

### RESEARCH ARTICLE

## Predictive equations for estimating resting energy expenditure in women with overweight and obesity at three postpartum stages

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#### Abstract

The objective was to investigate which predictive equations provide the best estimates of resting energy expenditure (REE) in postpartum women with overweight and obesity. Lactating women with overweight or obesity underwent REE measurement by indirect calorimetry, and fat-free mass (FFM) was assessed by dual-energy X-ray absorptiometry at three postpartum stages. Predictive equations based on body weight and FFM were obtained from the literature. Performance of the predictive equations were analysed as the percentage of women whose REE was accurately predicted, defined as a predicted REE within  $\pm 10\%$  of measured REE. REE data were available for women at 10 weeks ( $n$  71), 24 weeks ( $n$  64) and 15 months ( $n$  57) postpartum. Thirty-six predictive equations (twenty-five weight-based and eleven FFM-based) were validated. REE was accurately predicted in  $\geq 80\%$  of women at all postpartum visits by six predictive equations (two weight-based and four FFM-based). The weight-based equation with the highest performance was that of Henry (weight, height, age 30–60 years) (Henry<sub>WH30–60</sub>), with an overall mean of 83% accurate predictions. The Henry<sub>WH30–60</sub> equation was highly suitable for predicting REE at all postpartum visits (irrespective of the women's actual age), and the performance was sustained across changes in weight and lactation status. No FFM-based equation was remarkably superior to Henry<sub>WH30–60</sub> for the total postpartum period.

**Key words:** Resting energy expenditure: Predictive equations: Women: Postpartum period: Overweight: Obesity: Lactation

Overweight and obesity in women are strongly related to retention of weight acquired during pregnancy<sup>(1,2)</sup>. The postpartum period is a recognised window of opportunity for delivery of weight management interventions, due to the energy cost of breastfeeding, the increased autonomy provided by maternity leave, and the extra motivation for women to become good role models for their children and return to pre-pregnancy weight<sup>(3–5)</sup>. An accurate estimate of the resting energy expenditure (REE) of an individual may facilitate

calculation of the energy intake reduction required for weight loss. In this respect, methods to estimate REE in overweight and obese women postpartum is of special interest. As indirect-calorimetry measurements of REE are often inaccessible in clinical practice, predictive equations are commonly used to estimate REE. However, their use has been widely discouraged for individuals who differ from the reference population, since substantial prediction errors may occur<sup>(6,7)</sup>. No equation has previously been developed for postpartum

**Abbreviations:** FFM, fat-free mass; FM, fat mass; Henry<sub>WH30–60</sub>, Henry's predictive equation based on weight and height for age group 30–60 years; Johnstone<sub>FFM</sub>, Johnstone's predictive equation based on FFM, FM and age; Lazzet<sub>FFM</sub>, Lazzet's predictive equation based on FFM and FM for BMI group  $\geq 40$  kg/m<sup>2</sup>; Livingston, Livingston's predictive equation based on weight and age; mREE, measured REE; Müller<sub>FFM30</sub>, Müller's predictive equation based on FFM, FM and age for BMI group  $\geq 30$  kg/m<sup>2</sup>; Müller<sub>FFMall</sub>, Müller's predictive equation based on FFM, FM and age for all BMI groups; pREE, predicted REE; REE, resting energy expenditure; UNU, United Nations University.

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women, although they may be at particular risk for such errors due to the anomalous physiological condition associated with this period. For instance, postpartum women may be in a state of overhydration, associated with both pregnancy and obesity<sup>(8,9)</sup>. This may lead to an overestimation of the energy requirement. To our knowledge, only two publications have previously validated existing predictive equations in women postpartum at 1–10 d<sup>(10)</sup> and 3 months and 9 months postpartum, respectively<sup>(11)</sup>. Both studies were only observational and included both lactating and non-lactating women of several BMI categories. Pereira *et al.*<sup>(11)</sup> found similar patterns for performance of equations in BMI-specific categories, however, with larger individual variation in REE (increasing limits of agreement) with increasing BMI<sup>(11)</sup>.

We conducted a randomised controlled trial investigating the main effects of diet and exercise behaviour modification treatment (the Livsstil vid Effektiv Viktminskning under Amning (LEVA) study; Lifestyle for Effective Weight loss during lactation), in Sweden between 2007 and 2011<sup>(12)</sup>. There was a main effect of the dietary behaviour modification treatment resulting in a weight loss of 9 % after the 12-week intervention, and the weight loss sustained at 10 % at 15 months postpartum<sup>(12)</sup>. Exercise behaviour modification did not contribute significantly to weight loss. Thorough physiological measurements, including REE, anthropometry, body composition and breastfeeding status, were collected at three times: baseline (10 weeks postpartum), end of intervention (24 weeks postpartum) and 1-year follow-up (15 months postpartum).

The aim of the present study was to evaluate which predictive equations provide the best estimates of REE in women with overweight and obesity at each of these three different postpartum stages. Additionally, we aimed to investigate whether any equation would perform well across the entire postpartum period, despite changes in lactation status and body weight. Including measurement of fat-free mass (FFM) and fat mass (FM) may increase the precision in estimates of REE. However, equipment for measurement of body composition is not always accessible in clinical practice. Therefore, we aimed to identify the best performing equations, both with and without the inclusion of body composition variables.

## Methods

Women with overweight or obesity were recruited during pregnancy or early postpartum from fifteen antenatal clinics in Gothenburg, Sweden. Measurements of REE, anthropometry and breastfeeding status were available for seventy-one women at baseline (10 weeks postpartum), and sixty-four and fifty-seven of the same women at 24 weeks and 15 months postpartum, respectively. Body composition measurements by dual-energy X-ray absorptiometry were only available for fifty-six of the fifty-seven women at 15 months. All participating women in the present data analysis had a BMI  $\geq 25$  kg/m<sup>2</sup> at the 10-week postpartum visit, and had complete measurements of REE, height, weight and breastfeeding status on at least one visit. Written informed consent was obtained from

all participants. The study was approved by the regional ethics board in Gothenburg, Sweden (483-06).

## Measurements

The measurements were carried out by trained research staff at the laboratories of the Department of Internal Medicine and Clinical Nutrition, University of Gothenburg, Sweden, and at the Sahlgrenska University Hospital, Sweden. The women arrived at the research clinic in the morning, after an overnight fast, by car or public transport.

**RMR.** RMR was measured using the Deltatrac II Metabolic Monitor ventilated hood system (Datex-Ohmeda), after a 30-min rest in the supine position. The equipment was calibrated before each measurement in accordance with the instructions of the manufacturer. RMR was derived from the last 25 min of a 30-min measurement, and the value was extrapolated to 24 h to determine REE.

## Anthropometry and body composition measurements.

Height was measured to the nearest 0.5 cm using a wall-mounted stadiometer. The height measured at the baseline visit was used for all consecutive body composition analyses. Body weight was measured to the nearest 0.1 kg with light clothing, using an electronic scale (MC 180 MA; Tanita). FM (kg) and FFM (kg) were measured by dual-energy X-ray absorptiometry (Lunar Prodigy; GE Lunar Corp.).

## Predictive equations

Predictive equations of REE obtained from a literature search in the Pub Med database (January 2018) fulfilling the following criteria were included: (i) equations based on body weight, height, age and/or FFM and FM; (ii) equations derived for both sexes or women only; (iii) equations developed for adults. The following predictive equations were excluded: (i) equations developed only for (critically ill) patients, athletes, elderly or underweight populations; (ii) equations derived from small sample sizes ( $n < 20$ ); and (iii) equations being too complicated for use in clinical settings. When more than one equation was available from the same study, all equations relevant to our population were included. If there were multiple equations based on the same variables available, the equation with the highest value for explained variance ( $r^2$ ) was chosen.

The literature search resulted in an inclusion of thirty-six REE predictive equations from eighteen scientific papers<sup>(13–30)</sup>, of which twenty-five were weight-based and eleven were FFM-based (Supplementary Table S1).

## Statistics and data analyses

For analyses of predicted REE (pREE) and measured REE (mREE), the three time points were analysed separately and all participants with complete measurements at each visit were included in the analyses. For each woman at each visit,



**Table 1.** Background characteristics of the seventy-one lactating women with overweight or obesity included in the validation of resting energy expenditure (REE) predictive equations at three postpartum stages (Mean values and standard deviations; numbers and percentages)

	<i>n</i>	%
Height (cm)		
Mean	168.8	
SD	6.7	
BMI (kg/m <sup>2</sup> )		
Mean	30.2	
SD	2.9	
Age (years)		
Mean	32.8	
SD	4.2	
Parity		
1	35	49
2	30	42
3	6	9
Education		
Short education at high school	6	9
≤3 years beyond high school	14	20
>3 years beyond high school	51	72
Marital status		
Married or cohabitating	68	96
Single	2	3
Couple with different residences	1	1

the REE was predicted for all equations in MJ/d and compared with the REE measured by indirect calorimetry. The body weight, age, FFM and FM measured at the respective visit were used for this calculation. Equations derived for specific age or BMI groups were analysed as applied on the entire sample.

An accurate prediction of REE was defined as a pREE within  $\pm 10\%$  of mREE. A pREE less than 90% of mREE was classified as an under-prediction, and a pREE exceeding 110% of mREE was classified as an over-prediction. The bias was defined as the mean percentage error between pREE and mREE values. Systematic bias between pREE and mREE was defined as a bias of  $\geq \pm 5\%$ . The root mean sum of squared errors (RMSE) was used to indicate how well each equation predicted REE in our sample. To clarify the extent of clinical risk of prediction inaccuracy in any given individual, the maximal underestimation and maximal overestimation found with every equation were reported.

The performance of the equations was evaluated primarily based on the percentage of women whose REE was accurately predicted, and secondarily based on bias and RMSE. The weight-based and the FFM-based equation with the highest performance at each visit, along with the equations producing  $\geq 80\%$  accurate predictions at all three postpartum visits were graphically presented in Bland–Altman plots, in which the difference between pREE and mREE (pREE–mREE) was plotted against their averaged value (aREE). Furthermore, the differences (pREE–mREE) at 24 weeks and 15 months postpartum were plotted against percentage weight change from baseline (10 weeks postpartum), to analyse their predictive performance relative to weight change. Pearson's correlation was used to analyse whether there existed a relationship between differences (pREE–mREE) and aREE or percentage weight change.

Data were analysed using IBM SPSS version 25.0. *P* values  $< 0.05$  were considered statistically significant.

## Results

The participating women had a mean BMI of 30.2 (SD 2.9) kg/m<sup>2</sup> at 10 weeks postpartum, half of them were primiparous and the majority had a higher level of education (Table 1). There was a significant reduction in body weight between baseline and the subsequent follow-ups, mainly explained by the FM loss of those who were randomised to the dietary behaviour modification treatment (Table 2). The majority (93%) were exclusively breastfeeding at 10 weeks postpartum, partially breastfeeding at 24 weeks postpartum (86%) and no longer breastfeeding at 15 months postpartum (91%).

### Results from the individual postpartum visits

A total of twelve equations accurately predicted REE in  $\geq 80\%$  of women at 10 weeks postpartum, of which six were weight-based and six were FFM-based (Supplementary Table S2). The weight-based and the FFM-based equations with the highest performance were Henry<sub>W30–60</sub> and Lazzar<sub>FFM</sub>, which accurately predicted 89 and 92% of the women, respectively. At 24 weeks postpartum, REE was accurately predicted in  $\geq 80\%$  of the women by nine equations, of which four were weight-based and five were FFM-based (Supplementary Table S3). The equations achieving the highest percentage of accurately predicted women were Siervo (83%) and Johnstone<sub>FFM</sub> (86%). At 15 months postpartum, REE was accurately predicted in  $\geq 80\%$  of the women by ten equations, six of which were weight-based and four of which were FFM-based (Supplementary Table S4). Three weight-based equations (Henry<sub>WH30–60</sub>, Schofield<sub>W30–60</sub> and Schofield<sub>WH30–60</sub>) achieved 83% accurate predictions, whilst two FFM-based equations (Müller<sub>FFMall</sub> and Johnstone<sub>FFM</sub>) achieved 82% accurate predictions at this time point.

### Results from the total postpartum period

REE was accurately predicted in  $\geq 80\%$  of the women at all three postpartum visits by six predictive equations, of which two were weight-based: Henry<sub>WH30–60</sub> and Livingston, and four were FFM-based: Müller<sub>FFMall</sub>, Müller<sub>FFM30</sub>, Johnstone<sub>FFM</sub> and Lazzar<sub>FFM</sub> (Table 3). Of the two weight-based equations, the overall average of accurate predictions was 83% with Henry<sub>WH30–60</sub>, and 81% with Livingston. Both equations showed a moderate negative correlation between differences and averaged REE values at all three visits (Henry<sub>WH30–60</sub>:  $r -0.41$  and  $P = 0.000$  at 10 weeks,  $r -0.44$  and  $P = 0.000$  at 24 weeks, and  $r -0.44$  and  $P = 0.001$  at 15 months postpartum; Livingston:  $r -0.57$  and  $P = 0.000$  at 10 weeks,  $r -0.52$  and  $P = 0.000$  at 24 weeks, and  $r -0.51$  and  $P = 0.000$  at 15 months postpartum), indicating an overestimation of lower REE values and an underestimation of higher REE values (Fig. 1(a) and (b)). Of the four FFM-based equations, the overall average of accurate predictions was 83% with Müller<sub>FFMall</sub>, 83% with Müller<sub>FFM30</sub>, 84% with



**Table 2.** Resting energy expenditure (REE), anthropometry, body composition and breastfeeding status at baseline, end of intervention and follow-up (Mean values and standard deviations; changes; numbers and percentages)

	10 weeks postpartum (n 71)		24 weeks postpartum (n 64)		Δ From baseline	15 months postpartum (n 57)		Δ From baseline	Δ From 24 weeks
	Mean	SD	Mean	SD		Mean	SD		
REE (MJ/d)	6.3	0.6	6.2	0.7	-0.1	6.4	0.7	0.1	0.2*
REE/kg FFM (MJ/d)	0.141	0.012	0.141	0.015	0.000	0.142†	0.016	0.002	0.003*
Weight (kg)	86.1	9.5	81.3	10.6	-4.7**	81.3	11.2	-5.4**	-0.6
BMI (kg/m <sup>2</sup> )	30.2	2.9	28.5	3.3	-1.6**	28.3	3.5	-1.9**	-0.2
FFM (kg)	45.1	4.9	44.6	5.0	-0.6*	45.1†	5.2	-0.2	0.4
FM (kg)	37.7	7.1	33.5	8.4	-3.9**	33.1†	9.4	-5.0**	-0.9
Breastfeeding									
None					-			-	-
n	0		4			52			
%	0		6			91			
Partial					-			-	-
n	5		55			5			
%	7		86			9			
Exclusive					-			-	-
n	66		5			0			
%	93		8			0			

FFM, fat-free mass; FM, fat mass.

\*  $P < 0.05$ , \*\*  $P < 0.001$ .

† n 56.

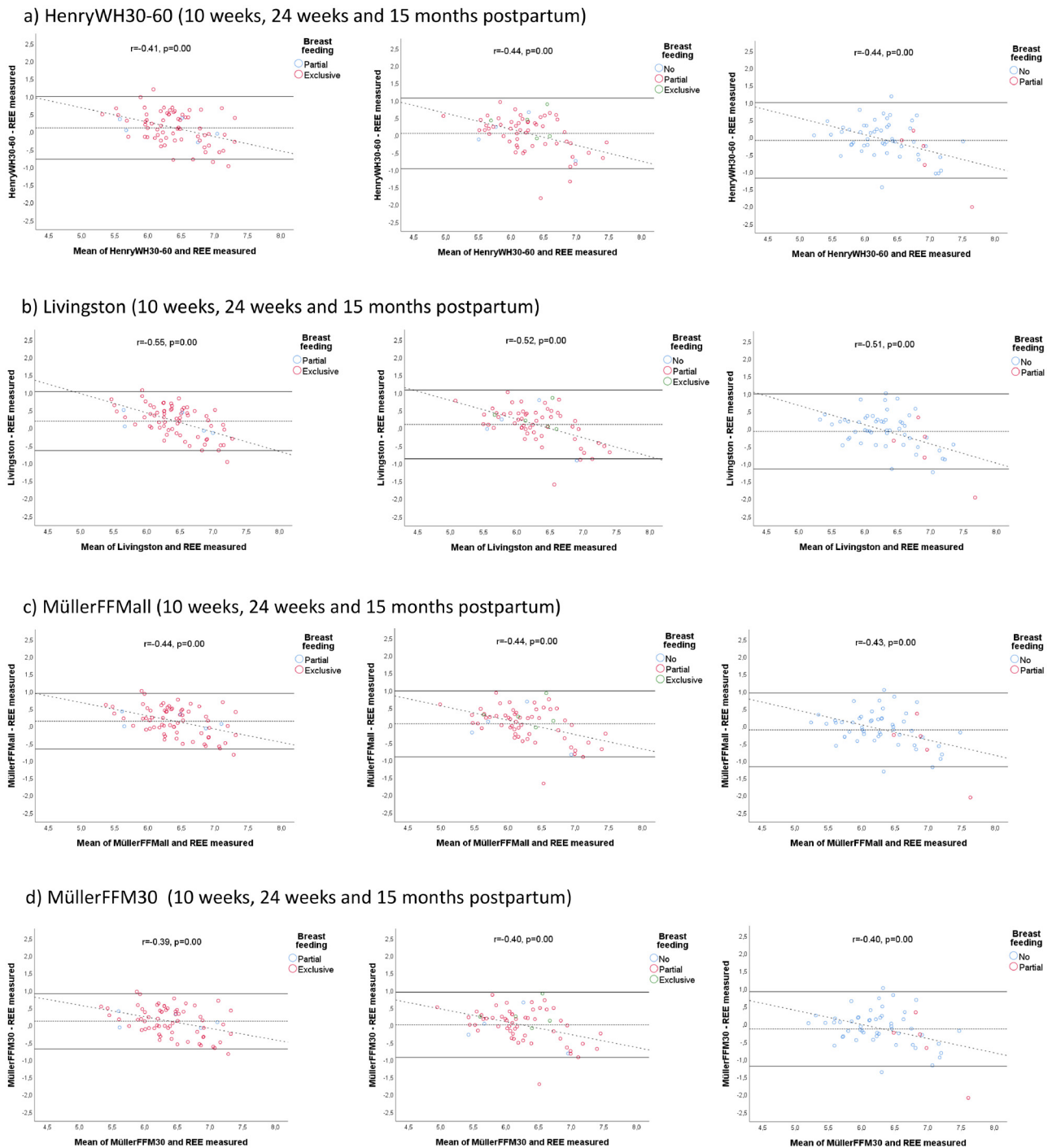
Johnstone<sub>FFM</sub> and 85 % with Lazzar<sub>FFM</sub>. Müller<sub>FFMall</sub> showed a moderate negative correlation between differences and averaged REE values at all three visits ( $r = -0.44$  and  $P = 0.000$  at 10 weeks,  $r = -0.44$  and  $P = 0.000$  at 24 weeks, and  $r = -0.43$  and  $P = 0.001$  at 15 months postpartum) (Fig. 1(c)). Müller<sub>FFM30</sub> showed a weak negative correlation between differences and

average REE values at 10 weeks ( $r = -0.39$  and  $P = 0.001$ ), and a moderate negative correlation at 24 weeks ( $r = -0.40$  and  $P = 0.001$ ) and 15 months ( $r = -0.40$  and  $P = 0.002$ ) (Fig. 1(d)). Neither Johnstone<sub>FFM</sub> nor Lazzar<sub>FFM</sub> showed any statistically significant correlation between differences and averaged REE values at any visit (Fig. 1(e) and (f)). Of the six equations with

**Table 3.** Presentation of resting energy expenditure (REE) predictive equations with  $\geq 80\%$  accurate predictions at all three postpartum visits<sup>(13-30)</sup>

REE predictive equations	REE (MJ/d)	SD (MJ/d)	Bias (%)	RMSE (MJ/d)	Maximum negative error (%)	Maximum positive error (%)	Accurate predictions (%)	Under-predictions (%)	Over-predictions (%)
10 weeks postpartum (n 71)									
Henry <sub>WH30-60</sub>	6.44	0.42	2	0.46	-13	22	85	6	10
Livingston	6.52	0.37	3	0.46	-13	20	83	1	16
Müller <sub>FFMall</sub>	6.47	0.42	3	0.43	-11	19	85	1	14
Müller <sub>FFM30</sub>	6.44	0.44	2	0.42	-11	18	89	1	41
Johnstone <sub>FFM</sub>	6.47	0.53	3	0.44	-10	18	83	1	16
Lazzar <sub>FFM</sub>	6.32	0.51	0	0.42	-11	16	92	4	4
24 weeks postpartum (n 64)									
Henry <sub>WH30-60</sub>	6.28	0.45	1	0.52	-25	18	81	8	11
Livingston	6.33	0.42	2	0.50	-22	19	80	6	14
Müller <sub>FFMall</sub>	6.27	0.46	1	0.48	-23	17	81	6	13
Müller <sub>FFM30</sub>	6.23	0.48	1	0.48	-23	16	80	8	13
Johnstone <sub>FFM</sub>	6.29	0.56	1	0.48	-21	16	86	5	9
Lazzar <sub>FFM</sub>	6.09	0.55	-2	0.51	-27	15	81	16	3
15 months postpartum (n 57)									
Henry <sub>WH30-60</sub>	6.29	0.47	-1	0.56	-23	20	83	11	7
Livingston	6.31	0.44	-1	0.55	-23	17	81	12	7
Müller <sub>FFMall</sub> †	6.27	0.48	-1	0.55	-24	18	82	9	9
Müller <sub>FFM30</sub> †	6.24	0.50	-2	0.55	-24	17	80	11	9
Johnstone <sub>FFM</sub> †	6.31	0.57	-1	0.54	-25	18	82	7	11
Lazzar <sub>FFM</sub> †	6.11	0.57	-4	0.62	-26	17	80	14	5

Bias, mean percentage error between predictive equation and measured value; RMSE, root mean sum of squared prediction error; Maximum negative error, the largest underprediction that was found with this predictive equation as a percentage of the measured value; Maximum positive error, the largest over-prediction that was found with this predictive equation as a percentage of the measured value; Accurate predictions, the percentage of subjects predicted by this equation within 10% of the measured value; Under-predictions, the percentage of subjects predicted by this equation  $< 10\%$  of the measured value; Over-predictions, the percentage of subjects predicted by this equation  $> 10\%$  of the measured value; Henry<sub>WH30-60</sub>, Henry's predictive equation based on weight and height for age group 30-60 years; Livingston, Livingston's predictive equation based on weight and age; Müller<sub>FFMall</sub>, Müller's predictive equation based on FFM, FM and age for all BMI groups; Müller<sub>FFM30</sub>, Müller's predictive equation based on FFM, FM and age for BMI group  $\geq 30$  kg/m<sup>2</sup>; Johnstone<sub>FFM</sub>, Johnstone's predictive equation based on FFM, FM and age; Lazzar<sub>FFM</sub>, Lazzar's predictive equation based on FFM and FM for BMI group  $\geq 40$  kg/m<sup>2</sup>. † n 56.



**Fig. 1.** (a–f) Bland–Altman plots of differences between predicted and measured resting energy expenditure (REE) for six predictive equations where resting energy expenditure was accurately predicted in  $\geq 80\%$  of the women at all three postpartum stages. Henry<sub>WH30-60</sub>, Henry's predictive equation for age group 30–60 years; Livingston, Livingston's predictive equation for all age and BMI groups; Müller<sub>FFMall</sub>, Müller's predictive equation for all BMI groups; Müller<sub>FFM30</sub>, Müller's predictive equation for BMI group  $\geq 30$  kg/m<sup>2</sup>; Johnstone<sub>FFM</sub>, Johnstone's predictive equation for all age and BMI groups; Lazzar<sub>FFM</sub>, Lazzar's predictive equation for BMI group  $\geq 40$  kg/m<sup>2</sup>.

overall  $\geq 80\%$  accurate predictions, a correlation between differences and percentage weight loss was present only with Lazzar<sub>FFM</sub> at 15 months; however, the positive correlation was weak ( $r$  0.28,  $P$  = 0.038) (Bland–Altman plot not shown).

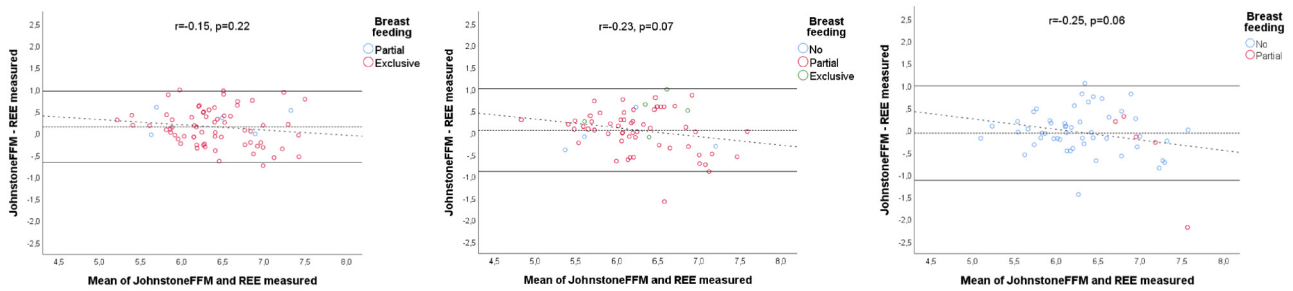
The best performing equations for the total postpartum period (Table 3) were in several cases also among the best performing at each of the postpartum visits (Supplementary Tables S2–S4).

## Discussion

In our population of Swedish postpartum women with overweight and obesity, REE was accurately predicted in  $\geq 80\%$  at all visits by six equations. Although weight and breastfeeding status changed during the postpartum period, there was little gain in the proportion of accurately predicted REE values by choosing time-specific equations. There was also limited gain in choosing FFM-based equations.



## e) JohnstoneFFM (10 weeks, 24 weeks and 15 months postpartum)



## f) LazerFFM (10 weeks, 24 weeks and 15 months postpartum)

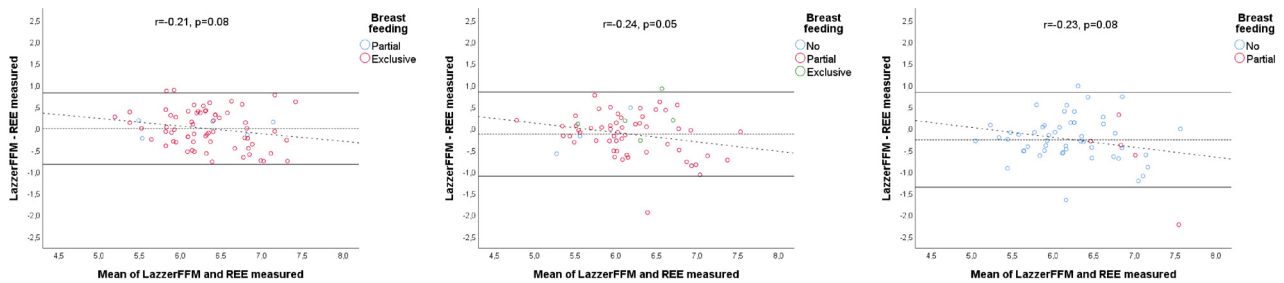


Fig. 1. Continued

*Weight-based equations*

Of the weight-based equations, Henry<sub>WH30–60</sub> achieved the overall highest performance, with better results at all postpartum visits compared with Livingston. In addition, none of the weight-based equations with the highest percentage accurate predictions at one visit was remarkably superior to the Henry<sub>WH30–60</sub> equation. The Henry<sub>WH30–60</sub> equation was more than sufficient for predicting REE at all postpartum visits, and hence it could be used for groups that share the same characteristics as ours. Noteworthy, although a quarter of our group of lactating women with overweight and obesity were younger than 30 years of age and none was older than 41 years of age, still, the Henry<sub>WH30–60</sub> performed better when applied to the whole group, irrespective of age. Actually, none of the age- or BMI group-specific equations provided higher percentages of accurate predictions at all three visits when applied to the intended age group only, as compared with the whole group. This becomes evident when looking at the low performance in general of the equations for the age group 18–30 years (Supplementary Tables S1–S3). Interestingly, the equations by Henry<sup>(17)</sup> have also been recommended for the general population in both the Nordic Nutrition Recommendations of 2012<sup>(31)</sup> and the European Food Safety Agency (EFSA) report on dietary reference values for energy of 2013<sup>(32)</sup>. Nevertheless, the maximum negative and positive errors found by use of Henry<sub>WH30–60</sub> compared with actual measurements of REE in our population were  $-25$  and  $22\%$ . The consequences of such errors in clinical practice must be granted careful evaluation.

*Fat-free mass-based equations*

Of the FFM-based equations, Lazer<sub>FFM</sub> achieved the highest overall mean percentage accurate predictions; however, the

high performance was mainly explained by the extraordinary results at 10 weeks postpartum, at which 92% of the women were accurately predicted, with no skewness in percentage under-predictions and over-predictions and small maximum errors. Johnstone<sub>FFM</sub>, the FFM-based equation with the second highest overall percentage of accurate predictions, provided more similar results from visit to visit, than did Lazer<sub>FFM</sub>. Therefore, if a single FFM-based equation were to be recommended for the entire postpartum period, Johnstone<sub>FFM</sub> would probably be the safer choice.

In agreement with other studies<sup>(11,33)</sup>, the FFM-based equations did not markedly improve accuracy compared with the weight-based equations. The overall performance of both Lazer<sub>FFM</sub> and Johnstone<sub>FFM</sub> cannot with certainty be considered superior to the overall performance of Henry<sub>WH30–60</sub>; thus, we do not consider it necessary to use an FFM-based equation for postpartum women when dual-energy X-ray absorptiometry is used to determine FFM. The discrepancies between the methods used to measure FFM comprise an additional uncertainty associated with these equations. Therefore, both the original population and the method used to measure FFM should be carefully considered before applying FFM-based equations to postpartum women.

*Strengths of the strategy used*

This study has several strengths. The measurements of REE were performed under well-controlled conditions and the population is well defined with regard to body composition and breastfeeding status. An additional strength of the present study is the broad range of well-documented statistical analyses used to validate the predictive equations. Each test measured a



different aspect of the performance of the equations. Because these equations are used in clinical practice to estimate an individual's REE, and because group mean data may mask larger individual errors, a measure of prediction accuracy on the individual level was the main variable assessed. Prediction accuracy was defined as the percentage of subjects predicted within 10% of the measured value, as described by Frankenfield *et al.*<sup>(34,35)</sup>. They considered this error limit on prediction accuracy to be consistent with accepted calorimetry measurement errors of 5% or less<sup>(36)</sup>. Validation of equations based on the number of accurate predictions is widely recognised as the preferred method of such<sup>(37)</sup>.

### Generalisability of our findings

It has been widely warned that caution should be exhibited when predictive equations are applied to groups that differ from the populations for which the equations were developed<sup>(6,7)</sup>. No equation has yet been developed specifically for prediction of REE in postpartum women; however, our findings indicate that multiple existing equations may be highly suitable for this purpose. This is somewhat contradictory to the findings by de Sousa<sup>(10)</sup> where most equations overestimated REE. However, they measured at 1–10 d postpartum while our first measurement was at 10 weeks. Our results are in better agreement with Pereira *et al.*<sup>(11)</sup> who found a number of equations with more than 80% accurate predictions at 3 months postpartum, including one with 100% (FAO/WHO/United Nations University (FAO/WHO/UNU), height and weight). We did not report here the results from FAO/WHO/UNU from 1985; however, we report the updated versions of these, the Schofield equations, which were not among the overall six best performing equations in our population. We have now also tested the 1985 equation from FAO/WHO/UNU and found a perfect correlation with Schofield although with a slight shift. Like the Schofield equations, those of the FAO/WHO/UNU (weight and height) from 1985 were not among the equations with the highest number of accurate predictions in our population. Previous studies differed from our study in that our population only had women with overweight/obesity and thereby was more homogeneous with respect to BMI. They had also lost on average 4.7 and 5.4 kg in weight at 6 months and 15 months, respectively. Another major difference is that we tested as many as thirty-six equations, also irrespective of the intended age group and found that this actually improved overall accuracy. Since predictive equations are expected to be valid for the original population only<sup>(6)</sup>, it is advisable to validate the equations for each single specific population<sup>(38)</sup>. Although postpartum women are a very specific group, they are highly likely to exhibit large variability in factors that might affect REE. Caution should therefore be exercised before generalising the results of this study to postpartum women from otherwise divergent populations.

Unlike Pereira *et al.*<sup>(11)</sup>, we did not stratify and perform BMI group-specific analyses. However, there was a large shift in BMI categories over the postpartum period due to diet treatment. Still, one single equation (Henry<sub>WH30–60</sub>) performed

well, irrespective of changes in weight and lactation status. In addition, equations measuring FFM did not improve accuracy. The results from our analyses are limited to women with pre-pregnancy BMI 25–35 kg/m<sup>2</sup> and cannot be extrapolated to a normal-weight population.

### Energy output in lactating women

For lactating women it is of crucial importance to acknowledge that the energy content of the human milk is not accounted for in estimations of REE; neither when measured by indirect calorimetry, nor when estimated by predictive equations. Therefore, this energy output, which for exclusively breastfeeding women approximates to 2.1 MJ/d<sup>(3)</sup>, must always be subsequently added.

### Limitations of predictive equations

Predictive equations hold a unique potential as a vital tool for health care providers due to their highly accessible nature. However, even if an equation with a perfect match, in regard to the characteristics of the population and the methods used, were to be selected, certain aspects need to be carefully considered before any credibility is assigned to its estimations. Even the most accurate predictive equations carry a clinically relevant error rate (about 20%) relative to REE measured by indirect calorimetry<sup>(34)</sup>. Use of adjusted body weight in predictive equations, as is often done for subjects with overweight and obesity, is discouraged as it has been found to decrease accuracy and drastically increase maximum underestimation errors<sup>(34)</sup>. Practitioners need be aware of the possible magnitude of errors associated with REE predictive equations, and clinical judgment must be exercised to determine what level of nutrition care should be based on their predictions. Furthermore, energy intake goals based on prediction of REE may need to be adjusted subsequently if weight management is not achieved<sup>(39)</sup>. For individuals in which accurate estimates are of particular importance, REE should always be determined by indirect calorimetry.

### Conclusion

The weight-based equation with the highest performance was Henry<sub>WH30–60</sub>, with an overall mean of 83% accurate predictions. The Henry<sub>WH30–60</sub> equation was highly suitable for prediction of REE at all postpartum visits, and the accuracy was sustained across changes in weight and lactation status, and also in women below the intended age interval. No FFM-based equation was remarkably superior to Henry<sub>WH30–60</sub>.

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### Supplementary material

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### References

- Gunderson EP (2009) Childbearing and obesity in women: weight before, during, and after pregnancy. *Obstet Gynecol Clin North Am* **36**, 317–332, ix.
- Endres LK, Straub H, McKinney C, *et al.* (2015) Postpartum weight retention risk factors and relationship to obesity at 1 year. *Obstet Gynecol* **125**, 144–152.
- Butte NF & King JC (2005) Energy requirements during pregnancy and lactation. *Public Health Nutr* **8**, 1010–1027.
- Phelan S (2010) Pregnancy: a “teachable moment” for weight control and obesity prevention. *Am J Obstet Gynecol* **202**, 135.e1–135.e8.
- Edvardsson K, Ivarsson A, Eurenus E, *et al.* (2011) Giving offspring a healthy start: parents’ experiences of health promotion and lifestyle change during pregnancy and early parenthood. *BMC Public Health* **11**, 936.
- da Rocha EE, Alves VG, Silva MH, *et al.* (2005) Can measured resting energy expenditure be estimated by formulae in daily clinical nutrition practice? *Curr Opin Clin Nutr Metab Care* **8**, 319–328.
- Thompson J & Manore MM (1996) Predicted and measured resting metabolic rate of male and female endurance athletes. *J Am Diet Assoc* **96**, 30–34.
- Buchholz AC, Bartok C & Schoeller DA (2004) The validity of bioelectrical impedance models in clinical populations. *Nutr Clin Pract* **19**, 433–446.
- Das SK, Roberts SB, Kehayias JJ, *et al.* (2003) Body composition assessment in extreme obesity and after massive weight loss induced by gastric bypass surgery. *Am J Physiol Endocrinol Metab* **284**, E1080–E1088.
- de Sousa TM, Maioli TU, Dos Santos ALS, *et al.* (2017) Energy expenditure in the immediate postpartum period: indirect calorimetry versus predictive equations. *Nutrition* **39–40**, 36–42.
- Pereira LCR, Purcell SA, Elliott SA, *et al.* (2019) The use of whole body calorimetry to compare measured versus predicted energy expenditure in postpartum women. *Am J Clin Nutr* **109**, 554–565.
- Bertz F, Brekke HK, Ellegard L, *et al.* (2012) Diet and exercise weight-loss trial in lactating overweight and obese women. *Am J Clin Nutr* **96**, 698–705.
- Bernstein RS, Thornton JC, Yang MU, *et al.* (1983) Prediction of the resting metabolic rate in obese patients. *Am J Clin Nutr* **37**, 595–602.
- Cunningham JJ (1980) A reanalysis of the factors influencing basal metabolic rate in normal adults. *Am J Clin Nutr* **33**, 2372–2374.
- De Lorenzo A, Tagliabue A, Andreoli A, *et al.* (2001) Measured and predicted resting metabolic rate in Italian males and females, aged 18–59 years. *Eur J Clin Nutr* **55**, 208–214.
- Harris JA & Benedict FG (1918) A biometric study of human basal metabolism. *Proc Natl Acad Sci U S A* **4**, 370–373.
- Henry CJ (2005) Basal metabolic rate studies in humans: measurement and development of new equations. *Public Health Nutr* **8**, 1133–1152.
- Horie LM, Gonzalez MC, Torrinhas RS, *et al.* (2011) New specific equation to estimate resting energy expenditure in severely obese patients. *Obesity (Silver Spring)* **19**, 1090–1094.
- Huang KC, Kormas N, Steinbeck K, *et al.* (2004) Resting metabolic rate in severely obese diabetic and nondiabetic subjects. *Obes Res* **12**, 840–845.
- Johnstone AM, Rance KA, Murison SD, *et al.* (2006) Additional anthropometric measures may improve the predictability of basal metabolic rate in adult subjects. *Eur J Clin Nutr* **60**, 1437–1444.
- Korth O, Bosity-Westphal A, Zschoche P, *et al.* (2007) Influence of methods used in body composition analysis on the prediction of resting energy expenditure. *Eur J Clin Nutr* **61**, 582–589.
- Lizzer S, Agosti F, Silvestri P, *et al.* (2007) Prediction of resting energy expenditure in severely obese Italian women. *J Endocrinol Invest* **30**, 20–27.
- Livingston EH & Kohlstadt I (2005) Simplified resting metabolic rate-predicting formulas for normal-sized and obese individuals. *Obes Res* **13**, 1255–1262.
- Mifflin MD, St Jeor ST, Hill LA, *et al.* (1990) A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr* **51**, 241–247.
- Müller MJ, Bosity-Westphal A, Klaus S, *et al.* (2004) World Health Organization equations have shortcomings for predicting resting energy expenditure in persons from a modern, affluent population: generation of a new reference standard from a retrospective analysis of a German database of resting energy expenditure. *Am J Clin Nutr* **80**, 1379–1390.
- Owen OE, Kavle E, Owen RS, *et al.* (1986) A reappraisal of caloric requirements in healthy women. *Am J Clin Nutr* **44**, 1–19.
- Roza AM & Shizgal HM (1984) The Harris Benedict equation re-evaluated: resting energy requirements and the body cell mass. *Am J Clin Nutr* **40**, 168–182.
- Schofield WN (1985) Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr* **39**, Suppl. 1, 5–41.
- Weijjs PJ & Vansant GA (2010) Validity of predictive equations for resting energy expenditure in Belgian normal weight to morbid obese women. *Clin Nutr* **29**, 347–351.
- Siervo M, Boschi V & Falconi C (2003) Which REE prediction equation should we use in normal-weight, overweight and obese women? *Clin Nutr* **22**, 193–204.
- Nordic Council of Ministers (2014) *Nordic Nutrition Recommendations 2012: Integrating Nutrition and Physical Activity*, 5th ed. Copenhagen: Nordic Council of Ministers.
- European Food Safety Agency Panel on Dietetic Products, Nutrition and Allergies (2013) Scientific opinion on dietary reference values for energy. *EFSA J* **11**, 3005.
- Poli VF, Sanches RB, Moraes AD, *et al.* (2016) Resting energy expenditure in obese women: comparison between measured and estimated values. *Br J Nutr* **116**, 1306–1313.
- Frankenfield D, Roth-Yousey L & Compher C (2005) Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. *J Am Diet Assoc* **105**, 775–789.
- Frankenfield DC, Rowe WA, Smith JS, *et al.* (2003) Validation of several established equations for resting metabolic rate in obese and nonobese people. *J Am Diet Assoc* **103**, 1152–1159.
- Phang PT, Rich T & Ronco J (1990) A validation and comparison study of two metabolic monitors. *JPEN J Parenter Enteral Nutr* **14**, 259–261.
- Madden AM, Mulrooney HM & Shah S (2016) Estimation of energy expenditure using prediction equations in overweight and obese adults: a systematic review. *J Hum Nutr Diet* **29**, 458–476.
- Weijjs PJ (2008) Validity of predictive equations for resting energy expenditure in US and Dutch overweight and obese class I and II adults aged 18–65 y. *Am J Clin Nutr* **88**, 959–970.
- Willis EA, Herrmann SD, Ptomey LT, *et al.* (2016) Predicting resting energy expenditure in young adults. *Obes Res Clin Pract* **10**, 304–314.