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=268), 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. $^{2}H_{2}O, ^{18}O$) 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) for 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; BTPS: 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$_{2}$: Physical Activity Level during the aggregate daytime activities; Sd: 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 BTPS /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...
upstream uptake factor (H in L of O₂ consumed/kcal expended), the ventilatory equivalent (VQ in L of air inhaled/L of oxygen consumed) and the sleep duration (Sld in hours/day). The order of magnitude of H data already has been published and depends on types of combustion metabolic fuels [53]. Values for VQ and Sld 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 [54,67,67,90], 2) pharmaceutical agents including antineoplastic agents, aerosolized drugs, volatile anesthetic gases [71-80], 3) surgical smoke [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 VQ, 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, 22th and 36th week of gestation. These calculations have been performed for five cohorts of women classified according to their body mass index (BMI) cut-offs recommended for ideal pregnancies (IOM 1990): under-weight (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. VO₂ 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]:

\[
VO_\beta = \frac{BEE}{1440} \times H_f
\]  
(1)

\[
VO_\alpha = \frac{(TDEE - BEE)}{(24 - Sld) \times 60} + \frac{BEE}{1440} \times H_f
\]  
(2)

\[
VE\beta = \frac{BEE}{1440} \times H_f \times VQ\beta
\]  
(3)

where, 1440 and 60 are the conversion factors from days to minutes and minutes to respectively and 24 is the number of hours in a day.

The H value corresponds to the volume of oxygen consumed at standard temperature and pressure, dry air (STPD) to produce 1 kcal of energy expended. H₂ and H₂ 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 ± 0.0181 L of O₂ per kcal of energy expended (mean for HF ± S.D.; n=31). A H₂ 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 H₂ and H₂ data have been determined using published sets of VO₂, CO₂ production rates (VCO₂) measured by indirect calorimetry at STPD in the same subjects [53]. VO is the ratio of the VE at body temperature and saturated with water vapour (BTPS) to the VO₂ at STPD. The following published data for non-gravid females aged 18 to 45 years were used in this study: VO₂β of 30.1 ± 2.3 (n=307) and VO₂β of 32.6 ± 3.7 (n=450) for under-/normal-weight females [53], VO₂β of 34.2 ± 9.5 (n=145) and VO₂β 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]:

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

(5)

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, 15, 31 and 40 days in pharmacy technicians, cleaners, clinical teachers, hospital clerks, and laboratory technicians, respectively [98,100-102,114-116]. 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 H₂O) 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<sub>EC</sub>= multiplying factors for energy costs of pregnancy MF<sub>EC</sub>=(BEE+gravid/BEE-non-gravid). BEE=basal energy expenditure measured by Butte et al. [106] in females during 24-hour periods, before (BEEnon-gravid) and during their pregnancy (BEEgravid) in a room calorimeter at the 9<sup>th</sup>, 22<sup>nd</sup> and 36<sup>th</sup> week of gestation. *Data taken from Butte et al. [106]. *Values based on data reported in Dunnin et al., Forsum et al., Goldberg et al., Spaaij et al., de Groot et al. and Butte et al. [113,119-123]. n=number of individuals; S.D=standard deviation; Min=minimum value; Max=maximum value.

| Weight classifications of pregnant females | n  | Progression of the reproductive cycle | Weight gains<sup>a</sup> (kg/week) | MF<sub>e/c</sub><sup>b</sup> (unitless) | TDEE<sup>c</sup> (kcal/day) |
|------------------------------------------|----|--------------------------------------|----------------------------------|--------------------------|---------------------|
|                                          |    |                                      | Mean ± S.D.                      | Min                       | Max                  |
| Under-weight                             | 17 | 9<sup>th</sup> week                   | 2.00 ± 0.69                     | 2.08                      | 8.25                |
|                                          |    | 22<sup>nd</sup> week                  | 7.80 ± 4.51                     | 6.16                      | 18.29               |
|                                          |    | 36<sup>th</sup> week                  | 13.10 ± 4.62                    | 11.42                     | 23.84               |
| Normal-weight                            | 34 | 9<sup>th</sup> week                   | 0.90 ± 0.73                     | 0.43                      | 7.26                |
|                                          |    | 22<sup>nd</sup> week                  | 5.80 ± 4.47                     | 4.03                      | 16.20               |
|                                          |    | 36<sup>th</sup> week                  | 12.90 ± 5.19                    | 12.02                     | 24.97               |
| Overweight/obesity                      | 12 | 9<sup>th</sup> week                   | 4.50 ± 4.26                     | 4.29                      | 14.42               |
|                                          |    | 22<sup>nd</sup> week                  | 8.50 ± 8.19                     | 5.34                      | 27.55               |
|                                          |    | 36<sup>th</sup> week                  | 16.50 ± 9.00                    | 13.49                     | 30.46               |

**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/m<sup>2</sup> (BMI from 19.8 to <30 kg/m<sup>2</sup> (BMI from 30 to <35 kg/m<sup>2</sup> (BMI ≥ 35 kg/m<sup>2</sup> (BMI <19.8 kg/m<sup>2</sup> (BMI ≥ 35 kg/m<sup>2</sup> BMI ≥ 35 kg/m<sup>2</sup> BMI ≥ 35 kg/m<sup>2</sup> | Body weight<sup>d</sup> (kg) | Height (cm) | BSA<sub>e</sub><sup>f</sup> (m<sup>2</sup>) | BEE<sup>a</sup><sub>e</sub><sup>f</sup> (kcal/day) | Full-time hospital jobs<sup>g</sup> |
|------------------------------------------|----|--------------------------------------|----------------------------------|--------------------------|---------------------|
| Under-weight females<sup>h</sup>         | 68 | 0 week                               | 50.75 ± 2.73                     | 164.5 ± 3.8              |
|                                          |    | 9<sup>th</sup> week                  | 54.54 ± 3.00                     | 164.3 ± 3.8              |
|                                          |    | 22<sup>nd</sup> week                 | 60.42 ± 3.79                     | 164.3 ± 3.8              |
| Normal-weight females<sup>i</sup>        | 268| 0 week                               | 59.55 ± 3.81                     | 164.3 ± 3.8              |
|                                          |    | 9<sup>th</sup> week                  | 61.03 ± 4.06                     | 164.3 ± 3.8              |
|                                          |    | 22<sup>nd</sup> week                 | 66.86 ± 4.81                     | 164.3 ± 3.8              |
| Overweight females<sup>j</sup>           | 42 | 0 week                               | 74.71 ± 6.37                     | 164.3 ± 6.7              |
|                                          |    | 9<sup>th</sup> week                  | 81.45 ± 6.26                     | 164.3 ± 6.7              |
|                                          |    | 22<sup>nd</sup> week                 | 85.32 ± 7.56                     | 164.3 ± 6.7              |
| Obese class 1 females<sup>k</sup>        | 68 | 0 week                               | 86.49 ± 8.54                     | 164.8 ± 6.6              |
|                                          |    | 9<sup>th</sup> week                  | 94.42 ± 8.35                     | 164.8 ± 6.6              |
|                                          |    | 22<sup>nd</sup> week                 | 98.29 ± 9.50                     | 164.8 ± 6.6              |
| Obese classes 2-3 females<sup>l</sup>    | 51 | 0 week                               | 105.87 ± 8.98                    | 165.1 ± 1.9              |
|                                          |    | 9<sup>th</sup> week                  | 131.78 ± 16.6                    | 165.1 ± 1.9              |
|                                          |    | 22<sup>nd</sup> week                 | 135.65 ± 7.66                    | 165.1 ± 1.9              |
|                                          |    | 36<sup>th</sup> week                 | 143.23 ± 6.89                    | 165.1 ± 1.9              |

samples of each free-living worker over a period of 10 to 31 days [52]. During the DLW method the disappearance rate of deuterium (H or D) reflects water output and that of heavy oxygen-18 (18O) corresponds to water output plus CO<sub>2</sub> production rates [52]. The difference between the two disappearance rates represents the CO<sub>2</sub> production rate, which is converted into units of energy (i.e. TDEE in kcal/day) by using the average respiratory quotient of the diet (RQ). The RQ value may be determined by a complete diet record over the duration of the study or respiratory gas-exchange measurements (RQ=CO<sub>2</sub> produced/O<sub>2</sub> consumed). The DLW method is notably described in detail in IDECG (1990) [52].

**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 9<sup>th</sup>, 22<sup>nd</sup> and 36<sup>th</sup> 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 VO<sub>2</sub>, VCO<sub>2</sub> 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<sub>E</sub>) varying from 1.020 ± 0.028 to 1.063 ± 0.010, 1.068 ± 0.041 to 1.125 ± 0.017 and 1.265 ± 0.046 to 1.340 ± 0.014 at the 9<sup>th</sup>, 22<sup>nd</sup> and 36<sup>th</sup> week of gestation respectively (Table 1). Minimal and maximal MF<sub>E</sub> values are based on data reported in Dunnin et al., Forsum et al., Goldberg et al., Spaaij et al., de Groot et al. and Butte et al. [101,112,113,119-123]. TDEEs values in pregnant females (TDEE

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pregnancy) were calculated in terms of MF_{ECB} (Table 1), BEE (Table 2) and AEE values by using the following equation:

$$TDEE_{pregnancy} = \left[ BEE \times MF_{ECB} \right] + AEE$$ (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., Kzizirmak et al. and Shiga et al. [124-127]. For the same classification of weeks of gestation, VO_{2}PB 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 Cugell et al., Knutgen 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_{2}, unit less) as follows:

$$PAL_{VO_{2}} = \frac{VO_{2}\alpha}{VO_{2}\beta}$$ (7)

A mean VO_{2}α value (referred to as VO_{2}α Level) with S.D., minimal and maximal data was determined for each level of PALVO_{2} (i.e. 1 ≤ 2, 2 ≤ 2.5, 2.5 ≤ 3, 3 ≤ 3.5 and 3.5 ≤ 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_{2} and VE values that have been simultaneously measured in gravid females [27,29,31,32,36,37,128,129]. Distributions of PALVO_{2} per centiles 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 percentages, percentages of pregnant females (Table 4) performing daytime activities at each VO_{2} Level were determined. Mean VO_{2}α values for each category of body weights at the 9th, 22nd and 36th week of gestation (Table 4) were then obtained by multiplying VO_{2}αLevel (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_{2} values and lognormal distributions for other input data (i.e. values for H_{2}, BEE, AEE, TDEE, body weight, body surface area, Sld, VO_{2}Qa, as well as weight gains and MF_{ECB} during pregnancy) were considered during calculations of mean, S.D. and percentile values for VO_{2}α 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 2.5α and 97.5th VO_{2}α and VE per centiles were calculated in order to obtain 95% confidence intervals (CI_{95 %}).

**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_{2} and H_{3} values range from -2 to +2% [53]. In the worst case scenario, simultaneous minimal and maximal mean errors associated with input BEE, TDEE, H_{2} and H_{3} data were shown to have a combined effect varying from +1 to +2.6% on the accuracy of VO_{2}β, VEβ, VO_{2}α and VEα 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 inhalation rates [53].

**Results**

VO_{2} 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_{2} and VE absolute means and per centiles (i.e. expressed in L/min) are observed at the 36th week of gestation of obese classes 2-3 women (Tables 5-8). CI_{95 %} for VO_{2} 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 VO_{2} and VE in the former and the latter groups of females range from 5.81 to 16.37 and 9.27 to 21.18 L/min respectively (Tables 7 and 8). Absolute VO_{2} 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 ± 1.82 L/m²-min), overweight (7.80 ± 1.57 to 8.38 ± 1.52 L/m²-min), obese class I (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 Medzer 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_{2} <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_{2} 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_{2} <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 22nd week of gestation respectively have PALVO_{2} values lower than 2 (Table 4).
### Table 3. Sleep duration and ventilatory equivalent (VQ) 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]. VQβ-ratio of the minute ventilation rate (VE in L/min at BTPS) to the oxygen uptake (VO₂ in L/min at STPD). VQα and VQβ=ventilatory equivalent values in females at rest and during their aggregate daytime activities respectively. VQβ and VQα for non-pregnant females have been calculated according to data reported in Brochu et al. [50,51]. VQβ 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.

| Progression of the reproductive cycle | Weight classifications of females* | Sleep duration (hours/day) | VQβ for females at rest (unitless) | VQα for active females (unitless) |
|--------------------------------------|---------------------------------|-----------------------------|----------------------------------|----------------------------------|
| 9th week                             | Underweight                     | Mean ± S.D.                 | Min                              | Max                              |
|                                      | 1668                            | 8.28 ± 0.61                 | 5.23                             | 13.56                            |
|                                      | Normal-weight                   | 268                         | 37%                              | 22%                              |
|                                      | Overweight                      | 42                           | 47%                              | 33%                              |
|                                     | Obese class 1                   | 68                           | 56%                              | 28%                              |
|                                     | Obese classes 2-3               | 51                           | 76%                              | 21%                              |
|                                     | Obese classes 2-3               | 51                           | 81%                              | 17%                              |
| 22nd week                            | Underweight                     | 68                           | 39%                              | 39%                              |
|                                      | Normal-weight                   | 268                         | 43%                              | 35%                              |
|                                      | Overweight                      | 42                           | 54%                              | 29%                              |
|                                      | Obese class 1                   | 68                           | 60%                              | 29%                              |
|                                      | Obese classes 2-3               | 51                           | 81%                              | 17%                              |
| 36th week                            | Underweight                     | 68                           | 59%                              | 32%                              |
|                                      | Normal-weight                   | 268                         | 59%                              | 32%                              |
|                                      | Overweight                      | 42                           | 70%                              | 26%                              |
|                                      | Obese class 1                   | 68                           | 78%                              | 20%                              |
|                                      | Obese classes 2-3               | 51                           | 93%                              | 6%                               |

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/VO₂β ratio. VO₂=([EE/1440]+H₂O·VO₂ (TDEE-BEE))/([24-St]) x 80([EE/1440]+H₂O) where, H₂O=oxygen uptake factor during fasting and postprandial phases respectively. H₂O (0.2057 ± 0.0018 L of O₂/kcal) and H₂O (0.2059 ± 0.0019 L of O₂/kcal) are reported in Brochu et al. [53]. TDEE and BEE are defined in Table 2. *Sid=Sleep duration (in hours/day). Sld values appear in Table 3. *VQα=ratio of the minute ventilation rate (VE/L/min at BTPS) to the oxygen uptake (VO₂ in L/min at STPD) during the aggregate daytime activities of pregnant females. The simultaneous VEα and VO₂α measurements used for VQα calculations 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.

| Progression of the reproductive cycle | Weight classifications of females | Oxygen consumption rates (L/min) |
|--------------------------------------|---------------------------------|----------------------------------|
|                                      | Mean ± S.D.                     | Percentiles (L/kg-min)²          |
|                                      | 2.5⁰      | 97.5⁰     | 99⁰     | 2.5⁰      | 97.5⁰     | 99⁰     | 2.5⁰      | 97.5⁰     | 99⁰     |
| 0 week                               | 0.180 ± 0.012                   | 0.157                             | 0.205                             | 0.210                             | 0.0036 ± 0.0003 | 0.0030 | 0.0042 | 0.0043 | 0.118 ± 0.009 | 0.101 | 0.137 | 0.141 |
| 9th week                             | 0.185 ± 0.013                   | 0.160                             | 0.214                             | 0.218                             | 0.0034 ± 0.0003 | 0.0028 | 0.0040 | 0.0042 | 0.117 ± 0.009 | 0.101 | 0.136 | 0.139 |
| 22nd week                            | 0.199 ± 0.014                   | 0.172                             | 0.228                             | 0.234                             | 0.0033 ± 0.0003 | 0.0027 | 0.0040 | 0.0041 | 0.120 ± 0.009 | 0.102 | 0.139 | 0.143 |
| 36th week                            | 0.236 ± 0.017                   | 0.205                             | 0.270                             | 0.277                             | 0.0036 ± 0.0003 | 0.0030 | 0.0043 | 0.0044 | 0.136 ± 0.010 | 0.116 | 0.157 | 0.161 |
| Normal-weight females                 | 0 week                           | 0.193 ± 0.018                   | 0.160                             | 0.233                             | 0.241                             | 0.0033 ± 0.0004 | 0.0026 | 0.0040 | 0.0042 | 0.117 ± 0.012 | 0.096 | 0.143 | 0.148 |
|                                     | 9th week                         | 0.198 ± 0.019                   | 0.163                             | 0.240                             | 0.248                             | 0.0033 ± 0.0004 | 0.0026 | 0.0041 | 0.0042 | 0.119 ± 0.012 | 0.097 | 0.144 | 0.150 |
|                                     | 22nd week                        | 0.211 ± 0.021                   | 0.172                             | 0.257                             | 0.264                             | 0.0032 ± 0.0004 | 0.0024 | 0.0039 | 0.0041 | 0.121 ± 0.012 | 0.098 | 0.147 | 0.152 |
|                                     | 36th week                        | 0.245 ± 0.025                   | 0.200                             | 0.300                             | 0.313                             | 0.0032 ± 0.0004 | 0.0025 | 0.0041 | 0.0042 | 0.132 ± 0.014 | 0.107 | 0.161 | 0.167 |
| Overweight females                   | 0 week                           | 0.215 ± 0.025                   | 0.175                             | 0.272                             | 0.283                             | 0.0029 ± 0.0004 | 0.0022 | 0.0038 | 0.0040 | 0.118 ± 0.015 | 0.093 | 0.150 | 0.157 |
|                                     | 9th week                         | 0.228 ± 0.026                   | 0.187                             | 0.288                             | 0.301                             | 0.0028 ± 0.0004 | 0.0022 | 0.0037 | 0.0038 | 0.119 ± 0.015 | 0.095 | 0.152 | 0.160 |
|                                     | 22nd week                        | 0.241 ± 0.028                   | 0.198                             | 0.306                             | 0.321                             | 0.0029 ± 0.0004 | 0.0021 | 0.0037 | 0.0039 | 0.123 ± 0.015 | 0.098 | 0.158 | 0.166 |
|                                     | 36th week                        | 0.287 ± 0.033                   | 0.234                             | 0.363                             | 0.380                             | 0.0031 ± 0.0004 | 0.0024 | 0.0041 | 0.0043 | 0.140 ± 0.017 | 0.112 | 0.179 | 0.188 |
Table 5: Means and percentiles of oxygen consumption rates in fasting females at rest aged 18 to 45 years during pregnancy. \( \gamma \nu \nu \gamma ^{\text{O}_{2}} \gamma \text{BEE}/1440 \) \( \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma 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Table 7: Means and percentiles of minute ventilation rates in fasting females at rest aged 18 to 45 years during pregnancy. VE=(BEE/1440) x H x VQβ. BEE and VQβ values are given in Tables 2 and 3 respectively. H$_{2}$ of 0.2057 ± 0.0018 L of O$_{2}$/kg is defined in Table 4. Minute ventilation 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. Min.=minimum, Max.=maximum.

| Weight classifications of females | Progression of the reproductive cycle | Mean ± S.D. | Percentiles |
|----------------------------------|--------------------------------------|-------------|-------------|
|                                  |                                      | 1st         | 25th        | 5th         | 10th         | 25th         | 50th         | 65th         | 75th         | 85th         | 90th         | 95th         | 97.5th       | 99th         |
| Obese classes 2-3 females        |                                      |             |             |             |             |             |             |             |             |             |             |             |             |             |
|                                  | 0 week                               | 13.91 ± 1.19| 11.69       | 16.37       | 16.76       | 0.397 ± 0.010| 0.08 | 0.117 ± 0.122| 5.42 ± 0.49  | 4.53 | 6.44       | 6.65       |             |             |             |
|                                  | 9th week                             | 12.19 ± 1.41| 9.63        | 15.07       | 15.74       | 0.093 ± 0.012| 0.072 | 0.117 ± 0.122| 4.93 ± 0.57  | 3.91 | 6.12       | 6.38       |             |             |             |
|                                  | 22nd week                            | 11.21 ± 1.07| 9.24        | 13.52       | 13.96       | 0.083 ± 0.009| 0.066 | 0.103 ± 0.106| 4.50 ± 0.44  | 3.70 | 5.43       | 5.61       |             |             |             |
|                                  | 36th week                            | 10.07 ± 1.19| 7.85        | 11.05       | 11.89       | 0.087 ± 0.010| 0.077 | 0.117 ± 0.122| 4.93 ± 0.57  | 3.91 | 6.12       | 6.38       |             |             |             |

Table 8: Distribution of minute ventilation rate (L/min) percentiles during the aggregate daytime activities of females aged 18 to 45 years. VEα=(TDEE-BEE) x (C24-Dad) x BEE/(1440) x H$_{2}$ x VQβ. BEE and TDEEs are reported in Table 2. Std data appear in Table 3. H$_{2}$ of 0.2059 ± 0.0018 L of O$_{2}$/kg is defined in Table 4. S.D.=standard deviation.

| Weight classifications of females | Progression of the reproductive cycle | Mean ± S.D. | Percentiles |
|----------------------------------|--------------------------------------|-------------|-------------|
|                                  | 0 week                               | 9.98 ± 2.84 | 5.64        | 16.26       | 18.79       | 0.080 ± 0.023| 0.045 | 0.133 ± 0.152| 4.21 ± 1.21  | 2.41 | 7.12       | 7.88       |             |             |             |
|                                  | 9th week                             | 12.19 ± 1.41| 9.63        | 15.07       | 15.74       | 0.093 ± 0.012| 0.072 | 0.117 ± 0.122| 4.93 ± 0.57  | 3.91 | 6.12       | 6.38       |             |             |             |
|                                  | 22nd week                            | 11.21 ± 1.07| 9.24        | 13.52       | 13.96       | 0.083 ± 0.009| 0.066 | 0.103 ± 0.106| 4.50 ± 0.44  | 3.70 | 5.43       | 5.61       |             |             |             |
|                                  | 36th week                            | 10.07 ± 1.19| 7.85        | 11.05       | 11.89       | 0.087 ± 0.010| 0.077 | 0.117 ± 0.122| 4.93 ± 0.57  | 3.91 | 6.12       | 6.38       |             |             |             |
(including notably benzene, toluene, ethyl benzene, xylene, styrene and aromatic polycyclic hydrocarbons) and organic solvents of cleaning products [203,208-213]. These chemicals and fat soluble 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...
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 xenobiotics. 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 fetuses 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 lead to genetic damages, structural defects, malformation of systems or growth retardations in newborns [182,223,227-229]. Diseases and developmental disorders could also occur in children, during their life course and in future generations [228]. The embryonic death occurs when future mothers absorb in their bloodstream teratogenic chemicals mainly by the inhalation process, before the implantation of their blastocyst [223]. For instance, the exposure to anesthetic gases, antineoplastic drugs and sterilizing agents were associated to high risks of spontaneous abortions in exposed female workers in hospitals, compared to those that were not exposed [68,226,230-234]. Significantly more congenital abnormalities were also found in children of some exposed female workers [232,233,235]. These high risks of spontaneous abortions are enhanced by the fact that working women in hospitals cannot know exactly when their pregnancy begins: the human chorionic gonadotropin (hCG) being only detected in the blood or urine samples after the implantation of the blastocyst, which occurs six to twelve days after the fertilization [222,223].

Conclusion

The present study provides a complete and original set of PALVO2, VQβ, VQα, VO2, and VE values during the aggregate daytime activity of under (n=68), normal (n=268), overweight (n=42), obese class 1 (n=68) and obese classes 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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Declaration of Interest

The authors report no declarations of interest.

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