistent increase throughout the range, while in relation to percentage body fat there is a progressive decrease in VC. The distribution of fat is also important in determining the final VC with truncal and upper body obesity having a relatively greater effect.[12–14]

Studies comparing the lung function of obese patients with a non-obese control group are more likely to show a difference than comparison with reference values from the literature, and sequential study after weight loss is the most revealing as the size of the "signal" is increased when measurements are repeated within an individual. Such studies, usually in the context of bariatric surgery, confirm that changes in respiratory function are by and large proportional to weight loss (table 1). Reports on carbon monoxide transfer factor (T_{LCO}) and transfer coefficient (K_{CO}) are variable with one showing no effect of obesity and no change after weight loss[6] but a second showing increased values in obese subjects with a fall after weight reduction.[5] An increase in K_{CO} would be expected in more obese subjects as a feature of progressive extrapulmonary volume restriction.

No major effects of obesity on airway function would be anticipated and, in general, none are seen provided studies are confined to non-smokers. An increase in airway resistance (measured by plethysmography) has been reported, but this is attributable to the low FRC as specific airway conductance was normal.[8] Some studies have suggested a reduction in maximum expiratory flow

Table 1 Effects of bariatric surgery

Reference	n	Average weight loss (kg)	VC	ERV	FRC	TLC	RV	Pmax	T_{LCO}	K_{CO}	Pa_{O_2}	Pa_{CO_2}
Ray *et al*[5]	29	54	↑	↑	→	→	→		↓ →*	↓ →*		
Thomas *et al*[6]	29	34	↑	↑	↑	↑	↑				↑	↓
Refsum *et al*[7]	34	32	↑	↑	↑	↑	→				↑	→
Weiner *et al*[10]	21	?	↑	↑	↑	↑	↑	↑				

* n = 16.
VC = vital capacity; ERV = expiratory reserve volume; FRC = functional residual capacity; TLC = total lung capacity; RV = residual volume; Pmax = maximum respiratory pressures; T_{LCO} = carbon monoxide transfer factor; K_{CO} = transfer coefficient; Pa_{O_2}, Pa_{CO_2} = arterial oxygen and carbon dioxide tensions.

at small lung volumes ($\dot{V}max_{25}$), implying narrowing of the small airways, but in most cases this is probably an effect of smoking. In one study in which obese non-smokers were compared with appropriate controls a small reduction was seen but this was of borderline statistical significance and was found in men but not in women.[8]

Reports on the effects of obesity on respiratory muscle function have been conflicting. In patients with the obesity hypoventilation syndrome (which is usually characterised by massive obesity), reductions in respiratory muscle pressures have been reported more consistently[15 16] but this condition affects only a very small proportion of the total obese population. Both muscle biopsy specimens[17] and measurements of CT density[18] show fatty infiltration of non-respiratory skeletal muscle in obese individuals, but the extent to which this affects muscle strength is unclear. Newham *et al*[18] reported an increased density of quadriceps accompanying weight loss after bariatric surgery but there was no corresponding increase in the strength of the muscle as assessed by maximal voluntary contraction. However, a recent report on function of the respiratory muscles showed increased maximum respiratory pressures six months after bariatric surgery. An even larger effect was seen on respiratory muscle endurance and the improvement was closely correlated with the decrease in BMI.[10] Similar improvements in the endurance of non-respiratory muscles have been reported following weight loss.[19] It therefore seems likely that respiratory muscle function in obesity is compromised both by the increased load which the muscles are required to overcome and by some reduction in their capacity. As in other conditions such as airway obstruction, an adverse load/capacity ratio is likely to contribute to breathlessness and eventually predispose to ventilatory failure.

Obesity and breathlessness

Breathlessness on exertion is a very common symptom in the obese. For example, in a large epidemiological survey, 80% of obese middle aged subjects reported shortness of breath after climbing two flights of stairs compared with only 16% of similarly aged non-obese controls, and this was despite smoking being significantly less frequent in the obese.[20] In a large study of patients with non-insulin dependent diabetes, one third reported troublesome shortness of breath and its severity increased with BMI.[21] Breathlessness in the obese may, of course, be due to any of several factors including co-existent (but often obesity related) cardiac disease, unrelated respiratory disease, or the effects of obesity itself on breathing.

Sahebjami[3] has extended the subject of breathlessness and obesity by asking whether, in some individuals, breathlessness *at rest* could be attributable solely to obesity. From an initial total of 60 patients recruited with BMI ≥ 28 he studied 23 after excluding those with coexisting conditions. Breathlessness was assessed using the Borg scale[22] and, on direct questioning, 15 of the 23 reported some difficulty in breathing at rest. The dyspnoeic patients were heavier and included more smokers than those with no breathlessness. The only significant differences in respiratory function between the two groups were that the dyspnoeic patients had lower $\dot{V}max_{25}$, maximum voluntary ventilation (MVV), and maximum expiratory pressures. The dyspnoeic group also showed non-significant trends towards a larger RV, smaller VC, and lower arterial oxygen tension, and TLCO. Because of the different proportions of smokers in the two groups, it seems likely that the breathlessness of most of the patients he studied is attributable to an interaction between the effects of smoking and obesity rather than to obesity per se. The level of dyspnoea was generally mild (average Borg grade 3.1) and it is not clear whether breathlessness at rest was a primary symptom of the individuals studied. Most importantly, the results emphasise the likely synergy between the effects of obesity and even minor degrees of airway obstruction (usually smoking related) in the generation of breathlessness. Swinburn *et al*[23] simulated the effects of an increase in body weight of 10 kg in patients with moderate chronic obstructive pulmonary disease (COPD) of normal BMI and showed a marked reduction in the number of steps climbed in a simple step test. This suggests that even a modest increase in body weight substantially worsens exercise performance against gravity (such as climbing stairs), with the corollary that the achievement of a normal BMI is likely to improve breathlessness in patients with lung disease, even when they are only modestly overweight. The benefits of weight loss by obese patients with respiratory disease are exemplified by a recent study[24] in asthma where weight reduction improved breathlessness and perceived health status and also resulted in less need for symptomatic treatment.

Obesity and respiratory mortality

A recent prospective epidemiological study[25] of more than one million adults in the USA showed a "J" shaped relation between the relative risk of death and BMI. Although cardiovascular disease is the most important cause of the increasing mortality with increasing BMI, mortality from non-cardiovascular disease showed a similar pattern. In patients with COPD, however, the picture appears to be rather different. A recent paper arising from the large Copenhagen City Heart Study[26] examined the prognostic importance of nutritional status in relation to mortality from COPD. The results

LEARNING POINTS

- **Conventional respiratory function tests are only mildly affected by obesity unless it is extreme**
- **Respiratory muscle work is greatly increased in obese subjects even at rest**
- **Obesity is a very common cause of breathlessness on exertion**
- **Obesity and airway obstruction probably act synergistically in the generation of breathlessness**

emphasised the markedly increased mortality associated with low BMI (<20). Less expectedly, they also suggested that the mortality of patients with more severe COPD was lowest in those who were overweight or frankly obese. No such trend was found in patients with mild to moderate airway obstruction in whom the mortality of overweight and normal weight individuals was similar. As the authors point out, there is no plausible reason why obesity should protect against mortality in COPD and the finding should be interpreted with caution as the number of deaths in obese individuals with severe COPD was very few.

Overall, the evidence suggests that nutritional advice – both for underweight and overweight patients with respiratory disease – should be aimed at achieving a BMI in the normal range.

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