How valid are predictive equations to estimate resting energy expenditure in obese elderly?

Bachelor Nutrition and Dietetics
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Preface

This thesis was written to complete our study ‘Nutrition and Dietetics’ at the Amsterdam University of Applied Sciences. We wrote this thesis during the period February 2012 until June 2012.

We have collected data for the Muscle Preservation Study in the food science laboratory of the Amsterdam University of Applied Sciences. This data was partly used to write our thesis.

First and foremost we would like to give our special thanks to our supervisor Ir. AM Verreijen for all her support, assistance and useful advises. She always made time for us and was very interested in our thesis. We would also like to thank the principal investigator of the Muscle Preservation Study Dr. Ir. PJM Weijs for his vision and expertise.

We are also very grateful for the support and assistance of SE van der Plas, T Haarsma and our colleagues at the food science laboratory.

Amsterdam, June 8th 2012

E Ruigrok & JM Koopman
Abstract

Introduction:

Equations are often used to predict resting energy expenditure (REE), because measuring REE using indirect calorimetry (IC) is hardly feasible in practice. It is unknown whether predictive equations are valid to estimate REE in obese elderly. Therefore the aim of this thesis is to investigate the validity of predictive equations to estimate REE in obese elderly compared to IC.

Methods:

Thirty predictive equations for estimating REE were tested and included, of which twenty equations based on weight and ten equations based on fat free mass (FFM). REE was measured in 44 Dutch obese elderly (age ≥ 55 y) using IC. The validity of the predictive equations was determined by comparing predicted REE to measured REE by using the following statistical tests: the percentage of accurate predictions (within 10% of REE measured), root mean squared error (RMSE), concordance correlation coefficient (CCC) and the mean bias.

Results:

The three equations giving best results for predicting REE in obese elderly when comparing accurate predictions, RMSE, CCC and bias are the equations of Harris & Benedict 1984 (68% accurate predictions; RMSE 189 kcal/d; CCC 0.731; bias -72 kcal/d), Huang et al. (68% accurate predictions; RMSE 189 kcal/d; CCC 0.754; bias -50 kcal/d) and Korth et al. (66% accurate predictions; RMSE 168 kcal/d; CCC 0.769; bias 7 kcal/d). Of all equations in this study most formulas underestimate REE more often than they overestimate REE. Equations using FFM provided no advantage for accurately estimating REE compared to equations using weight only.

Conclusion:

The equations of Harris & Benedict 1984, Huang et al. and Korth et al. are accurate for predicting REE in obese elderly. The equations of Huang et al. and Korth et al. are probably not very well known in dietary practice. The Harris & Benedict 1984 equation however is one of the most commonly used formulas in dietary practice. It is therefore advisable to use the Harris & Benedict 1984 equation for predicting REE in obese elderly.

Keywords: resting energy expenditure; indirect calorimetry; predictive equations; formulas; obese elderly
Introduction

The prevalence of obesity has more than doubled worldwide since 1980. According to an estimation of the World Health Organization, over 200 million adult men and 300 million adult women suffered from obesity in 2008.1 At the moment the prevalence of obesity is a major health concern and the prevalence is still rising.1,2 The main causes are a decreased physical activity and an increased consumption of energy-dense foods.1 Energy-dense foods are available everywhere, are convenient, relatively cheap, and quite tasty.3,4 In The Netherlands almost 19% of the population currently suffers from obesity.5

Not only the prevalence of obesity is increasing, the number of elderly is also rising rapidly.6 In 2002 were approximately 605 million elderly worldwide. This is expected to grow to 1.2 billion in 2025.7 The age group older than sixty years is the fastest growing age group in most countries in the world.7 The causes are increasing life expectancy, lower birth rates and in The Netherlands the aging of the baby boomers who were born after World War II.8,9 Expected is that in Europe the proportion of people aged 65 and older will increase from 14% in 2010 to 25% in 2050.10,11 At the moment, the median age in Europe is already the highest in the world.10

Currently, more than fifteen percent of the Dutch population above 65 years old suffer from obesity and this percentage is still rising.12 Obesity is clearly related to metabolic risk factors for cardiovascular diseases, diabetes mellitus and some cancers.1,13-16 Obesity also plays a significant role in non-fatal physical disability in the elderly.1,16 Voluntary weight loss in obese elderly leads to better metabolic control with better glucose regulation, lower blood pressure, better pulmonary function and improved functional ability.13,15.

In The Netherlands, a CBO guideline is developed for the treatment of obese adults. This guideline advises an energy intake of 600 kilocalories less than the daily energy expenditure.17 The daily energy expenditure can be calculated by multiplying resting energy expenditure (REE) by physical activity level. REE is the amount of energy the body needs for vital functions such as breathing, regulating body temperature, blood circulation, digestion and absorption of food.18 The golden standard for measuring REE is the indirect calorimetry (IC).19-21 It measures oxygen consumption and carbon dioxide production.22 By using the Weir formula, REE can be calculated.23

However, there are some disadvantages to measuring REE with the IC. At first, the dietetic institution needs an indirect calorimeter which is very expensive. Secondly, the client is not allowed to eat for at least four hours and exercise for at least 24 hours before the measurement. Thirdly, the measurement is time consuming and the indirect calorimeter can only be operated by trained personnel.24,25 Since January 2012 dietary counseling is no longer being reimbursed by basic health insurance in The Netherlands.26 This makes measurements with an indirect calorimeter extremely expensive for clients. Therefore, the IC is not feasible in practice for the treatment of obese elderly. To estimate the resting energy expenditure in a cheap and easy way, energy formulas are often used.22,24,25

REE is different for obese elderly as compared to normal weight adults: obese adults have a higher total REE, but the REE per kg of body weight is lower than in normal weight adults.25 This is due to a higher percentage of body fat which has a low metabolic rate.27-33 In elderly REE is lower than in adults.6,25,34,35 REE decreases with aging because fat free mass (mainly muscle) declines.6 After the age of 20 REE decreases approximately 1 or 2% per decade.36

Most equations are developed and tested in healthy, normal weight, adult subjects.22,25 In obese people and elderly, equations are probably less accurate.20,22,25

In obese adults, most predictive equations tend to underestimate REE.22 The Mifflin equation37 is the most accurate equation to estimate REE in overweight or obese adults in the USA.20,22,25,38 For the Dutch overweight or obese adults however, no accurate equation has been published. Weijs et al.39 have developed an equation that is accurate in 81% of Dutch adult obese subjects, but this equation has yet to be published.39 Although the Mifflin equation37 is accurate in overweight or obese Americans, the Mifflin equations tends to underestimate the REE in American elderly.25
In American adults the Harris-Benedict 1919\textsuperscript{40} equation is accurate for people with a normal bodyweight, but also for the overweight and obese.\textsuperscript{23} The Harris-Benedict 1919\textsuperscript{40} equation is also seems accurate in elderly people.\textsuperscript{25,41} Currently it is unknown whether predictive equations are valid to estimate REE in obese elderly.\textsuperscript{20} Therefore the aim of this thesis is to investigate the validity of predictive equations to estimate REE in obese elderly compared to indirect calorimetry.
**Methods**

In this study, baseline data from the Muscle Preservation Study (MPS) were used. The MPS investigates the superiority of a specialized oral nutritional supplement on preservation of muscle mass in Dutch obese elderly during a weight loss program. The participants were measured three times during the study: at baseline, after seven weeks and after thirteen weeks. We only used data from the baseline measurements. Measurements were conducted between March 1st 2011 and February 24th 2012 at the laboratory of the Amsterdam University of Applied Sciences. The study protocol of the MPS was approved by the Medical Ethical Committee of the VU medical centre.

**Subjects**

Obese elderly were recruited for participation by the distribution of flyers to citizens in district Amsterdam Nieuw West. Flyers and posters were placed at general practices, community centres and supermarkets. Additionally an advertisement was placed in the local newspapers Westerpost and Gazet.

Main inclusion criteria were: age 55-85 years, if women: postmenopausal, healthy, obese: BMI ≥30 kg/m² or BMI ≥28 kg/m² and waist circumference ≥88 cm (women) or ≥102 cm (men). Main exclusion criteria were: Participation in a weight loss diet and/or participation in a resistance exercise program three months before the start of the study and during the study. The complete inclusion and exclusion criteria of the Muscle Preservation Study can be found in Appendix I.

All subjects were screened within three weeks before the baseline measurement. All subjects gave informed consent.

**Measurements**

The following data were collected: gender, ethnicity, age in years, height in cm measured with a wall mounted stadiometer (Seca 222, Seca, Hamburg, Germany) to the nearest cm, weight measured in kg by using the BodPod precision scale (Life Measurement Inc, Concord, CA, USA) to the nearest 0.001 kg, fat mass (FM) and fat free mass (FFM) in kg measured by using the BodPod system (Life Measurement Inc, Concord, CA, USA) and REE in kcal/d measured by using IC with ventilated hood system (Vmax Encore n29; Viasys Healthcare, Houten, The Netherlands).

Measurements with BodPod and IC were performed on the same day. To minimize the thermic effect of food, the subjects were measured after a 5 h fast. Low caloric beverages were allowed until one hour before the measurement. The subjects had not been physically active for at least 12 hours before the measurement.

**BodPod**

Air displacement plethysmography was used to measure body composition by using the BodPod sytem. The BodPod system was calibrated every morning and additionally before each measurement. During the measurement subjects had to wear tightly fitting underwear or bathing clothes and a swim cap. They were not allowed to wear jewellery.

Each subject was measured two times. If the difference in body volume between the two measurements was less than 0.2 L, the measurement was adopted. The average data of two measurements were used.
Indirect calorimetry

REE was measured using the golden standard: the IC. The measurements were performed with a ventilated hood system. Before using, the Vmax was calibrated each day for volume with two standard gasses. The Vmax also automatically recalibrated every five minutes.

During the measurement, the subjects were in a supine position and in a quiet environment at room temperature (20°C -25°C). Falling asleep and coughing were not allowed. The ventilated hood was placed over the head and sealed from outside air. The IC measures oxygen consumption and carbon dioxide production. The measurement took twenty minutes. The steady state period of the measurement was selected according to the procedures of the Vmax system. A steady state period is a ≥ five minute period in which oxygen consumption and carbon dioxide production change by <10%. The Vmax system calculated REE for a 24h period (kcal/d) by using the Weir formula.

Selection of predictive equations

Predictive equations were selected using the US National Library of Medicine's PubMed database. Used keywords were: ‘resting energy expenditure’, ‘resting metabolic rate’, ‘predictive equation(s)’, and ‘indirect calorimetry’. The additional terms were ‘formula’, ‘estimate’, ‘predict’, ‘obesity’, and ‘obese’. All terms were used in every possible combination. Limitations placed on initial search strategies were: English language, adults (≥18 y) and human subjects.

In 2008 Weijs studied which predictive equations are most valid for predicting REE in US and Dutch overweight and obese adults aged 18-65 years old. The same formulas as in Weijs 2008 were also used in this study. Additionally three more recent formulas were included (Lazzer et al. 2010, Lazzer et al. 2010 FFM and an unpublished equation of Weijs et al. developed in 2010). All formulas were selected by the following inclusion criteria: suitable for every age group, n ≥ 50. Exclusion criteria were as follows: formulas developed by using a study population aged <18y, (critically ill) patients, specific ethnic groups, small sample size (n≤50).

Thirty predictive equations were included in this study of which 20 equations based on weight (Table 1A) and 10 equations based on FFM (Table 1B).
Statistics

The following statistical tests were used to evaluate the validity of the different predictive equations using the data of the IC as reference: bias (mean difference), root mean squared error (RMSE), Bland-Altman plots, concordance correlation coefficient (CCC) and the percentage of accurate predictions. Data were analysed by using Predictive Analytics Software, former SPSS (PASW statistics, version 18.0.0, SPSS Inc., Chicago, IL). A P-value of <0.05 was considered statistically significant. The RMSE and percentage of accurate predictions were calculated by using MS Excel 2007. To calculate Bland-Altman and CCC MedCalc software was used (MedCalc, version 12.1.1, Mariakerke, Belgium).

Bias and RMSE

The bias is the mean difference between REE predicted by formula and REE measured by IC. The bias is a measure of accuracy in groups, but large individual errors can be averaged out. To investigate the accuracy on an individual level, the RMSE was used. The RMSE is calculated as follows: individual differences between predicted REE and measured REE were squared. These squared errors were summated. The root of the sum of squared errors was taken and divided by n. The lower the RMSE, the more accurate the formula.

Bland-Altman

A Bland-Altman plot visualises the difference between predicted REE and measured REE. The x-axis represents REE measured by IC. The y-axis represents the difference between REE predicted by formula and REE measured by IC. In a Bland-Altman plot every dot represents a subject. If the dots are located at y=0 this means there is no difference between the formula and the IC. If the dots are located at y>0, this means that the formula overestimates REE. If the dots are located at y<0, this means that the formula underestimates REE. The mean of the differences is the bias. The bias is drawn as a line in the Bland-Altman plot. An accurate formula had a bias line close to y=0. The limits of agreement are two lines located at +1.96 and -1.96 times the standard deviation of the mean difference. Approximately 95% of the data are located between the limits of agreement. An accurate formula has narrow limits of agreements.

Concordance correlation coefficient

The CCC was used to measure precision and accuracy. The CCC differs from the Pearson's correlation coefficient. The Pearson's correlation coefficient measures only the correlation between REE predicted and REE measured, while the CCC also takes the deviation from the x=y line (Cb) into account. CCC is the product of the Pearson's correlation coefficient and the Cb, in which the Pearson's correlation coefficient represents the precision and the Cb represents the accuracy. CCC = 1 means that the formula predicts REE perfectly. CCC = 0 means that the formula is not accurate at all.

Percentage of accurate predictions

An accurate prediction in a subject is defined as a difference of +/- \leq 10% between measured REE and predicted REE. To examine the accuracy of a formula, the percentage of accurate predictions was calculated. The accuracy of all included formulas were compared to determine the most accurate equation. A difference of <10% was classified as an underprediction. A difference of >10% was considered an overprediction. Similar studies have also used this method to examine accuracy.
Table 1A: Predictive equations for resting energy expenditure using gender, age, weight, height and/or BMI.

<table>
<thead>
<tr>
<th>Author(s) and year of publication</th>
<th>Subjects</th>
<th>Predictive equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bernstein et al. 1983</td>
<td>n = 202</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48 M</td>
<td>M: Mean age 40 ±13 y</td>
</tr>
<tr>
<td></td>
<td>154 F</td>
<td>F: Mean age 39 ± 12 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight 60-204 kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean weight 103 kg ± 26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M: 11,02 × WT + 10,23 × HTCM – 5,8 × AGE – 1032 = kcal/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F: 7,48 × WT – 0,42 × HTCM – 3 × AGE + 844= kcal/d</td>
</tr>
<tr>
<td>FAO/WHO/UNU 1985</td>
<td>n ≈11 000</td>
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<tr>
<td></td>
<td>30-82 y</td>
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<tr>
<td></td>
<td></td>
<td>Equations using weight only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M 30-60 y: 11,6 × WT + 879 = kcal/d</td>
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<tr>
<td></td>
<td></td>
<td>M ≥60 y: 13,5 × WT + 487 = kcal/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F 30-60 y: 8,7 × WT + 829 = kcal/d</td>
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<tr>
<td></td>
<td></td>
<td>F ≥60 y: 10,5 × WT + 596 = kcal/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Equations using weight and height</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M 30-60 y: 11,3 × WT – 16 × HTM + 901 = kcal/d</td>
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<tr>
<td></td>
<td></td>
<td>M ≥60 y: 8,8 × WT + 1128 × HTM – 1071 = kcal/d</td>
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<tr>
<td></td>
<td></td>
<td>F 30-60 y: 8,7 × WT – 25 × HTM + 865 = kcal/d</td>
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<tr>
<td></td>
<td></td>
<td>F ≥60 y: 9,2 × WT + 637 × HTM - 302 = kcal/d</td>
</tr>
<tr>
<td>Harris and Benedict 1919</td>
<td>n = 239</td>
<td></td>
</tr>
<tr>
<td></td>
<td>136 M</td>
<td>M: Mean age 27 ± 9 y</td>
</tr>
<tr>
<td></td>
<td>103 F</td>
<td>F: 15-74 y Mean age 31 ± 14 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M: 11,6 × WT + 879 = kcal/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F: 7,48 × WT – 0,42 × HTCM – 3 × AGE + 844= kcal/d</td>
</tr>
<tr>
<td>Harris and Benedict equation re-evaluated by Roza et al. 1984</td>
<td>n = 337</td>
<td></td>
</tr>
<tr>
<td></td>
<td>168 M</td>
<td>M: Mean age 30 ± 14 y</td>
</tr>
<tr>
<td></td>
<td>169 F</td>
<td>F: Mean age 44 ± 22 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M: 11,6 × WT + 879 = kcal/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F: 7,48 × WT – 0,42 × HTCM – 3 × AGE + 844= kcal/d</td>
</tr>
<tr>
<td>Henry 2005</td>
<td>n = 2901</td>
<td></td>
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<tr>
<td></td>
<td>1544 M</td>
<td>M: Mean age 51 y</td>
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<tr>
<td></td>
<td>1357 F</td>
<td>F: Mean age 49 y</td>
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<tr>
<td></td>
<td></td>
<td>M: Mean BMI 23 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>F: Mean BMI 24 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>Equations using weight only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M 30-60 y: 0,0592 × WT + 2,48 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>M ≥60 y: 0,0563 × WT + 2,15 = MJ/d</td>
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<td></td>
<td>F 30-60 y: 0,0407 × WT + 2,9 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>F ≥60 y: 0,0424 × WT + 2,38 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>Equations using weight and height</td>
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<tr>
<td></td>
<td></td>
<td>M 30-60 y: 0,0476 × WT + 2,26 × HTM – 0,574 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>M ≥60 y: 0,0478 × WT + 2,26 × HTM – 1,07 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>F 30-60 y: 0,0342 × WT + 2,1 × HTM – 0,0486 = MJ/d</td>
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<tr>
<td></td>
<td></td>
<td>F ≥60 y: 0,0356 × WT + 1,76 × HTM + 0,0448 = MJ/d</td>
</tr>
<tr>
<td>Huang et al. 2004</td>
<td>n = 1088</td>
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<tr>
<td></td>
<td>279 M</td>
<td>Mean age 45 ± 13 y</td>
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<tr>
<td></td>
<td>759 F</td>
<td>Mean BMI 35 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>Mean BMI 46 ± 8 kg/m^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10,158 × WT + 3,933 × HTCM – 1,44 × AGE + 273,821 × GENDER + 60,655 = kcal/d</td>
</tr>
<tr>
<td>Korth et al. 2007</td>
<td>n = 104</td>
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<tr>
<td></td>
<td>50 M</td>
<td>20-70 y</td>
</tr>
<tr>
<td></td>
<td>54 F</td>
<td>M: Mean age 37 ± 15 y</td>
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<tr>
<td></td>
<td></td>
<td>F: Mean age 35 ± 15 y</td>
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<tr>
<td></td>
<td></td>
<td>BMI 18-41 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>M: Mean BMI 26 ± 4 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>F: Mean BMI 26 ± 4 kg/m^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41,5 × WT + 35,0 × HTCM + 1107,4 × GENDER – 19,1 × AGE – 1731,2 = kJ/d</td>
</tr>
<tr>
<td>Lazzer et al. 2007</td>
<td>n = 346</td>
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<tr>
<td></td>
<td>164 M</td>
<td>M: 20-65 y</td>
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<tr>
<td></td>
<td>182 F</td>
<td>F:19-60 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M: Mean BMI 45 kg/m^2</td>
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<td></td>
<td></td>
<td>F: Mean BMI 46 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>M: 0,048 × WT + 4,655 × HTM –0,020 × AGE – 3,605 = MJ/d</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F: 0,042 × WT + 3,619 × HTM – 2,678 = MJ/d</td>
</tr>
<tr>
<td>Lazzer et al. 2010</td>
<td>n = 7368</td>
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<tr>
<td></td>
<td>2000 M</td>
<td>18-74 y</td>
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<tr>
<td></td>
<td>5368 F</td>
<td>M: Mean age 46 ± 14 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F: Mean age 48 ± 14 y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M: Mean BMI 42 ± 7 kg/m^2</td>
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<tr>
<td></td>
<td></td>
<td>F:Mean BMI 42 ± 7 kg/m^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46 × WT – 14 × AGE + 1,14 × GENDER + 3,252 = kJ/d</td>
</tr>
<tr>
<td>Study</td>
<td>n</td>
<td>Male</td>
</tr>
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<td>------------------------------</td>
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<tr>
<td>Livingston and Kohlstadt</td>
<td>655</td>
<td>229</td>
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<td>De Lorenzo et al.</td>
<td>320</td>
<td>127</td>
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<td>Mifflin et al.</td>
<td>498</td>
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<td>Müller et al.</td>
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<td>1027</td>
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<td>Owen et al.</td>
<td>104</td>
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<td>Schofield</td>
<td>1106</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Weijs et al.</td>
<td>136</td>
<td>41</td>
</tr>
</tbody>
</table>

Data are displayed as mean ± standard deviation; M = male; F = female; D = diabetic; ND = non diabetic; WT = weight in kg; HTCM = height in cm; HTM = height in m; GENDER: M = 1 F = 0; AGE = age in years
Table 1B: Predictive equations for resting energy expenditure using gender, age, FFM and/or FM.

<table>
<thead>
<tr>
<th>Author(s) and year of publication</th>
<th>N</th>
<th>Age</th>
<th>Weight or BMI</th>
<th>Predictive equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bernstein et al. 1983</td>
<td>202</td>
<td>40 ±13 y</td>
<td>60-204 kg</td>
<td>19.02 × FFM + 3.72 × FM – 1.55 × AGE + 236.7 = kcal/d</td>
</tr>
<tr>
<td>Huang et al. 2004</td>
<td>1088</td>
<td>45 ± 13 y</td>
<td>103 kg ± 26</td>
<td>14.188 × FFM + 9.367 × FM – 1.515 × AGE + 220.863 × GENDER + 521,995 = kcal/d</td>
</tr>
<tr>
<td>Johnstone et al. 2006</td>
<td>150</td>
<td>47 ± 10 y</td>
<td>85 ± 18 kg</td>
<td>90,2 × FFM + 31,6 × FM – 12,2 × AGE + 1613 = kJ/d</td>
</tr>
<tr>
<td>Korth et al. 2007</td>
<td>104</td>
<td>35 ±15 y</td>
<td>69 ± 17 kg</td>
<td>108,1 × FFM + 1231 =kJ/d</td>
</tr>
<tr>
<td>Lazzer et al. 2007</td>
<td>346</td>
<td>20-65 y</td>
<td>M: 45 kg/m²</td>
<td>M: 0.081 × FFM + 0.049 × FM – 0.019 × AGE – 2.194 = MJ/d</td>
</tr>
<tr>
<td>Lazzer et al. 2010</td>
<td>7368</td>
<td>18-74 y</td>
<td>M: 42 ± 7 kg/m²</td>
<td>82 × FFM – 10 × AGE – 44 × GENDER + 3.517 = kJ/d</td>
</tr>
<tr>
<td>Mifflin et al. 1990</td>
<td>498</td>
<td>19-78 y</td>
<td>Mean BMI 46 ± 14 y</td>
<td>19,7 × FFM + 413 = kcal/d</td>
</tr>
<tr>
<td>Müller et al. 2004</td>
<td>2528</td>
<td>5-91 y</td>
<td>Mean BMI 27 kg/m²</td>
<td>Equation suitable for everyone 0,05192 × FFM + 0,04036 × FM + 0,869 × GENDER – 0,01181 × AGE + 2,992 = MJ/d</td>
</tr>
<tr>
<td>Owen et al. 1986-1987</td>
<td>104</td>
<td>18-82 y</td>
<td>M: 20-59 kg/m²</td>
<td>Equation suitable for BMI 25-30 0,03776 × FFM + 0,03013 × FM + 0,93 × GENDER – 0,01196 × AGE + 3,928 = MJ/d</td>
</tr>
<tr>
<td></td>
<td>60 M 44 F</td>
<td>Mean age 38 ± 16 y</td>
<td>M: 22.3 × FFM + 290 = kcal/d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1501 F</td>
<td>Mean age 35 ± 12 y</td>
<td>F: 19.7 × FFM + 334 = kcal/d</td>
<td></td>
</tr>
</tbody>
</table>

Data are displayed as mean ± standard deviation; M = male; F = female; D = diabetic; ND = non diabetic; WT = weight in kg; HTCM = height in cm; HTM = height in m; GENDER: M = 1 F = 0; AGE = age in years; FFM = fat free mass; FM = fat mass
Results

Subject characteristics

44 subjects were included in this study (Figure 1), 18 were male and 26 were female. Table 2 shows body composition, anthropometric and REE data of all subjects and for men and women separately.

Males differ significantly from women on weight, height, fat weight, lean weight and REE IC. Women were shorter (p<0.001), lighter (p=0.002), had more FM (p=0.012), less FFM (p<0.001) and a lower REE (P<0.001) than males.

82% of the subjects were of Dutch origin. The country of birth of other subjects was Suriname (7%), Netherlands Antilles (2%), Iran (2%), Egypt (2%), Croatia (2%) and South Africa (2%).

Table 2: Subject characteristics: body composition, anthropometric data and resting energy expenditure

<table>
<thead>
<tr>
<th></th>
<th>Total (n=45)</th>
<th></th>
<th>Women (n=26)</th>
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<th>P-value</th>
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<tr>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>62 ± 5</td>
<td>55-77</td>
<td>64 ± 5</td>
<td>61 ± 5</td>
<td>0.126</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>95.4 ± 12.2</td>
<td>74.3-124.3</td>
<td>102.0 ± 8.7</td>
<td>90.9 ± 12.3</td>
<td>0.002*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170 ± 9</td>
<td>154-188</td>
<td>177 ± 7</td>
<td>165 ± 6</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>33.2 ± 4.6</td>
<td>28.1-51.3</td>
<td>32.7 ± 2.4</td>
<td>33.5 ± 5.7</td>
<td>0.508</td>
</tr>
<tr>
<td>FM (kg)</td>
<td>40.1 ± 10.1</td>
<td>21.9-77.8</td>
<td>35.6 ± 6.4</td>
<td>43.2 ± 11.1</td>
<td>0.012*</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>55.3 ± 10.9</td>
<td>39.0-78.7</td>
<td>66.4 ± 6.4</td>
<td>47.6 ± 5.3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>REE IC (kcal)</td>
<td>1767 ± 296</td>
<td>1299-2462</td>
<td>2014 ± 239</td>
<td>1601 ± 200</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

Data are displayed as means ± standard deviation
REE = resting energy expenditure; FM = fat mass; FFM = fat free mass; REE IC = resting energy expenditure measured by indirect calorimetry
* Significant difference between males and females (P <0.05)

Results on validity of the predictive equations are shown in Table 3A and 3B. Data are displayed as: REE in kcal/d, bias in kcal/d, maximum negative error (underprediction) and maximum positive error (overprediction) in kcal/d, RMSE in kcal/d and percentage of accurate -, under - and overpredictions.
### Table 3A: Analysis of predictive equations based on bodyweight

<table>
<thead>
<tr>
<th>Predictive equation</th>
<th>Mean REE</th>
<th>SD</th>
<th>Bias</th>
<th>Maximum negative error</th>
<th>Maximum positive error</th>
<th>RMSE</th>
<th>CCC</th>
<th>Accurate predictions</th>
<th>Under predictions</th>
<th>Over predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>REE IC</td>
<td>1770</td>
<td>296</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bernstein et al. 1983 “</td>
<td>1377</td>
<td>176</td>
<td>-303</td>
<td>-224</td>
<td>371</td>
<td>441</td>
<td>0.282</td>
<td>9</td>
<td>91</td>
<td>0</td>
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<tr>
<td>FAO/WHO/UNU 1985 weight “</td>
<td>1708</td>
<td>203</td>
<td>-62</td>
<td>-331</td>
<td>399</td>
<td>194</td>
<td>0.709</td>
<td>59</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>FAO/WHO/UNU 1985 weight and height “</td>
<td>1705</td>
<td>187</td>
<td>-65</td>
<td>-310</td>
<td>365</td>
<td>202</td>
<td>0.673</td>
<td>61</td>
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<td>9</td>
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<tr>
<td>Harris and Benedict 1919 “</td>
<td>1698</td>
<td>228</td>
<td>-72</td>
<td>-318</td>
<td>416</td>
<td>195</td>
<td>0.731</td>
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<td>11</td>
</tr>
<tr>
<td>Harris and Benedict 1954 “</td>
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<td>-52</td>
<td>-320</td>
<td>409</td>
<td>189</td>
<td>0.740</td>
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<td>Henry 1955 weight “</td>
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<td>406</td>
<td>201</td>
<td>0.721</td>
<td>59</td>
<td>30</td>
<td>11</td>
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<td>Henry 2055 weight and height “</td>
<td>1665</td>
<td>219</td>
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<td>-353</td>
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<td>212</td>
<td>0.687</td>
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<td>Huang et al. 2004 “</td>
<td>1720</td>
<td>243</td>
<td>-50</td>
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<td>399</td>
<td>189</td>
<td>0.754</td>
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<tr>
<td>Korth et al. 2007 “</td>
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<td>262</td>
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<td>460</td>
<td>188</td>
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<tr>
<td>Lazzer et al. 2007 “</td>
<td>1811</td>
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<td>41</td>
<td>-330</td>
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<td>204</td>
<td>0.664</td>
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<td>36</td>
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<tr>
<td>Lazzer et al. 2010 “</td>
<td>841</td>
<td>132</td>
<td>-929</td>
<td>-224</td>
<td>332</td>
<td>957</td>
<td>0.050</td>
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<tr>
<td>Livingston and Kohlstedt 2005 “</td>
<td>1591</td>
<td>193</td>
<td>-179</td>
<td>-276</td>
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<td>256</td>
<td>0.576</td>
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<tr>
<td>De Lorenzo et al. 2001 “</td>
<td>1743</td>
<td>211</td>
<td>-27</td>
<td>-335</td>
<td>375</td>
<td>188</td>
<td>0.728</td>
<td>64</td>
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<tr>
<td>Mifflin et al. 1990 “</td>
<td>1615</td>
<td>207</td>
<td>-155</td>
<td>-335</td>
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<td>0.611</td>
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<td>Müller et al. 2004 “</td>
<td>1721</td>
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<td>-49</td>
<td>-327</td>
<td>361</td>
<td>190</td>
<td>0.731</td>
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<td>Müller et al. 2004 BMI “</td>
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<td>222</td>
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<td>Owen et al. 1986-1987 “</td>
<td>1641</td>
<td>251</td>
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<td>-312</td>
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<td>-314</td>
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<td>Weijs et al. 2010 “</td>
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<td>248</td>
<td>107</td>
<td>-390</td>
<td>467</td>
<td>218</td>
<td>0.697</td>
<td>52</td>
<td>7</td>
<td>41</td>
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</table>

REE = resting energy expenditure; SD = standard deviation; RMSE = root mean squared error; CCC = concordance correlation coefficient; REE IC = resting energy expenditure measured by indirect calorimetry; BMI = body mass index.

### Table 3B: Analysis of predictive equations based on fat free mass

<table>
<thead>
<tr>
<th>Predictive equation</th>
<th>Mean REE</th>
<th>SD</th>
<th>Bias</th>
<th>Maximum negative error</th>
<th>Maximum positive error</th>
<th>RMSE</th>
<th>CCC</th>
<th>Accurate predictions</th>
<th>Under predictions</th>
<th>Over predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>Kcal/d</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>REE IC</td>
<td>1770</td>
<td>296</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Bernstein et al. 1983 FFM “</td>
<td>1341</td>
<td>197</td>
<td>-429</td>
<td>-310</td>
<td>406</td>
<td>466</td>
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<tr>
<td>Huang et al. 2004 FFM “</td>
<td>1678</td>
<td>236</td>
<td>-92</td>
<td>-350</td>
<td>394</td>
<td>198</td>
<td>0.736</td>
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<td>32</td>
<td>9</td>
</tr>
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<td>Johnstone et al. 2006 FFM “</td>
<td>1699</td>
<td>220</td>
<td>-71</td>
<td>-353</td>
<td>436</td>
<td>190</td>
<td>0.738</td>
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<td>34</td>
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<td>Korth et al. 2007 FFM “</td>
<td>1723</td>
<td>283</td>
<td>-47</td>
<td>-420</td>
<td>605</td>
<td>198</td>
<td>0.764</td>
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<td>1316</td>
<td>388</td>
<td>-454</td>
<td>-697</td>
<td>714</td>
<td>741</td>
<td>-0.250</td>
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<td>Lazzer et al. 2010 FFM “</td>
<td>931</td>
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<td>-639</td>
<td>-318</td>
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<td>Mifflin et al. 1990 FFM “</td>
<td>1502</td>
<td>215</td>
<td>-269</td>
<td>-320</td>
<td>462</td>
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<td>1697</td>
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<td>0.723</td>
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<td>27</td>
<td>14</td>
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<td>Müller et al. 2004 FFM BMI “</td>
<td>1678</td>
<td>216</td>
<td>-92</td>
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<td>Owen et al. 1986-1987 FFM “</td>
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<td>275</td>
<td>-294</td>
<td>-373</td>
<td>570</td>
<td>349</td>
<td>0.505</td>
<td>25</td>
<td>75</td>
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</tbody>
</table>

REE = resting energy expenditure; SD = standard deviation; RMSE = root mean squared error; CCC = concordance correlation coefficient; REE IC = resting energy expenditure measured by indirect calorimetry; FFM = fat free mass; BMI = body mass index.
Figure 2A: Percentage accurate resting energy expenditure (REE) prediction (within 10% of measured REE)
FFM= fat free mass; W= weight; H= height; BMI= body mass index
Equations are ranked from high accuracy to low percentage accuracy. The three equations with the highest percentage accurate predictions are coloured pink.

Figure 2B: Root mean squared error (RMSE) in kcal/day
FFM= fat free mass; W= weight; H= height; BMI= body mass index
Equations are ranked from low RMSE to high RMSE. The three equations with the lowest RMSE are coloured pink.
Figure 2C: Concordance correlation coefficient (CCC). FFM= fat free mass; W= weight; H= height; BMI= body mass index. Equations are ranked from high CCC to low CCC. The three equations with the highest CCC are coloured pink.

Figure 2D: Bias in kcal/day. FFM= fat free mass; W= weight; H= height; BMI= body mass index. Equations are ranked from high bias to low bias. The three equations a bias closest to zero are coloured pink.
Predictive equations compared to indirect calorimetry

The comparison between REE predicted by equations and REE measured by IC is shown in Table 3A and Table 3B.

The bias varied from -929 until 107 kcal/d. The largest negative error was -697 kcal/d. The largest positive error was 714 kcal/d. The RMSE varied from 188 until 957 kcal/d. CCC varied from -0.250 until 0.769. The highest percentage accurate predictions was 68%. The lowest percentage accurate predictions was 0%. Most formulas underestimate REE more often than they overestimate REE.

The predictive equations with the highest percentage of accurate predictions are Harris & Benedict 1984 with 68%, Huang et al. with 68% and Korth et al. with 66% respectively. In all other formulas the percentage of accurate predictions were ≤ 64%. The equations of Lazzer et al. 2010 did not predict REE accurately in any subject (Figure 2A).

RMSE’s were the lowest in the formulas of Korth et al. and De Lorenzo et al., both 188 kcal/d. The equations of Harris & Benedict 1984 and Huang et al. had the second lowest RMSE’s, both 189 kcal/d (Figure 2B). CCC was the highest in the formula of Korth et al. with a CCC of 0.769 (Figure 2C). The bias was remarkably low in the Korth et al. equation with a bias of only 7 kcal/d (Figure 2D).

The FFM equations had a lower percentage of accurate predictions than the weight and height equations. The FFM equations with the highest percentage of accurate predictions were Müller et al. FFM with BMI, Müller et al. FFM and Huang et al. FFM, with 61%, 59% and 59% respectively. In all other FFM equations accurate predictions were ≤ 57%. The FFM equations of Bernstein et al. and Lazzer et al. did not predict REE accurately in any subject, they show 100% underprediction. All FFM equations underestimate REE more often than they overestimate REE.

Bland-Altman plots of the Harris & Benedict 1984, Huang et al. and Korth et al. equations are shown in Figure 3A,3B,3C. Bland-Altman plots of all other formulas are shown in Appendix II.
Figure 3A: Bland-Altman plot of the Harris & Benedict 1984 equation in kcal/day

Figure 3B: Bland-Altman plot of the Huang et al. equation in kcal/day

Figure 3C: Bland-Altman plot of the Korth et al. equation in kcal/day
Discussion

This study shows that the three equations giving best results for predicting REE in obese elderly based on percentage accurate predictions, RMSE, CCC and bias are the equations of Harris & Benedict 198451, Huang et al.53 and Korth et al.54 Of all equations in this study most formulas underestimate REE more often than they overestimate REE. Equations using FFM provided no advantage for accurately estimating REE compared to equations using weight only. The Harris and Benedict 198451, Huang et al.53 and Korth et al.54 equations all have a RMSE of ≥188 kcal/d. For dieticians this means a deviation of approximately one bottle of standard enteral formula a day.64

The equations of Harris & Benedict51 and Huang et al.53 had the highest percentages of accurate predictions, 68%. The Huang et al.53 equation is developed on a study group of obese adults (age 45 ± 13 y). The mean BMI of the study group was 46 ± 8 kg/m². The results of our study show that the equation of Huang et al.53 is suitable for obese elderly. This result could be explained by the obese study group of Huang et al.53. The Harris & Benedict 1984 equation was based on a study group of normal weight adults (age men 30 ± 14 y; age women 44 ± 12 y). The Korth et al.54 equation, which had 66% accurate predictions, was based on a study group of normal weight and overweight adults (age men 37 ± 15 y; age women 35 ± 15 y). The mean BMI of the study group was 26 ± 4 kg/m². Hence, it is remarkable that the Harris & Benedict 198451 and the Korth et al.54 equations predict REE well in obese elderly.

Our results are comparable to other studies. In a similar study of Wejs 200822, who studied the validity of predictive equations in obese Dutch adults, the Korth et al.54 equation had the highest percentage of accurate predictions with 67%. The Harris & Benedict 198451 equation estimated fairly well with 63% accurate predictions. The Huang et al.53 equation however performed poorer with 49% accuracy. The bias, CCC and RMSE of the Korth et al.54, Harris & Benedict 198451 and Huang et al.53 equations were ranked in the same way (bias: -0.9%, -3.8%, -8.1%; CCC: 0.792, 0.753, 0.683; RMSE: 198, 211, 251 in kcal/d, respectively). Wejs & Vasant65 showed that the Huang et al.53 equation is accurate in normal weight to morbid obese Belgium women with 71% accuracy. The Harris & Benedict 198451 equation also gave accurate results with 68% accuracy. The formula of Korth et al.54 was accurate in 63%. The bias and RMSE of the Huang et al.53, Harris & Benedict 198451 and Korth et al.54 equations were ranked in the same way (bias: -1.7%, 3.0%, 4.5%; RMSE: 168, 169, 179 in kcal/d, respectively).

Hofsteenge et al.66 studied the validity of predictive equations in obese adolescents. In this study the equation of Korth et al.54 gave accurate predictions in 72% of all subjects with a bias of 3.4% and a RMSE of 187 kcal/d. Harris & Benedict 198451 equation was accurate in 70%, had a bias of -0.1% and a RMSE of 186 kcal/d. The Huang et al.53 equation was less accurate with 55%, a bias of -6.9% and a RMSE of 229 kcal/d. However, comparing Hofsteenge et al.66 to our study is difficult because of the major difference in age between obese adolescents and obese elderly.

Many studies show that equations using FFM do not provide any advantage over equations using weight. Authors of equations using weight often also made an equation using FFM. The equations using FFM usually had a lower percentage of accurate predictions and a slightly higher RMSE.22,65-68 This confirms our findings.

There are also differences between this study and other studies. In other studies, the Mifflin equation turned out to be the most accurate equation for predicting REE in overweight and obese subjects.20,22,25,38,67,68 Most of these studies are performed on an American study group. Contrary to other studies, this study used only Dutch subjects. Furthermore, this study used elderly subjects while other studies used adults. This could explain the different results. The Mifflin equation is known to underestimate REE in elderly25. In our study, the Mifflin equation underestimates approximately 155 kcal. Compared to the other equations in this study, a bias of -155 kcal/d is relatively large.

There are only a few studies which examined the validity of Harris & Benedict 198451 equation, the Huang et al.53 equation and/or the Korth et al.54 equation. This makes it difficult to compare our results to other studies. Most validation studies examined the validity of the original Harris & Benedict 191940 equation and a few other commonly used equations. The original Harris & Benedict 191940 equation often performed well in elderly and in obese adults.25,41,70,71 The Harris & Benedict 198451 equation was based on the same study group as the original Harris & Benedict 191940 equation, however 98 additional subjects were added.51
Incorrect equation

The equation of Lazzer et al. 2007 using FFM gives extremely inaccurate results. The CCC was exceptionally low, -0.250. The equation did not predict REE accurately in any male subject, in women however the equation had 58% accurate predictions. The lectureship weight management of the Hogeschool van Amsterdam, contacted sir S. Lazzer to ask for an explanation. The published article of Lazzer et al. in 2007 appeared to contain a publication error in the FFM equation for males. The formula developed by Lazzer et al. using FFM for males which should have been published is REE (MJ/d) = 0.081 * FFM + 0.049 * FM - 0.019 * AGE + 2.194. This corrected formula preformed well with 57% accurate predictions, a RMSE of 181 kcal/d, a CCC of 0.753 and a bias of -25 kcal/d. In this study only equation as published (incorrect equation) was included.

Two other equations of sir S. Lazzer (Lazzer et al. 2010 and Lazzer et al. 2010 using FFM) also gave inaccurate results. It is unknown whether these equations also contain publication errors.

Limitations and strengths

This study has a couple of strengths and limitations. A limitation of this study is the small number of subjects. The study started with 82 subjects. Two subjects dropped out before the end of the study. The 35 subjects were removed from the dataset mainly because of measurement errors like a to large difference between two BodPod measurements. Also some subjects did not fast or worn clothes that were not tightly fitting which could influence our results. A few subjects were claustrophobic making it impossible to conduct IC or BodPod measurements. Only 44 subjects were actually included. This means that each included subject accounts for approximately 2% in this study. A larger study group would give a more reliable result. However, a reliable dataset is also very important.

Another limitation of this study is the allowance of coffee until before the measurement. According to the MPS protocol, subjects were allowed to drink low caloric beverages (including coffee) until one hour before the measurement. Coffee however contains caffeine, which is known to elevate REE. The consumption of 200 mg caffeine elevates REE approximately 7% during three hours (200 mg caffeine is about two small cups of coffee = 250 ml in total or four small cups of tea, which also contains caffeine = 500 ml in total). This could have influenced our results.

A comment on this study is that the subjects were measured in three different groups. The first group was measured in February 2011, the second group in September 2011 and the third group in February 2012. Data were collected by three different teams of approximately eight trained persons. One of them participated in collecting data of all three groups and made sure that the measurements were performed the same way in all three groups. All data were collected in the same dataset. To get the most reliable dataset, all entered data were double checked.

In order to get results as reliable as possible each subject was measured twice in the BodPod. The average of two measurements was used as data. The maximum difference in volume between two measurements of the BodPod in the MPS protocol was set at 0,15L. This study adopted a maximum of 0,2L. This resulted in a difference in fat percentage of <0,5% between two BodPod measurements. A difference in volume >0,2L would give major differences in FM and FFM and would result in unreliable data. Therefore, subjects with volume differences >0,2L were excluded from the study.

Another comment on this study is that the stadiometer (Seca 222, Seca, Hamburg, Germany) was mounted 7mm too low on the wall. This meant a measurement error for all subjects of -7mm in height. The measurement error was detected after all measurements were conducted. To correct this measurement error, 7 mm was added to the height of all subjects afterwards. Unfortunately all calculations were already done before the measurement error was detected. This meant that all results had to be recalculated.

A strength of this study is that few subjects (18%) were from foreign origin: 7% is Surinamese, 2% is Netherlands Antilleans, 2% is Iranian, 2% is Egyptian, 2% is Croatian and 2% is South African. The difference in body composition between people from different countries has influence the results. However, the largest part 82% of the subjects in this study are from Dutch origin. Therefore the subjects born in other countries will have limited influence on the results of this study.
Recommendations

It is not recommended to use equations using FFM, because these equations are less accurate than equations using weight. Measuring FFM is also time consuming in dietary practice.

This study showed that the three equations giving best results for predicting REE in obese elderly are the equations of Harris & Benedict 1984, Huang et al. and Korth et al. The equations of Huang et al. and Korth et al. are probably not very well known in dietary practice. The Harris & Benedict 1984 equation however is one of the most commonly used formulas in dietary practice, so this equation is well known to dieticians. Our findings that the Harris & Benedict 1984 equation predicts REE accurately in the obese are also confirmed by other studies. Therefore it is advisable to use the Harris & Benedict 1984 equation for predicting REE in obese elderly.
Conclusion

This study investigated the validity of 30 predictive equations in obese elderly. There was a major difference in accuracy between the equations. The accuracy of the equations varied between 0 and 68% accurate predictions. Most formulas underestimate REE more often than they overestimate REE.

Equations using FFM provided no advantage over equations using weight for accurately estimating REE. Therefore, it is not recommended to use equations using FFM. Measuring FFM is also time consuming in dietary practice.

This study shows that the three equations giving best results for predicting REE in obese elderly based on percentage accurate predictions, RMSE, CCC and bias are the equations of Harris & Benedict 1984, Huang et al. and Korth et al. The equations of Huang et al. and Korth et al. are probably not very well known in dietary practice. The Harris & Benedict 1984 equation however is one of the most commonly used formulas in dietary practice, so this equations is well known to dieters. Our findings that the Harris & Benedict 1984 equation predicts REE accurately in the obese are also confirmed by other studies. It is therefore advisable to use the Harris & Benedict 1984 equation for predicting REE in obese elderly.
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Appendix I: Inclusion and exclusion criteria Muscle Preservation Study

Inclusion criteria Muscle Preservation Study

- Age 55-85 years
- If women: postmenopausal
- BMI $\geq 30$ kg/m$^2$ or BMI $\geq 28$ kg/m$^2$ and waist circumference $\geq 88$ cm (women), $\geq 102$ cm (men)
- Ability to sign informed consent
- Willingness and ability to comply with the protocol, including:
  - Maintaining current dietary habits
  - Participation in study visits
  - Taking the study product every day
  - Ability to comply with the complete study protocol
  - Ability to understand and fill out questionnaires
- Physiotherapist’s professional view that the subject is physically fit and it is safe to participate in the resistance exercise program

Exclusion criteria Muscle Preservation Study

- Any malignant disease during the last five years except for adequately treated prostate cancer without evidence of metastases, localized bladder cancer, cervical carcinoma in situ, breast cancer in situ or non-melanoma skin cancer
- Previously known:
  - Kidney failure
  - Liver failure
  - Anaemia
  - (Chronic) inflammatory status
- Medication
  - Corticosteroids for systemic use
  - Immunosuppressant’s
  - Insulin
- Dietary of lifestyle characteristics:
  - Participation in a weight loss diet three months before staring and during the study
  - Use of protein-containing or amino acid-containing nutritional supplements three months before staring and during the study
  - Participation in a resistance exercise program three months before staring and during the study
  - Current alcohol or drug abuse
- Indications related to interaction with the study product:
  - More than 10 μg (400 IU) of daily Vitamin D intake from medical sources
  - More than 500 mg of daily calcium intake from medical sources
  - Known allergy to milk and milk products
  - Known galactosaemia
- Uncertainty about the willingness or ability of the subject to comply with the protocol requirements
- Participation in any other study involving investigational or marketed products concomitantly or within four weeks prior to entry into the study
Appendix II: Bland-Altman plots

- Bernstein et al. 1983 - REE measured
  - Mean: -393.4
  - 1.96 SD: -787.9
  - -1.96 SD: -787.9

- Bernstein et al. 1983 FFM - REE measured
  - Mean: -428.9
  - 1.96 SD: -785.8
  - -1.96 SD: -72.0

- FAO/WHO/UNU 1985 W - REE measured
  - Mean: -61.5
  - 1.96 SD: -427.0
  - -1.96 SD: 304.0

- FAO/WHO/UNU 1985 W&H - REE measured
  - Mean: -64.8
  - 1.96 SD: -443.2
  - -1.96 SD: 313.6

- Harris & Benedict 1919 - REE measured
  - Mean: -72.1
  - 1.96 SD: -432.5
  - -1.96 SD: 287.8

- Harris & Benedict 1984 - REE measured
  - Mean: -52.1
  - 1.96 SD: -343.1
  - -1.96 SD: 308.9
Johnstone et al. 2006 FFM - REE measured
Mean
-71,1
-1.96 SD
-420,8
+1.96 SD
278,6

Korth et al. 2007 - REE measured
Mean
7,1
-1.96 SD
-365,2
+1.96 SD
379,5

Korth et al. 2007 FFM - REE measured
Mean
-46,9
-1.96 SD
-428,0
+1.96 SD
334,2

Lazzer et al. 2007 - REE measured
Mean
40,6
-1.96 SD
-356,5
+1.96 SD
437,7
Müller et al. 2004 BMI - REE measured
Mean
-55.4
-1.96 SD
-421.2
+1.96 SD
310.4

Müller et al. 2004 FFM - REE measured
Mean
-72.7
-1.96 SD
-428.0
+1.96 SD
282.6

Müller et al. 2004 FFM BMI - REE measured
Mean
-91.6
-1.96 SD
-449.0
+1.96 SD
265.8

Owen et al. 1986/1987 - REE measured
Mean
-129.4
-1.96 SD
-497.0
+1.96 SD
238.1

Owen et al. 1986/1987 FFM - REE measured
Mean
-293.9
-1.96 SD
-667.8
+1.96 SD
80.1

Schofield 1985 W - REE measured
Mean
-121.9
-1.96 SD
-499.5
+1.96 SD
255.7

Schofield 1985 W&H - REE measured
Mean
-106.0
-1.96 SD
-476.8
+1.96 SD
264.7

Weijs et al. 2010 - REE measured
Mean
106.7
-1.96 SD
-271.4
+1.96 SD
484.7