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The effect of adiposity measured by dual-energy X-ray absorptiometry on lung function

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ABSTRACT: **Respiratory function is impaired in obesity but there are limitations with body mass index and skin-fold thickness in assessing this effect. The present authors hypothesised that the regional distribution of body fat and lean mass, as measured by dual-energy X-ray absorptiometry (DXA), might be more informative than conventional measurements of total body fat.**

In total, 107 subjects (55 female, 51.4%) aged 20–50 yrs with no respiratory disease were recruited. Respiratory function tests, anthropometric measurements and a DXA scan were performed. Partial correlation and linear regression analyses were used to explore the effect of adiposity and lean body mass on respiratory function.

The majority of respiratory function parameters were significantly correlated with DXA and non-DXA measurements of body fat. Neither thoracic nor abdominal fat had a greater effect. There were some differences in the effect of adiposity between the sexes. Respiratory function was negatively associated with lean body mass in females but positively associated in males. This disappeared after adjustment in females but remained in males.

The effects of thoracic and abdominal body fat on respiratory function are comparable but cannot be separated from one another.

KEYWORDS: **Lung function, obesity, physiology, X-ray absorptiometry**

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STATEMENT OF INTEREST
None declared.

Respiratory function is impaired in obesity and the magnitude of impairment is more clearly demonstrable in the morbidly obese [1]. The mechanism for any mechanical effect of obesity on respiratory function is difficult to identify. It may be mediated by the deposition of adipose tissue around the thorax restricting expansion, or by abdominal adiposity impeding diaphragmatic excursion.

Body mass index (BMI) is the most commonly used measure of obesity in population-based studies but the impact of increasing BMI on respiratory function is variable [1–7]. Other investigations have estimated body fat composition from skin-fold thickness or by bio-electrical impedance, and have demonstrated a negative association with respiratory function [4, 7].

Alternative measurements, such as waist/hip ratio (WHR), which reflects central adiposity, and subscapular skin-fold thickness, which reflects thoracic adiposity, have been used to explore the effect of body fat distribution. These have also provided mixed results. WHR is negatively associated with spirometry in some studies [2, 8–10], and this appears to be more so in males [3, 4]. Furthermore, skin-fold thickness has been shown to be negatively correlated with respiratory function in some populations [4, 11, 12].

However, these investigative methods of regional adiposity and respiratory function have limitations. Regional skin-fold measurements are only a surrogate measure of thoracic fat distribution, only provide an estimate of body fat composition and are operator dependent.

The use of dual-energy X-ray absorptiometry (DXA) is an established method of evaluating body composition. Using low-level radiation, DXA is able to quantify fat and lean tissue more reliably than estimations of body fat based on skin-fold thickness. To date, DXA has been used to demonstrate an association between total body fat and respiratory function parameters in groups

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of elderly males [6], children [13] and obese subjects undergoing weight loss through a calorie-restricted diet [14].

An additional benefit of DXA is that it is possible to quantify fat and lean mass in specific regions of the body. Thus, it can be used to quantify thoracic and abdominal fat and lean mass accurately and distinctly, and relate this to respiratory function. The current authors hypothesised that the distribution of thoracic and abdominal fat has an important influence on respiratory function. Furthermore, it was hypothesised that thoracic lean mass would also be correlated with respiratory function. Body fat and lean mass around the thorax and abdomen were quantified with DXA in females and males, and the effects on respiratory function were measured. To the present authors' knowledge, this more detailed approach has not been reported previously.

METHODS

Subjects attended an initial screening visit at which demographic, anthropometric and clinical data were recorded. Subjects were selected if inclusion and exclusion criteria were met, until the numbers of male and female study subjects with normal, overweight and obese body habitus were balanced. Inclusion criteria were being healthy and 20–50 yrs of age. To decrease the likelihood of subclinical airways disease, exclusion criteria were: current respiratory symptoms; history of respiratory disease; ex-smokers with a smoking history of >10 pack-yrs or who had smoked in the last year; cardiac or neurological comorbidity; structural abnormalities of the chest wall; and an exhaled nitric oxide concentration of >35 ppb [15] or a positive methacholine challenge [16]. The study was approved by the Lower South Ethics Committee (Dunedin, New Zealand) and all participants gave written informed consent.

Respiratory function tests

Forced expiratory volume in one second (FEV1) and forced vital capacity (FVC) were measured using a rolling seal spirometer (Sensormedics, Yorba Linda, CA, USA) and lung volumes were measured using a plethysmograph (Medgraphics, St Paul, MN, USA). Each instrument was calibrated daily and all tests complied with American Thoracic Society criteria [17, 18].

Anthropometry measurements: non-DXA-derived variables

Weight (kg) was measured on a calibrated segmental body composition analyser (BC-418MA; Tanita, Tokyo, Japan) and height (m) was measured using a wall-mounted stadiometer. During both measurements patients wore light clothing and were barefoot. BMI (in $kg \cdot m^{-2}$) was derived from these measurements. Waist and hip circumference measurements (cm) were performed by experienced personnel. Waist measurements were made halfway between the 10th rib laterally and the most superior part of the anterior superior iliac crest. Hip measurements were made halfway between the anterior superior iliac crest and the greater trochanter. WHR was then calculated.

Body fat measurements: DXA-derived variables

After removal of all metal objects, *e.g.* watches, belts and jewellery, a total body scan was performed with subjects wearing light clothing, using a Lunar DPX-L scanner (Lunar Corporation, Madison, WI, USA). The scanner determines total body fat mass and lean mass in kg. The percentage of body fat mass was calculated as follows:

$$[\text{fat mass}/(\text{fat mass}+\text{lean mass}+\text{bone mineral content})]\times 100 \quad (1)$$

The coefficients of variation for scanning precision were 2.6, 0.9 and 2.5% for total fat mass, lean mass and percentage of body fat mass, respectively. The results were analysed with software package 1.35 (Lunar Corporation).

Following the measurement of total body fat mass and lean mass, specific anatomical regions were manually determined using the ''scanner region of interest'' function of the software package (fig. 1). The trunk region was defined as the region horizontally below the chin, with vertical borders lateral to the ribs and oblique lines through the femoral neck (standard default DXA trunk region). The thoracic and abdominal sections were delineated by bisecting the trunk at the most infero-lateral limit of the rib cage. While this included some of the soft tissue of the upper abdomen in the thoracic section, the infero-lateral area of the rib cage was preferred because it was more easily identified than a specific vertebra or rib. The thoracic section was further divided into three ''tertiles'' by dividing the vertical height of the thoracic section equally into three: the upper thoracic, mid thoracic (area around the breast region) and lower thoracic sections. Finally, the waist region was defined as a box 9.6 cm in height with the lower border positioned superior to the iliac crest, and the hip region as a box, of the same height, positioned so that the centre of the box was at the level of the greater trochanters [19].

Statistical analysis

Associations with respiratory function were explored using partial correlations with the anthropometric (non-DXA) and DXA-derived measures of adiposity and lean mass adjusted for age and height. The effect of adiposity was further explored

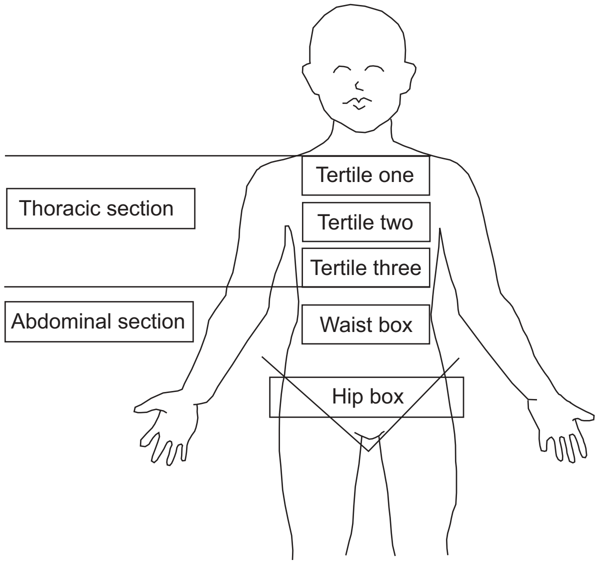

FIGURE 1. The specific anatomical regions manually determined for each patient. The ''scanner region of interest'' function of the Lunar DPX-L scanner (Lunar Corporation, Madison, WI, USA) was used to help in the determination of the anatomical regions shown.

TABLE 1 Demographics of the study population

	Females[#]	Males[¶]
Age yrs	37.3±8.6 (20–50)	36.5±8.5 (22–49)
Height m	1.65±0.06 (1.52–1.80)	1.79±0.05 (1.68–1.88)
Weight kg	80.0±17.4 (43.4–112.7)	90.5±13.6 (67.6–124.2)
BMI kg·m^{-2}	29.4±6.4 (18.1–41.9)	28.3±4.5 (21.1–37.6)
Body fat %	39.7±9.8 (14.6–53.2)	27.7±8.8 (12.5–46.0)
Waist circ. cm	90.3±16.1 (64–127)	95.2±13.3 (74–126)
Hip circ. cm	106.9±14.4 (81–138)	101.7±8.0 (84–124)
Waist/hip ratio	0.84±0.07 (0.72–1.02)	0.93±0.08 (0.79–1.15)
DXA-derived thoracic fat %[+]	39.0±11.2 (12.2–55.5)	31.3±10.3 (13.8–48.4)
DXA-derived waist fat %[+]	39.7±12.3 (8.4–56.9)	33.4±10.6 (14.6–50.9)
DXA-derived hip fat %[+]	45.3±8.8 (20.5–58.8)	31.4±8.9 (14.8–52.1)

Data are presented as mean± SD (range). BMI: body mass index; circ.: circumference; DXA: dual-energy X-ray absorptiometry. [#]: n=55; [¶]: n=52; [+]: proportion of adipose mass in each of the three anatomical regions determined using DXA scanning. See Methods section for full details. There was a significant difference between males and females ($p<0.05$) in all demographics except age, BMI and waist circumference.

using hierarchical linear regression. Preliminary analyses showed that body fat distribution as well as respiratory function differed significantly between males and females. As there were several positive sex interactions between the body fat measures and respiratory function parameters, all analyses were stratified by sex. A squared function for each body fat parameter was used to explore whether any of the relationships between body fat and respiratory function were nonlinear.

RESULTS

In total, 52 males and 55 females were recruited (table 1). The majority of the participants (104 out of 107) were European and the frequency of ex-smokers was similar for males and females (18.2 and 17.3%, respectively). Height and weight were normally distributed.

There was a trend for a decrease in FEV1, FVC, total lung capacity (TLC), functional residual capacity (FRC) and expiratory reserve volume (ERV) with increasing BMI and increasing body fat percentage in both males and females (data not shown).

Association between non-DXA-derived variables and respiratory function

In females, there were significant negative associations between FVC, all lung volume parameters, and weight, waist circumference and hip circumference (table 2). FRC and ERV were the only lung function parameters associated with WHR in females. FEV1 was significantly correlated with hip circumference but not with any other non-DXA-derived variable.

In males, FRC and ERV were the only lung volume parameters to be negatively associated with the non-DXA-derived variables. FVC was negatively associated with both waist circumference and WHR. In contrast with females, the FEV1/FVC ratio was significantly and positively associated with weight and waist circumference.

Association between DXA-derived variables and respiratory function

In females, FVC and the lung volume parameters were negatively associated with all the DXA-derived variables of adiposity (table 3). The FEV1/FVC ratio was only associated with abdominal fat. The correlations were numerically of similar magnitude, indicating a comparable effect of adiposity on respiratory function irrespective of the variable used to assess body fat distribution. The strongest correlations were with FRC.

A similar pattern of outcomes was found in males. Overall, FVC and the lung volume parameters (excluding residual volume) were found to have a significant negative association with each of the DXA-derived variables. In contrast with females, there was a significant positive association between the FEV1/FVC ratio and the majority of DXA variables (table 4). The magnitude

TABLE 2 Relationship between respiratory function variables and the non-dual-energy X-ray absorptiometry (DXA)-derived adiposity variables in females and males

	Females[#]				Males[¶]			
	Weight kg	**Waist circ. cm**	**Hip circ. cm**	**WHR**	**Weight kg**	**Waist circ. cm**	**Hip circ. cm**	**WHR**
FEV1 L	-0.220	-0.198	-0.291*	0.067	-0.069	-0.194	-0.140	-0.186
FVC L	-0.350**	-0.288*	-0.404**	0.074	-0.177	-0.294*	-0.213	-0.279*
FEV1/FVC %	0.244	0.173	0.224	-0.020	0.304*	0.298*	0.255	0.244
TLC L	-0.458***	-0.377**	-0.485***	0.019	-0.148	-0.265	-0.199	-0.240
RV L	-0.386**	-0.344*	-0.376**	-0.120	-0.152	-0.158	-0.229	-0.037
FRC L	-0.653***	-0.621***	-0.610***	-0.318*	-0.474***	-0.537***	-0.444***	-0.473***
ERV L	-0.571***	-0.563***	-0.519***	-0.337*	-0.481***	-0.552[+]***	-0.404**	-0.541***

Data are presented as partial correlations for non-DXA-derived variables adjusted for age and height. Circ.: circumference; WHR: waist/hip ratio; FEV1: forced expiratory volume in one second; FVC: forced vital capacity; TLC: total lung capacity; RV: residual volume; FRC: functional residual capacity; ERV: expiratory reserve volume. [#]: n=55; [¶]: n=52; *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$.

TABLE 3 Relationship between respiratory function parameters and all parameters measured by dual-energy X-ray absorptiometry (DXA) in 55 females

	Total body fat kg	Trunk fat g	Waist fat g	Hip fat g	Thoracic fat g	Abdominal fat g	Tertile 1	Tertile 2	Tertile 3
FEV$_1$ L	-0.204	-0.184	-0.218	-0.191	-0.173	-0.191	-0.157	-0.177	-0.173
FVC L	-0.329*	-0.327*	-0.348*	-0.294*	-0.307*	-0.338*	-0.303*	-0.309*	-0.301*
FEV$_1$/FVC %	0.232	0.263	0.247	0.191	0.243	0.276*	0.256	0.240	0.236
TLC L	-0.445***	-0.459***	-0.460***	-0.403*	-0.434***	-0.472***	-0.429***	-0.433***	-0.431***
RV L	-0.398**	-0.424**	-0.405**	-0.366**	-0.392**	-0.446***	-0.406**	-0.382**	-0.390**
FRC L	-0.634***	-0.659***	-0.668***	-0.572***	-0.634***	-0.665***	-0.635***	-0.628***	-0.632***
ERV L	-0.534***	-0.545***	-0.575***	-0.475***	-0.539***	-0.534***	-0.529***	-0.539***	-0.537***

Data are presented as partial correlations for DXA-derived variables adjusted for age and height. FEV$_1$: forced expiratory volume in one second; FVC: forced vital capacity; TLC: total lung capacity; RV: residual volume; FRC: functional residual capacity; ERV: expiratory reserve volume. *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$.

of these relationships was similar and the correlations were strongest with FRC, as was found in the females. A summary of the significant associations between adiposity and respiratory function variables is presented in table 5.

The three respiratory variables that were most frequently associated with body fat mass were FVC, TLC and FRC. Hierarchical linear regression demonstrated that an additional 29.5% of the variability in FRC in females and 22.2% in males could be explained by the effect of adiposity. This was equal to that explained by both height and age, and was significant for both sexes (table 6). The effect of adiposity on TLC was in the region of 10% for both females and males, and 6–8% on FVC. Again, the addition of body fat to the regression analysis was statistically significant.

None of the results in these models were significantly altered using a body fat squared function, demonstrating that the relationship between respiratory function and adiposity was linear in this population.

Association between DXA-derived variables of lean mass and respiratory function

In females, similar to the measurements of adiposity, there were significant negative associations between the majority of the lean mass variables and lung volumes after adjustment for height and age (for more information, refer to the online supplementary material). FVC was only associated with total lean mass. In contrast, all the significant associations in males were positive. These were between FEV$_1$, TLC and total lean mass, thoracic lean mass and the lean mass at tertile 1. Unlike the females, there were no associations between the respiratory function variables and lean mass in the trunk, abdomen or tertile 2 or 3 in males.

The correlation between lean mass and fat mass was significant in females ($r=0.520$, $p<0.001$) but not significant in males ($r=0.074$, $p=0.603$). Given that the direction of association was different between the sexes, the models were then adjusted for body fat in the region of interest. All the significant associations between lean mass and respiratory function variables disappeared in females, but they remained significant in males.

DISCUSSION

The present study aimed to establish whether the distribution of fat and lean mass, measured by DXA scanning, is more effective in determining respiratory function than conventional non-DXA-derived measurements of body fat. In general, this was not the case. The majority of respiratory function

TABLE 4 Relationship between respiratory function parameters and all parameters measured by dual-energy X-ray absorptiometry (DXA) 52 males

	Total body fat kg	Trunk fat g	Waist fat g	Hip fat g	Thoracic fat g	Abdominal fat g	Tertile 1	Tertile 2	Tertile 3
FEV$_1$ L	-0.241	-0.269	-0.302*	-0.208	-0.255	-0.279*	-0.198	-0.278	-0.261
FVC L	-0.328*	-0.360**	-0.398**	-0.295*	-0.340*	-0.375**	-0.276	-0.360**	-0.351*
FEV$_1$/FVC %	0.287*	0.289*	0.304*	0.290*	0.269	0.306*	0.245	0.263	0.278*
TLC L	-0.333*	-0.368**	-0.409**	-0.307*	-0.340*	-0.393**	-0.253	-0.355*	-0.367**
RV L	-0.216	-0.261	-0.270	-0.195	-0.247	-0.271	-0.182	-0.265	-0.264
FRC L	-0.537***	-0.588***	-0.585***	-0.502***	-0.593***	-0.570***	-0.548***	-0.615***	-0.586***
ERV L	-0.520***	-0.556***	-0.549***	-0.490***	-0.570***	-0.529***	-0.552***	-0.586***	-0.553***

Data are presented as partial correlations for DXA-derived variables adjusted for age and height. FEV$_1$: forced expiratory volume in one second; FVC: forced vital capacity; TLC: total lung capacity; RV: residual volume; FRC: functional residual capacity; ERV: expiratory reserve volume. *: $p<0.05$; **: $p<0.01$; ***: $p<0.001$.

TABLE 5 Summary of significant correlations between respiratory function parameters and body fat variables

	Dependent variable	Independent variable
Females		
Negative	FVC, TLC, RV, FRC, ERV	Weight, waist circumference, hip circumference
Negative	FRC, ERV	WHR
Positive	FEV_1/FVC	DXA measured abdominal fat
Negative	FVC, TLC, RV, FRC, ERV	All DXA variables
Males		
Positive	FEV_1/FVC	Weight, waist circumference
Negative	FVC	Waist circumference, WHR
Negative	FRC, ERV	Weight, waist circumference, hip circumference, WHR
Positive	FEV_1/FVC	All DXA variables, except thoracic fat and tertiles 1 and 2
Negative	FVC, TLC, FRC, ERV	All DXA variables, except tertile 1

FVC: forced vital capacity; TLC: total lung capacity; RV: residual volume; FRC: functional residual capacity; ERV: expiratory reserve volume; WHR: waist/hip ratio; FEV_1: forced expiratory volume in one second; DXA: dual-energy X-ray absorptiometry.

parameters were significantly associated with both DXA- and non-DXA-derived measures of body fat mass in both males and females. The magnitude of these associations was similar across all variables and neither thoracic nor abdominal regional fat mass was shown to have a relatively greater effect on respiratory function. The same was true for each of the subdivisions of thoracic fat distribution. Furthermore, a number of respiratory function parameters were negatively associated with lean mass in females but positively associated in males. This relationship disappeared after adjustment for body fat in females but remained in males.

TABLE 6 Hierarchical linear regression using the most frequently correlated respiratory function parameters as the dependent variable

	Females[#]		Males[¶]	
	R^2	p-value[+]	R^2	p-value[+]
FVC				
Step 1	0.381		0.151	
Step 2	0.475		0.204	
Step 3	0.532	0.012	0.289	0.015
TLC				
Step 1	0.432		0.168	
Step 2	0.432		0.179	
Step 3	0.544	<0.001	0.270	0.014
FRC				
Step 1	0.275		0.230	
Step 2	0.278		0.230	
Step 3	0.569	<0.001	0.452	<0.001

FVC: forced vital capacity; TLC: total lung capacity; FRC: functional residual capacity; step 1: height; step 2: adjusted for age; step 3: adjusted for body fat. #: n=55; ¶: n-52; +: significance of the difference in variance explained by the addition of body fat to the model at step 3.

The present authors' work extends from studies already undertaken by a number of other investigators. Previously, significant relationships between obesity and respiratory function have been described using a variety of body fat measures, including waist circumference [2], WHR [8, 9], abdominal height [10], skin-fold thickness [4, 12] and total body fat [4, 6, 7]. The current study is one of the first to explore these relationships in detail using DXA scanning in otherwise healthy adults with a wide range of BMI.

There were some unexpected findings in the present study. The association between adiposity and respiratory function was consistent across a wide range of body fat variables, and irrespective of the variable used to quantify body fat, a similar effect was demonstrated. Thus, DXA scanning cannot be considered as a new ''gold standard'' for body fat measurement in relation to respiratory function. This has reassuring implications in clinical practice: assessing the effect of adiposity on respiratory function may be adequately undertaken using a simple measurement, such as waist circumference.

Previously, a negative association between skin-fold thickness as a measure of thoracic fat and respiratory function has been described [4, 11, 12] and similar negative associations have been reported for abdominal fat. The present authors have directly compared the effect of both thoracic fat and abdominal fat on respiratory function and found them to be equivalent. This supports the hypothesis that abdominal fat may impede diaphragmatic position and flattening during inspiration [20], but also that thoracic deposition of fat may alter chest wall recoil [4, 11]. These factors could operate as a continuum rather than exert independent effects.

The current study also provides some evidence that the effect of adiposity on respiratory function is different in females compared with males. First, there were a number of correlations between the variables of adiposity and respiratory function that were stronger in females compared with males, (the correlations with TLC, for example) and so the effect of adiposity is greater. In contrast, the effect of adiposity on the

FEV1/FVC ratio reached significance in males but not females. Secondly, the addition of body fat to the regression models had a greater effect overall in females compared with males; there was more variance explained in the three-step model in females compared with males. These findings may serve to emphasise that measures of adiposity should be included in prediction equations for each sex, notably for lung volumes.

The present study found significant positive associations between measures of lean mass and respiratory function in males, whereas significant associations were negative in females. This negative association in females disappeared after adjustment for body fat but remained positive in males. Several other investigators have explored respiratory function in relation to lean mass [4, 6, 7]. These studies suggested a significant positive relationship for FEV1 and FVC in both sexes and it is unclear why the current results differ. However, it was concluded that, because the relationship in females disappears after adjustment for body fat, the negative association in females is not attributable to lean mass *per se*, but rather because lean mass is a further measure of body weight. In males, the greater thoracic muscle bulk is probably associated with a comparable increase in overall thoracic size, and with a relative increase in TLC, FEV1 is likely to increase as it is volume dependent. These findings warrant further investigation and serve to further highlight the differences in the effects of body mass on respiratory function between females and males.

What are the clinical implications of these results? The respiratory function variable that was most closely correlated with any DXA-derived measure of fat mass was FRC. Using hierarchical linear regression, it was demonstrated that total body fat explains as much variability of FRC as that explained by height and age. Interestingly, this result was not significantly different when waist circumference was used as a measure of adiposity. In clinical terms, the effect of an increase in total body fat of 1 kg is an average reduction in FRC of 0.028 and 0.031 L in females and males, respectively. If an individual is 40 kg overweight, of which 75% of this excess is due to fat, this will give rise to a reduction in FRC of 0.84 and 0.93 L in females and males, respectively. This reduction is likely to have a relatively greater impact on females due to their smaller initial lung volume. The exact relationship between a change in lung volume of this magnitude and dyspnoea is unknown and further work needs to be carried out to explore this question.

In conclusion, the current authors have confirmed that there is a significant effect of adiposity on respiratory function and have shown that this relationship is robust whichever measure of adiposity is employed. Some differences in the effect of adiposity on respiratory function between the sexes have been demonstrated. Furthermore, lean mass has a positive effect on respiratory function in males but not in females. The functional significance of this sex-related difference warrants further investigation.

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