Ventilation Rates during the Aggregate Daytime Activities of Working Females in Hospitals: Data before their Pregnancy and at their 9th, 22nd and 36th Week of Gestation

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Abstract

Working females in hospitals may inhale pharmaceutical agents, chirurgical smokes, organic solvents, bacteria and/or viruses. These inhaled agents may generate adverse effects in gravid females, their embryo or fetus. Therefore, minute ventilation rates (VE) during the aggregate daytime activities of under (n=68), normal (n=258), overweight (n=42), obese class 1 (n=68) and classes 2-3 (n=51) females working in hospitals were determined before and during their pregnancy using published measurements of energy expenditures. For comparison purposes, VE values were also calculated for the same females at rest. Activity energy expenditures were based on disappearance rates of oral doses of water isotopes (i.e. $^3$H$_2$O, $^2$H$_2$O, $^{18}$O) monitored in urine samples of free-living hospital workers during 175 days by gas-isotope-ratio mass spectrometry. Basal energy expenditures were obtained by indirect calorimetry, whereas energy costs for pregnancy were measured in a room calorimeter. Sleep durations (7.30 ± 1.59 to 8.09 ± 1.25 hours/day; mean ± standard deviation) and ventilatory equivalents (31.7 ± 0.93 to 39.3 ± 3.3 L of air inhaled/L of oxygen consumed) during pregnancy were determined and integrated into the calculation process. Based on VE percentiles some non-pregnant and pregnant female workers inhale more air (thus more air pollutants), than the default VE value of 20.83 L/min (i.e. 10 m$^3$ in an 8 hour workday) notably used for calculations of hygienic standards for airborne xenobiotics. Highest 99th percentiles of 34.28, 29.27 26.49 and 29.52 L/min were found in obese classes 2-3 female workers, before their pregnancy and at their 9th, 22nd and 36th week of gestation, respectively. Considering what precedes and the fact that the human chorionic gonadotropin is detected in the blood or urine samples of women after the implantation of their blastocyst, which occurs many days after fertilization, the non-exposure of female workers to teratogenic agents in hospitals is recommended before and during their pregnancy. The same applies for the exposure to carcinogens which may generate procarcinogenic DNA damage in the fetus.

Keywords: Ventilation rates; Oxygen consumption rates; Female workers in hospitals; Pregnancy; Physical activity levels; Risk assessment; Ventilatory equivalent; Energy expenditure

Abbreviations

α: Data for the aggregate daytime activities of females; β: Data for females under resting conditions; AEE: Activity Energy Expenditure; BEE: Basal Energy Expenditure (BMR expressed on a 24-hour basis); BMI: Body Mass Index; BMR: Basal Metabolic Rate (punctual measurement); BSA: Body Surface Area; BTBS: Body Temperature and Saturated with water vapour; Bw: Body Weight; DLW: Doubly Labeled Water; H: oxygen uptake factor; volume of oxygen (at STPD) consumed to produce 1 kcal of energy expended, PAL: Physical Activity Level Based on a 24-h period (TDEE/BEE ratio); PALVO: Physical Activity Level during the aggregate daytime activities; Std: Sleep Duration; STPD: Standard Temperature and Pressure Dry air; TDEE: Total Daily Energy Expenditure; VCO$_2$: carbon dioxide production rate; VE: Minute Ventilation Rate; VO$_2$: Oxygen consumption rate (also known as the oxygen uptake); VQ: Ventilatory Equivalent for VO$_2$ (VE at BTBS /VO$_2$ at STPD)

Introduction

Pregnancy in the workplace has become a relatively common occurrence over the last three decades [1–26]. However, acceptable working conditions in non-pregnant females may no longer be so in gravid females, notably by considering respiratory parameters for the latter compared to those for the former. Oxygen consumption rates (VO$_2$ in L/min) in pregnant females at rest and during submaximal weight-bearing exercises (e.g. walking, stepping, and treadmill exercise) are significantly increased, compared with the non-gravid state [27–30]. The same applies for minute ventilation rates (VE) when expressed in L/min [29,31–42]. These higher VE values result from an increase of tidal volumes with little or no change of respiratory frequencies [34,35,39]. Since the physiological dead space to tidal volume ratio in pregnancy remains unchanged, alveolar ventilation rates (VA) also increase as a function of incremental VE values [32,36,42–48]. Higher respiratory drive during the reproductive cycle has been showed to increase the intake of inhaled air pollutants on a 24 h basis in gravid females [49]. The same conclusion could be observed in pregnant workers. In spite of what precedes, VE values during the aggregate daytime activities of working pregnant females have never been determined. These calculations can be conducted by converting activity energy expenditures (AEE) of gravid females into VE values, as done by Brochu et al. [50,51] for males and non-gravid females. The AEE value corresponds to the subtractions of the basal energy expenditure (BEE) from the total daily energy expenditure (TDEE), both data obtained by indirect calorimetry and spectrometric values respectively measured in the same subjects during the doubly labeled water (DLW) method (IDECG 1990) [52]. In turn, AEE values can be converted into VE data by using three key input parameters [50,51], namely the oxygen

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These respiratory values (in L/min) were expressed in terms of BEE (in kcal) and VEα values were determined during their postprandial phase. Input data in non-gravid females have been performed for five cohorts of women classified according to their Pregnancy and at their 9th, 22nd and 36th Week of Gestation. Values for VO₂ and VEβ have been determined for non-gravid women [51,53], but not for pregnant females.

An impressive number of women are working in hospitals [15,54-65], even during their pregnancy [1,15,23,66-68], and notably as cleaners, nurses, physicians, pharmacists, laboratory or pharmacy technicians. They notably may be exposed to and affected by 1) bacteria and/or viruses [54,67,69,70], 2) pharmaceutical agents including antineoplastic agents, aerosolized drugs, volatile anesthetic gases [71-80], 3) chirurgical smokes [81-86], 4) organic solvents for cleaning and sterilization of workplaces and operation rooms [8,9,87-91], and finally, 4) ionizing radiations during radiology, nuclear medicine, tomography, cancer therapy or cardiac catheterization [92-95]. The breathing process allows the penetration of occupational air pollutants and notably viruses into the respiratory airways [96]. Therefore, the aim of this study is to determine mean, standard deviation (S.D.) and percentile values for VE during the aggregate daytime activities of working pregnant females in hospitals. Prior observations indicate that heavier subjects inhale more air (thus more air pollutants during similar exposure conditions), compared to their thinner counterparts [51]. Consequently, calculations in this study will be performed for under-weight, normal-weight, overweight and obese females. Prior to these calculations, values for VO₂, Sld, AEE, VO₂ and physical activity levels (PAL) will be determined for pregnant females.

Methodology

Study design

Mean, S.D. and percentile values for VO₂ and VE were calculated in the same non-pregnant and pregnant females aged 18 to 45 years (n=457) at rest (referred to as β) and during their aggregate daytime activities (referred to as α), when having full-time hospital jobs (referred to as active females). Values for VO₂ and VE during pregnancy were calculated at the 9th, 22nd and 36th week of gestation. These calculations have been performed for five cohorts of women classified according to IOM body mass index (BMI) cut-offs recommended for ideal pregnancies (IOM 1990): underweight (BMI < 19.8 kg/m²; n=68), normal weight (BMI from 19.8 to <27 kg/m²; n=268), overweight (BMI from 27 to <30 kg/m²; n=42), obese class 1 (BMI from 30 to <35 kg/m²; n=68), obese classes 2 and 3 (BMI ≥ 35 kg/m²; n=51) females. VO₂β and VEβ data were calculated in fasting subjects, whereas their VO₂α and VEα values were determined during their postprandial phase. These respiratory values (in L/min) were expressed in terms of BEE (in kcal/day), TDEE (in kcal/day) and Sld (in hours/day) values by using following equations [51]:

\[ VO_2^\beta = \frac{BEE}{1440} \times H_f \]  
\[ VO_2^\alpha = \frac{(TDEE - BEE)}{(24 - Sld) \times 60} + \frac{BEE}{1440} \times H_f \]  
\[ VE^\beta = \frac{BEE}{1440} \times H_f \times VQ^3 \]  

where, 24 and 360 are the conversion factors from days to minutes and hours to minutes respectively and 24 is the number of hours in a day.

The VO₂ value corresponds to the volume of oxygen consumed at standard temperature and pressure, dry air (STPD) to produce 1 kcal of energy expended. H₀ and H₄ correspond to H values for subjects during fasting and postprandial phases respectively. The combustion of metabolic fuels (i.e. glycogen, glucose, 3-hydroxybutyric acid, acetoacetic acid, triacylglycerol) in fasting subjects required 0.2057 ± 0.0018 L of O₂ per kcal of energy expended (mean for HF ± S.D.; n=31). A H₄ value of 0.2059 ± 0.0019 L of O₂/kcal (n=1245) has been calculated during the postprandial combustion of carbohydrates, proteins and fats. These H₀ and H₄ data have been determined using published sets of VO₂ and CO₂ production rates (VCO₂) measured by indirect calorimetry at STPD in the same subjects [53]. VQ is the ratio of the VE at body temperature and saturated with water vapour (BTSP) to the VO₂ at STPD. The following published data for non-gravid females aged 18 to 45 years were used in this study: VQβ of 30.1 ± 2.3 (n=307) and VQα of 32.6 ± 3.7 (n=450) for under-/normal-weight females [53], VQβ of 34.2 ± 9.5 (n=145) and VQα of 31.9 ± 9.2 (n=220) for overweight/obese women [51] and Sld of 8.28 ± 0.61 hours/day (n=1668) [53].

Values for VO₂ and VE (in L/min) were expressed per unit of body surface area (BSA in m²) using the following formula expressed in terms of height (cm) and body weight (Bw in kg) values [96]:

\[ BSA = \frac{\text{height} \times \text{Bw}^{0.5}}{3600} \]  

This equation is preferentially recommended for accurate BSA calculations in adults, compared to other algorithms [24,97].

Input data in non-gravid females

Published sets of body weight, height and BEE values (Table 2) that have been systematically measured for the same non-gravid females (n=497) have been used to determine the baseline pre-pregnancy input data for the resting state [98-109]. Published sets of BEE and TDEE values measured in the same non-gravid workers (n=11) by the DLW method were used to calculate an AEE mean of 1242.9 ± 600.0 kcal/day (i.e. AEE=TDEE-BEE) for full-time jobs in hospitals during the postprandial phase, with minimal and maximal values of 389.3 and 2132.9 kcal/day, respectively [98,100-102]. BEE values (in kcal/day) correspond to basal metabolic rates (BMRs in kcal/min) expressed on a 24 hr basis. BMR values are calculated from the respiratory gas-exchange rates of oxygen (O₂) and carbon dioxide (CO₂) monitored by indirect calorimetry in fasting subjects usually 40 minutes immediately after waking-up [110-113]. TDEE values were systematically encompassing voluntary and involuntary energy expended in hospitals workers (i.e. notably for BEE, thermogenesis, physical activities, synthetic cost of growth) during real-life situations and their normal surroundings each minute of the day, 24-hours per day, on a daily basis for 175 days: 60 days in nurses and medical doctors, as well as 14, 15, 31 and 40 days in pharmacy technicians, cleaners, clinical teachers, hospital clerks, and laboratory technicians, respectively [98,100-102,114]. TDEE data were calculated by using gas-isotope-ratio mass spectrometric measurements of disappearance rates of oral doses of water isotopes (i.e. H₂O and H₂¹⁸O) in urine...
Table 1: Weight gains and energy costs of pregnancy in healthy females aged 18 to 40 years. *Weight gains in pregnant females compared to their baseline values before pregnancy measured by Butte et al. [106]. MF = multiplying factors for energy costs of pregnancy. **MF = multiplying factors for energy costs of pregnancy. MF = multiplying factors for energy costs of pregnancy. Mean ± S.D. = mean ± standard deviation. Min = minimal value; Max = maximal value.

<table>
<thead>
<tr>
<th>Weight classifications of pregnant females</th>
<th>n</th>
<th>Progression of the reproductive cycle</th>
<th>Weight gains* (kg/week)</th>
<th>MF ECP (unitless)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Mean ± S.D.</td>
<td>Min</td>
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<tr>
<td>Under-weight</td>
<td>17</td>
<td>9th week</td>
<td>2.00 ± 0.69</td>
<td>0.982</td>
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<tr>
<td></td>
<td></td>
<td>22nd week</td>
<td>7.80 ± 4.51</td>
<td>1.050</td>
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<tr>
<td></td>
<td></td>
<td>36th week</td>
<td>13.10 ± 4.62</td>
<td>1.169</td>
</tr>
<tr>
<td>Normal-weight</td>
<td>34</td>
<td>9th week</td>
<td>0.90 ± 0.73</td>
<td>0.982</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22nd week</td>
<td>5.80 ± 4.47</td>
<td>1.050</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36th week</td>
<td>12.90 ± 5.19</td>
<td>1.169</td>
</tr>
<tr>
<td>Overweight/obesity</td>
<td>12</td>
<td>9th week</td>
<td>4.50 ± 4.26</td>
<td>0.982</td>
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<tr>
<td></td>
<td></td>
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<td>8.50 ± 5.19</td>
<td>1.050</td>
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<td></td>
<td></td>
<td>36th week</td>
<td>16.50 ± 6.00</td>
<td>1.169</td>
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Table 2: Anthropometric and energetic measurements in healthy non-pregnant and pregnant females aged 18 to 45 years. *Based on body mass index (BMI) cut-offs for an ideal pregnancy in females. BMI < 19.8 kg/m². BMI from 19.8 to < 27 kg/m². BMI from 27 to < 30 kg/m². BMI ≥ 30 kg/m². **BMI ≥ 35 kg/m². BSA=body surface area. **BEE=basal energy expenditure (i.e. basal metabolic rate expressed on a 24-hour basis) measured by indirect calorimetry. BEE values were taken from the literature [98-104,108,109]. **TDEE=BEE+AEE. AEE=Activity energy expenditures based on indirect calorimetric and spectrometric measurements in the same subjects. The gas-isotope-ratio mass spectrometry has been used to measure disappearance rates of oral doses of D₂O and H₂O from urine samples in free-living adults. AEE values are based on published data [98,100-102]. n, S.D. min and max acronyms are defined in Table 1.

Input data during pregnancy

Energy costs of pregnancy were calculated by comparing 24-h energy expenditures of females measured in a room calorimeter by Butte et al. [106], before their pregnancy and at their 9th, 22nd and 36th week of gestation (Table 1). The latter study has been conducted in under (n=17), normal weight (n=34) and overweight/obese pregnant women (n=12). Resulting energy expenditures have been computed by using continuous measurements of VO₂, VCO₂ and urinary nitrogen excretion in females according to the procedure of Livesey and Elia [117]. The performance of the calorimeter for such measurements is described in Moon et al. [118]. The baseline BEE values of under, normal and overweight/obese non-pregnant women were increased by mean multiplying factors (MF ECP) varying from 1.020 ± 0.028 to 1.063 ± 0.010, 1.068 ± 0.017 to 1.265 ± 0.046 to 1.340 ± 0.014 at the 9th, 22nd and 36th week of gestation respectively (Table 1). Minimal and maximal MF ECP values are based on data reported in Durnin et al., Forsum et al., Goldberg et al., Spaaij et al., de Groot et al. and Butte et al. [101,112,113,119-123]. TDEE values in pregnant females (TDEE...
pregnancy) were calculated in terms of MF_{ECR} (Table 1), BEE (Table 2) and AEE values by using the following equation:

\[ TDEE_{pregnancy} = \left[ BEE \times MF_{ECR} \right] + AEE \]  

(6)

Weight gains varying form 2.00 ± 2.69 to 13.10 ± 4.62, 0.90 ± 2.73 to 12.90 ± 5.19, 4.50 ± 4.26 to 16.50 ± 6.00 kg/week of pregnancy measured by Butte et al. [105] in under, normal-weight and overweight/obese gravid females respectively (Table 1) were added to body weights of non-gravid females in order to obtain adequate total weight values at the 9th, 22nd and 36th week of gestation.

Values for Sld of 8.09 ± 1.25 (n=122), 7.83 ± 1.36 (n=1397) and 7.30 ± 1.59 hours/day (n=684) were calculated for pregnant females at the 9th, 22nd and 36th week of gestation respectively (Table 3) by using data reported in Williams et al., Ko et al., Kzzihrmek et al. and Shiga et al. [124-127]. For the same classification of weeks of gestation, VO\beta of 39.3 ± 3.3 (n=33), 34.2 ± 1.8 (n=157) and 35.7 ± 1.3 (n=213) were determined (Table 3) according to respiratory data measured in pregnant females at rest by Cugel et al., Knutten et al., Pernoll et al., Pivarnik et al., Lotgering et al., Jaque-Fortunato et al., Heenan et al. and Jensen et al. [27,29,31,32,36,37,128,129].

PAL values for 24-hour periods are frequently calculated based on TDEE/BEE ratios [101,104-106,120,123,130-136]. However, PAL values in this study were not calculated for a 24-hour basis, but during the aggregate daytime activities of females (referred to as PALVO_{atal} unit less) as follows:

\[ PALVO_{atal} = \left[ \frac{VO}{Qo} \right] \]  

(7)

A mean VO\alpha value (referred to as VO\alpha Level) with S.D. minimal and maximal data was determined for each level of PALVO\alpha (i.e. ≥ 2, ≥ 2.5, ≥ 3, ≥ 3.5 and ≥ 4.5) that could be performed during daytime activities of females at their 9th, 22nd and 36th week of gestation. These calculations were conducted by using published sets of VO\alpha and VE values that have been simultaneously measured in gravid females [27,29,31,32,36,37,128,129]. Distributions of PALVO\alpha percentiles were then calculated for under, normal, overweight, obese class 1 and obese classes 2-3 females at their 9th, 22nd and 36th week of gestation. Based on these percentiles, percentages of pregnant females (Table 4) performing daytime activities at each VO\alpha Level were determined. Mean VO\alpha values for each category of body weights at the 9th, 22nd and 36th week of gestation (Table 4) were then obtained by multiplying VO\alpha Level (not reported in Tables) by former percentages.

Statistical analysis

Monte Carlo simulations were necessary to integrate S.D. values of input data into the calculation process of parameters of interest. They were conducted based on random sampling involving 10 000 iterations for each calculation process. A normal distribution for H\beta values and lognormal distributions for other input data (i.e. values for H\alpha, BEE, AEE, TDEE, body weight, body surface area, Sld, VO\beta VQ\alpha, as well as weight gains and MF_{ECR} during pregnancy) were considered during calculations of mean, S.D. and percentile values for VO\alpha and VE. The best fit distribution (i.e. lognormal or normal) per type of values has been determined in our previous studies [49,51,53] notably by carrying out Anderson-Darling goodness-of-fit tests on individual data. Spans of values between 2.5\alpha and 97.5\alpha and VO\alpha and VE percentiles were calculated in order to obtain 95\% confidence intervals (CI_{5\%}).

Accuracy of input data

The accuracy of BEE and TDEE data vary from +1 to +2 and -1.0 to +3.3\%, respectively [52,137], whereas the one for H\alpha and H\beta values range from -2 to +2\% [53]. In the worst case scenario, simultaneous minimal and maximal mean errors associated with input BEE, TDEE, H\alpha and H\beta data were shown to have a combined effect varying from +1 to +2.6\% on the accuracy of VO\beta, VE\beta, VO\alpha and VE\alpha values [53]. The possible shorter sleep durations in overweight/obese females compared to their normal-weight counterparts was found to have a negligible influence (less than -0.2\%) on the order of magnitude of inletation rates [53].

Results

VO\alpha data in resting and active females increase from 0.180 ± 0.012 to 0.390 ± 0.030 (Table 5) and 0.420 ± 0.083 to 0.616 ± 0.085 L/min (Table 6), respectively as the pregnancy progresses. To support such oxygen demands, VE values in these women range from 5.43 ± 0.57 to 13.91 ± 1.19 (Table 7) and 13.75 ± 3.17 to 21.68 ± 3.07 L/min, respectively (Table 8). Highest VO\alpha and VE absolute means and percentiles (i.e. expressed in L/min) are observed at the 36th week of gestation of obese classes 2-3 women (Tables 5-8). CI_{5\%} for VO\alpha values in resting and active gravid females vary from 0.160 to 0.450 and 0.278 to 0.801 L/min, respectively (Tables 5 and 6). Those for VE values in the former and the latter groups of females range from 5.81 to 16.37 and 9.27 to 28.19 L/min respectively (Tables 7 and 8). Absolute VO\alpha data increase as a function of the increase of BMI values. For instance, lowest and highest mean values of active under-weight and obese classes 2-3 gravid females range from 14.07 ± 2.82 to 15.22 ± 2.71 and 20.19 ± 3.54 to 21.68 ± 3.07 L/min respectively (Table 8). The inverse tendency is observed when data are expressed per unit of body weight (Tables 7 and 9). For instance, lowest and highest VE means are found in active obese classes 2-3 (0.138 ± 0.024 to 0.153 ± 0.028 L/kg-min) and under-weight gravid females (0.231 ± 0.043 to 0.259 ± 0.054 L/kg-min) respectively (Table 9). VE means expressed per unit of body surface area in under-weight (8.28 ± 1.63 to 9.05 ± 2.11 L/m²/min), normal-weight (8.11 ± 1.67 to 8.88 ± 1.61 L/m²/min), overweight (7.80 ± 1.57 to 8.38 ± 1.52 L/m²/min), obese class 1 (7.74 ± 1.53 to 8.48 ± 1.50 L/m²/min) and obese classes 2-3 active females (7.17 ± 2.38 to 8.46 ± 1.22 L/m²/min) do not show a clear tendency as a function of BMI values, nor as the pregnancy progresses (Table 10). The same conclusion applies for data expressed in L/m²/min in females at rest (Table 7).

Discussion

Data of Melzer et al. [138] indicate that females aged 20 to 40 years (n=27) perform a low intensity of activity levels in late pregnancy (38.2 ± 1.5 weeks of gestation) during 20.37 h/day (85%) with metabolic equivalents (METs) less than 2. This is consistent with our data. In the present study, the percentage of active females performing low levels of exertions during daytime activities (PALVO\alpha <2) increases as the pregnancy progresses (Table 4). For instance, 37, 43 and 59\% of active normal-weight females (n=268) at the 9th, 22nd and 36th week of gestation respectively have PALVO\alpha values lower than 2 (Table 4). In accordance with data reported in Brochu et al. [51] for non-gravid individuals, most percentages of active gravid females performing low intensity of activity levels (PALVO\alpha <2) reported in this study increases as a function of the increase of overweight levels based on BMI cutoffs. For instance, 39, 43, 54, 60 and 81\% of active under, normal, overweight, obese class 1 and obese classes 2-3 females at 22\text{nd} week of gestation respectively have PALVO\alpha values lower than 2 (Table 4).
Table 3. Sleep duration and ventilatory equivalent (VQo) values in healthy non-pregnant and pregnant females aged 18 to 45 years. Values for non-pregnant females have been calculated according to data reported in Brochu et al. [50]. Sleep durations of gestating females are based on published values [124-127]. VQo/ratio of the minute ventilation rate (VE in L/min at BTPS) to the oxygen uptake (VO2 in L/min at STPD). VQo and VQα=ventilatory equivalent values in females at rest and during their aggregate daytime activities respectively. VQo and VQα for non-pregnant females have been calculated according to data reported in Brochu et al. [50,51]. VQo for gravid females were based on values reported in the literature [27,29,31,32,36-38,128]. NP=Non-pregnant. n=number of individuals; S.D.=standard deviation; Min=minimal value; Max=maximal value.

Table 4. Physical activity levels and ventilatory equivalents during daytime activities of pregnant females with full-time hospital jobs. *Defined in Table 2. Based on percentiles of PALVO2. **PALVO2=VO2/kcal ratio. VO2=[(BEE/1440)+ H x VQo](TDEE-BEE)/(24-Study by 60)=[(BEE/1440)+ H x VQo] where, H and x/oxygen uptake factor during fasting and postprandial phases respectively. H (0.259± 0.0019 L of O2/kg) and H (0.259± 0.0019 L of O2/kg) are reported in Brochu et al. [33]. TDEE and BEE are defined in Table 2. Sd=Sleep duration (in hours/day). Sd values appear in Table 3. VQo/ratio of the minute ventilation rate (VEi in L/min at BTPS) to the oxygen uptake (VO2i in L/min at STPD) during the aggregate daytime activities of pregnant females. The simultaneous VEi and VO2i measurements were taken from the literature [27,29,31,32,36-38,128]. n=number of individuals; S.D.=standard deviation; Min=minimal value; Max=maximal value.
Table 5: Means and percentiles of oxygen consumption rates in fasting females at rest aged 18 to 45 years during pregnancy. \(^\text{VO}_{2}\) (\text{L} / \text{min}) \times H. \text{BEE} values are given in Table 2. \(H_3\) = oxygen uptake factor during fasting phase. \(H_2\) of 0.2057 \(\pm 0.0018\) L of O/\text{kcal} is defined in Table 4. Oxygen consumption rates in L/min were divided by body weight and body surface area values reported in Table 2 in order to obtain values expressed in L/kg-min and L/m²/min respectively. S.D.=standard deviation.

<table>
<thead>
<tr>
<th>Weight classifications of females</th>
<th>Progression of the reproductive cycle</th>
<th>Oxygen consumption rates(^a) (L/min)</th>
<th>(L/min)(^b)</th>
<th>(L/min)(^c)</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Mean ± S.D.</td>
<td>Mean ± S.D.</td>
<td>Percentiles</td>
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<tr>
<td></td>
<td></td>
<td>2.5(%)</td>
<td>97.5(%)</td>
<td>99(%)</td>
</tr>
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</table>

| Obese class 1 females            | 0 week                                | 0.128 ± 0.276 | 0.0083 ± 0.0017 | 0.277 ± 0.056 |
|                                  | 9 week                                | 0.277 ± 0.056 | 0.181 ± 0.397 |
|                                  | 22\(\text{nd}\) week                  | 0.181 ± 0.397 | 0.420          |
|                                  | 36\(\text{th}\) week                  | 0.277 ± 0.056 | 0.181 ± 0.397 |

| Obese class 2-3 females          | 0 week                                | 0.420 ± 0.276 | 0.0083 ± 0.0017 | 0.277 ± 0.056 |
|                                  | 9 week                                | 0.277 ± 0.056 | 0.181 ± 0.397 |
|                                  | 22\(\text{nd}\) week                  | 0.181 ± 0.397 | 0.420          |
|                                  | 36\(\text{th}\) week                  | 0.277 ± 0.056 | 0.181 ± 0.397 |

Table 6: Means and percentiles of oxygen consumption rates during the aggregate daytime activities of females aged 18 to 45 years. \(^{\text{VO}}_{2\text{pf}}\)(\text{TDEE-\text{BEE}}) \((\text{24-Sid} \times 60)\) \((\text{BEE}1440) \times H. \text{BEEs} and TDEEs appear in Table 2. \text{Std}=sleep duration (hours/day). \text{Std} values are presented in Table 3. \(H_3\) of 0.2059 \(\pm 0.0019\) L of O/\text{kcal} is defined in Table 4. Oxygen consumption rates in L/min were divided by body weight and body surface area values reported in Table 2 in order to obtain values expressed in L/kg-min and L/m²-min respectively. S.D.=standard deviation.

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<th>Progression of the reproductive cycle</th>
<th>Minute ventilation rates(^a) (L/min)</th>
<th>(L/min)(^b) Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± S.D.</td>
<td>Percentiles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.5(%)</td>
<td>97.5(%)</td>
</tr>
</tbody>
</table>

| Under-weight females             | 0 week                                | 4.47 ± 6.63 | 0.107 ± 0.013 | 0.36 ± 0.36 |
|                                  | 9 week                                | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 22\(\text{nd}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 36\(\text{th}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
| Normal-weight females            | 0 week                                | 4.47 ± 6.63 | 0.107 ± 0.013 | 0.36 ± 0.36 |
|                                  | 9 week                                | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 22\(\text{nd}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 36\(\text{th}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
| Overweight females               | 0 week                                | 4.47 ± 6.63 | 0.107 ± 0.013 | 0.36 ± 0.36 |
|                                  | 9 week                                | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 22\(\text{nd}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 36\(\text{th}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
| Obese class 1 females            | 0 week                                | 4.47 ± 6.63 | 0.107 ± 0.013 | 0.36 ± 0.36 |
|                                  | 9 week                                | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 22\(\text{nd}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
|                                  | 36\(\text{th}\) week                  | 0.36 ± 0.36 | 4.47 ± 6.63 |
Table 7: Means and percentiles of minute ventilation rates in fasting females at rest aged 18 to 45 years during pregnancy. 

Such data are also consistent with the fact that overstrain and overwork in pregnant females are usually avoided by reducing physical activity, increasing work efficiency and adjusting daily physical activities [101,105,110,122,134-136,139,140-146]. Values for VQβ (based on respiratory measurements in pregnant females at rest) and VQα (based on percentages of gravid females per cohort performing daytime activities at various PALVO) are consistent with VQ as well as sets of VE and VO2 measurements reported in the literature for gravid women [27,29,31,32,36-38,128].

The pregnancy requires absolute oxygen demands (in L/min) with VO2 mean values increasing by 2.4 to 6.3, 8.8 to 12.5 and 26.4 to 33.9% at the 9th, 22nd and 36th week of gestation respectively compared to baseline values for non-gravid females (Table 5). To support such oxygenation rates VE mean increases by 22.1 to 34.3, 12.2 to 25.6 and 39.4 to 55.0% for the same classification of weeks of gestation respectively (Table 6). Moreover, absolute VE means during aggregate daytime activities of non-pregnant and pregnant females at rest (Table 7: 5.43 ± 0.57 to 13.91 ± 1.19 L/min) increase by 1.6 to 2.5 folds when they have full-time hospital jobs (Table 8: 13.75 ± 3.17 to 21.68 ± 3.07 L/min). These working females inhale 7.77 to 8.32 L of additional volumes of air per minute in order to be adequately oxygenated during their aggregate daytime activities compared to baseline values at rest (Tables 7 and 8).

Based on our percentiles (Table 8), about 2.5% of under and normal weight women as well as 10, 15 and 50% of overweight, obese class I and classes 2-3 females of our cohorts at the 36th week of gestation respectively inhale more air (thus more air pollutants) than the default VE value of 20.83 L/min (i.e. 10 m3 in an 8-hour workday) that can be used for conducting occupational exposure assessments and/or hygienic standards for airborne toxic chemicals [147-150].

All adults are expected to have residues of organic chemicals and/or metals stored in their tissues resulting from sporadic exposures to environmental pollutants since their childhood: mainly by the ingestion of food, drinking water, dust and/or soil, and/or the inhalation of indoor and/or outdoor air [149,151-188]. For instance, cadmium and lead are stored in kidneys and bones respectively [189] and an impressive number of fat soluble environmental xenobiotics are stored in the adipose tissue including notably organochlorine pesticides and organic solvents [168,190-201].

As observed with organic environmental pollutants [195,199,202], drugs tend to dissolve into lipid-rich spaces [203] as shown by their lipophilic octanol-water partition coefficients [204-207]. Consequently, workers in hospitals inhaled concentrations of organic lipophilic toxic chemicals that are absorbed into their body and stored in their adipose tissue, including notably pharmaceutical aerosolized medications, volatile anesthetic gases, aromatic components of cirurgical smoke.

<table>
<thead>
<tr>
<th>Weight classifications of females</th>
<th>Progression of the reproductive cycle</th>
<th>Mean ± S.D.</th>
<th>Minute ventilation rates* (L/min)</th>
<th>Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st</td>
<td>50th</td>
<td>99th</td>
</tr>
<tr>
<td>Under-weight females</td>
<td></td>
<td>1st</td>
<td>50th</td>
<td>99th</td>
</tr>
<tr>
<td>0 week</td>
<td>13.75 ± 3.17</td>
<td>7.91</td>
<td>9.13</td>
<td>11.47</td>
</tr>
<tr>
<td>9th week</td>
<td>14.07 ± 2.82</td>
<td>8.67</td>
<td>9.89</td>
<td>12.02</td>
</tr>
<tr>
<td>22nd week</td>
<td>13.74 ± 2.66</td>
<td>8.69</td>
<td>9.21</td>
<td>11.79</td>
</tr>
<tr>
<td>36th week</td>
<td>15.22 ± 2.71</td>
<td>10.05</td>
<td>11.21</td>
<td>13.24</td>
</tr>
<tr>
<td>Normal-weight females</td>
<td></td>
<td>0 week</td>
<td>14.14 ± 3.34</td>
<td>7.86</td>
</tr>
<tr>
<td>9th week</td>
<td>14.62 ± 3.09</td>
<td>8.73</td>
<td>9.38</td>
<td>10.04</td>
</tr>
<tr>
<td>22nd week</td>
<td>14.14 ± 2.85</td>
<td>8.67</td>
<td>9.34</td>
<td>9.95</td>
</tr>
<tr>
<td>36th week</td>
<td>15.49 ± 2.91</td>
<td>9.95</td>
<td>10.60</td>
<td>11.19</td>
</tr>
<tr>
<td>Overweight females</td>
<td></td>
<td>0 week</td>
<td>14.55 ± 5.21</td>
<td>6.20</td>
</tr>
<tr>
<td>9th week</td>
<td>15.94 ± 3.28</td>
<td>9.67</td>
<td>10.37</td>
<td>11.05</td>
</tr>
<tr>
<td>22nd week</td>
<td>15.28 ± 2.98</td>
<td>9.59</td>
<td>10.13</td>
<td>11.10</td>
</tr>
<tr>
<td>36th week</td>
<td>17.18 ± 3.03</td>
<td>11.47</td>
<td>12.03</td>
<td>12.66</td>
</tr>
<tr>
<td>Obese class 1 females</td>
<td></td>
<td>0 week</td>
<td>15.40 ± 5.41</td>
<td>6.72</td>
</tr>
<tr>
<td>9th week</td>
<td>17.31 ± 3.52</td>
<td>10.54</td>
<td>11.40</td>
<td>12.07</td>
</tr>
<tr>
<td>22nd week</td>
<td>16.31 ± 3.13</td>
<td>10.36</td>
<td>11.05</td>
<td>11.62</td>
</tr>
<tr>
<td>36th week</td>
<td>18.59 ± 3.20</td>
<td>12.57</td>
<td>13.23</td>
<td>13.87</td>
</tr>
<tr>
<td>Obese class 2-3 females</td>
<td></td>
<td>0 week</td>
<td>17.08 ± 5.64</td>
<td>7.77</td>
</tr>
<tr>
<td>9th week</td>
<td>20.19 ± 3.54</td>
<td>13.28</td>
<td>13.99</td>
<td>14.82</td>
</tr>
<tr>
<td>22nd week</td>
<td>18.67 ± 3.00</td>
<td>12.64</td>
<td>13.39</td>
<td>14.09</td>
</tr>
<tr>
<td>36th week</td>
<td>21.68 ± 3.07</td>
<td>15.57</td>
<td>16.30</td>
<td>17.04</td>
</tr>
</tbody>
</table>

Table 8: Distribution of minute ventilation rate (L/min) percentiles during the aggregate daytime activities of females aged 18 to 45 years. 

References:
[147-150]
Table 9: Distribution of minute ventilation rate (L/kg-min) percentiles during the aggregate daytime activities of females aged 18 to 45 years. *VEo=([TDEE-VEE]/(24-Sld) x 60)+(BEE)/1440] x H x vQco. BEEs and TDEEs are reported in Table 2. Std data appear in Table 3. H2 of 0.2059 ± 0.0019 L of O2/kg is defined in Table 4.  
*Values expressed in L/kg-min were obtained by dividing VEs in L/min of Table 7 by body surface area values presented in Table 2. S.D=standard deviation.

<table>
<thead>
<tr>
<th>Weight classifications of females</th>
<th>Progression of the reproductive cycle</th>
<th>Mean ± S.D.</th>
<th>Percentiles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st</td>
<td>2.5th</td>
</tr>
<tr>
<td>Under-weight females</td>
<td>0 week</td>
<td>9.05 ± 2.11</td>
<td>5.16</td>
</tr>
<tr>
<td></td>
<td>22nd week</td>
<td>8.28 ± 1.63</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>9th week</td>
<td>8.77 ± 1.88</td>
<td>5.23</td>
</tr>
<tr>
<td></td>
<td>36th week</td>
<td>8.35 ± 1.60</td>
<td>5.35</td>
</tr>
<tr>
<td>Obese 1 females</td>
<td>0 week</td>
<td>7.96 ± 2.86</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>9th week</td>
<td>8.32 ± 1.75</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>22nd week</td>
<td>7.80 ± 1.57</td>
<td>4.83</td>
</tr>
<tr>
<td>Obese classes 2-3 females</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 week</td>
<td>8.38 ± 1.52</td>
<td>5.55</td>
</tr>
<tr>
<td></td>
<td>22nd week</td>
<td>8.38 ± 1.74</td>
<td>5.06</td>
</tr>
<tr>
<td>Obese class 1 females</td>
<td>0 week</td>
<td>8.57 ± 1.91</td>
<td>4.36</td>
</tr>
<tr>
<td></td>
<td>9th week</td>
<td>8.82 ± 1.45</td>
<td>5.37</td>
</tr>
<tr>
<td>Obese class 2-3 females</td>
<td>0 week</td>
<td>8.46 ± 1.22</td>
<td>6.06</td>
</tr>
</tbody>
</table>

Table 10: Distribution of minute ventilation rate (L/min) percentiles during the aggregate daytime activities of females aged 18 to 45 years. *VEo=([TDEE-BEE]/(24-Sld) x 60)+(BEE)/1440] x H x vQco. BEEs and TDEEs are reported in Table 2. Std data appear in Table 3. H2 of 0.2059 ± 0.0019 L of O2/kg is defined in Table 4.  
*Values expressed in L/min were obtained by dividing VEs in L/min of Table 7 by body surface area values presented in Table 2. S.D=standard deviation.

Environmental xenobiotics sequestered in adipose tissues as well as lead stored in bones are released into the bloodstream of female workers during their pregnancy, lactation and menopause and workers

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of both genders during weight loss resulting from an energy-restricted diet [168,174,214]. The mobilization of lead from bone tissues increases during calcium-deficient diets [215-220].

The adipose tissue may act as a reservoir for the accumulation of fat soluble drugs and toxicants. Large fat storage sites in obese women could increase their body’s capacity for the accumulation of lipophilic xenobiotics, compared to those in under and normal weight females [221-223]. Moreover, published plasma levels of organochlorines suggest that high circulating concentrations of fat soluble pollutants mobilized from the adipose tissue could be related to high BMI values [221]. Therefore, obese female workers are at risk to have higher blood concentrations of total toxicants during their pregnancy, compared to their thinner counterparts, considering their high intakes and uptakes of air pollutants resulting from their high minute ventilation rates and blood concentrations of xenobiotics released from their adipose tissue. These blood concentrations of chemicals may generate adverse effects in gravid females, their embryo or fetus and even their newborns [224,225]. This is explained by the fact that most of these chemicals may be transferred to the embryos or fetus by the umbilical cord after crossing the placenta, or transferred to newborns during the breastfeeding [168,225]. Prenatal exposure to carcinogens could result in differentially higher levels of procarcinogenic DNA damage in the fetus [226]. This may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime. The inhalation and absorption of teratogenic chemicals by pregnant female workers, after the implantation of their blastocyst, may disproportionately increase the probability of the latter to develop a cancer over his lifetime.

Conclusion

The present study provides a complete and original set of PALVO₂, QVO₂, QVa, VO₂ and VE values during the aggregate daytime activity of under (n=68), normal (n=268), overweight (n=42), obese class I (n=68) and obese class 2-3 (n=51) females with full-time hospital jobs, before their pregnancy, and at their 9th, 22nd and 36th week of gestation. The integration into the calculation process of BEE, TDEE and H data has assured mean low potential errors on VE data varying from +1 to +2.6%. The use of published BEE, TDEE, body weight and height values that have been systematically measured in the same females has allowed accurate calculations of VE data per unit of body weight or body surface area. Therefore, VE percentiles reported in this study are recommended for conducting occupational health risk assessment and management of potential toxic air pollutants in non-pregnant and pregnant females working in hospitals. However, the non-exposure of female workers to teratogenic and carcinogenic agents in hospitals is recommended before and during their pregnancy.

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The authors thank Dr Dennis Jensen from the McGill University in Montreal for his data that he has shared with us and that he had published in McAuley et al. (2005). The authors are also grateful to Mrs. Jessie Ménard from the School of Public Health of the University of Montreal for her contribution to this project.

Declaration of Interest

The authors report no declarations of interest.

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