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# Resting energy expenditure of a diverse group of South African men and women

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## Abstract

**Background:** In South Africa, overweight/obesity is a public health concern, disproportionally affecting Black females. A contributory role of a lower resting energy expenditure (REE) is suggested for African Americans. The present study assessed the REE of Black and White South African adults aiming to better understand the underlying predictors to overweight/obesity and transform this into locally appropriate recommendations.

**Methods:** In 328 (63% female; 39% Black) healthy South African adults, REE was measured with indirect calorimetry and body composition with multi-frequency bioelectrical impedance analysis. The REE was estimated with 30 sets of published equations. Black–White differences in REE, as measured and adjusted (analysis of covariance), were determined with quantile regression. Reliability/agreement of estimated (against measured) REE was determined with intra-class correlations (ICCs) and Bland–Altman analysis. A new equation was developed by median regression followed by preliminary validation.

**Results:** Measured REE (adjusted for age along with fat-free mass [FFM], FFM index, FFM plus fat mass, FFM index plus fat mass index) in White subjects was significantly higher ($p < 0.001$) than in Black subjects for men and women alike, regardless of obesity class. None of the sets of estimation equations had good agreement with measured REE for Black, White, male and female subjects simultaneously. A new estimation equation, based on whole-body variables, had good reliability (ICC = 0.79) and agreement (mean difference: 27 kJ) and presents practical opportunities for groups at the local grass-roots level.

**Conclusions:** The REE in Black South African adults is lower than in White adults. Tailored REE equations may improve REE estimation of racially/ethnically diverse South African groups and contribute to improved obesity management.

KEYWORDS

body composition, estimation equations, indirect calorimetry, obesity, race/ethnicity, resting energy expenditure

## Key points

- A lower resting energy expenditure (REE) may partially explain the disproportionate prevalence of overweight/obesity among Black South African females. The present study assessed the REE of Black and White

South African men and women to improve the understanding of the underlying predictors to overweight/obesity and to transform this into locally appropriate recommendations.

- The REE, when adjusted for age along with body composition variables, of Black subjects were significantly lower than in White subjects for both males and females alike. This may indicate the need for population-specific prediction equations to calculate REE in resource-limited settings where access to REE measurements are limited.
- As a secondary objective, the reliability/agreement between measured REE and estimation equations, typically used in local settings to calculate REE, was determined. Informed by the outcome, a new population-specific equation was developed followed by preliminary validation for application at the local grass-roots level.

## INTRODUCTION

The importance of knowing the energy expenditure of individuals or groups is universally acknowledged in health and nutrition care[1,2] and in research.[3–5] Among the components of total energy expenditure, resting energy expenditure (REE) constitutes the largest fraction.[3,6] REE, in turn, is related to various predictors, including age, sex, genetics, body size, body composition or a recent energy imbalance.[3,6,7]

South Africa, a low- to middle-income country with diverse races/ethnicities, is burdened by a disproportionately high prevalence of overweight (26.5%) or obesity (40.9%) among African Black women.[8] Simultaneously, it is possible that the high prevalence of stunting in childhood (27% of children under 5 years[8]) may track into adult shortness, again especially among the Black population. In this context, all predictors of energy balance, including REE and factors related to it, should be studied as objectively as possible to direct tailored obesity management, keeping in mind resource limitations in those settings where this problem is most prevalent. International studies (e.g., among African Americans) suggested race/ethnicity differences in REE[9] mainly among women. This was confirmed by some previous local work limited to women being overweight,[10] whereas another South African group[11] disagreed. The question arises whether race/ethnicity differences in REE, if they exist, are sex-specific.

The present study aimed to determine whether Black and White South African adults differed in terms of measured REE (within sex), unadjusted and adjusted for relevant predictors, including anthropometry, body composition and age. Body composition was conceptualised in terms of fat-free mass (FFM), fat-free mass index (FFMI), fat mass (FM) and fat mass index (FMI). Informed by the outcome of the aforementioned, a secondary objective was to determine whether selected estimation equations of REE could differentiate between the measured REE in Black and White adult males and females, that is, the reliability/agreement[12] of the equations. Lastly, we developed and preliminarily validated an equation for South African practice. This referred to a whole-body estimation equation[13] for application at grass-roots (i.e., clinical and community level) in a resource-limited setting, where the overweight/obesity challenges are most prevalent. Race/ethnicity referred to a self-reported classification as Black or White. The REE was taken to reflect basal energy expenditure plus diet-induced thermogenesis.[14]

## METHODS

In this cross-sectional study, we conveniently recruited anthropometrically diverse Black and White adults via printed notices posted in hospital tearooms, electronic invitations to local recreational sport clubs (such as runners and volleyball players), and word of mouth invitations to staff and students in the Faculty of Health Sciences at the Univesrity of Pretoria. Self-reported illness, including acute infections and chronic disease, medications known to be related to energy expenditure, implantable electronic devices, and self-reported weight change exceeding 5 kg in the past 6 months, acted as exclusion criteria. Comparison of Black and White subjects with respect to REE, for both females and males, was considered for sample size calculation. In a post-hoc analysis, it was determined that the power of the study was in excess of 90% when using a two-sided two-group Student's paired $t$ test at $p < 0.05$ (sample size and power determination in Stata, version 14; StataCorp).

REE and bioelectrical impedance analysis data were collected in a thermo-neutral (22–25°C) secluded venue at the Faculty of Health Sciences. In preparation for the assessment, participants were requested to be fasted, consuming water only for ≥5 h (self-reported energy intake [by means of a short questionnaire] before this fasting period did not exceed 1200 kJ and assessments were completed during the morning) and abstain from alcohol, smoking, stimulants and exercise for at least

4 h.[1,2] The REE was measured with indirect, open-circuit calorimetry (Quark RMR; Cosmed). The device has evidence of reliability and accuracy.[15] For the assessment of body composition, multifrequency bioelectrical impedance analysis (Quadscan 4000; Bodystat) was used. Weight and height were measured with a digital scale (Sensa 804; Seca) and a stadiometer (Seca), respectively. The standardised protocol followed for measurement of REE including pretesting of the metabolic cart, achieving and identifying steady state, body composition and anthropometry has been described previously.[10] All measurements were taken by trained dietitians. The Quadscan 4000 outputs were used to attain measures for FFM, FM and percentage body fat (%BF). Equipment was fully serviced prior to the study and daily calibration/verification was performed in accordance with the manufacturers' instructions.

Raw data were entered into Excel (Microsoft Corp.), where basic calculations, including estimations of REE, were done (the REE estimation equations typically used in clinical and local settings were selected). Twenty sets of equations are based on whole-body parameters, and 10 include body composition data. For calculating body mass index (BMI), FMI and FFMI, respectively, body mass, FM and FFM (all three in kg), were divided by height in metres squared. Obesity class was a dichotomous variable, with obesity defined as BMI $\geq$ 30 kg m$^{-2}$ based on the World Health Organization (WHO) classification. Energy conversion from kcal to kJ was done through multiplication by 4.2.

Stata, version 14 (StataCorp) was used for statistical analyses. Continuous variables were summarised by race/ethnicity and sex reporting the linear estimated means (predictive margins), including a 95% confidence interval (CI). For REE outcome variables, a quantile regression model with bootstrap estimates race/ethnicity by sex was employed with covariates (five models for REE adjusted for age plus (a) FFM, (b) FFMI, (c) FFM plus FM, (d) FFMI plus FMI and (e) height, respectively). The combinations for these models were guided by factors influencing REE of race/ethnic groups and the findings of our previous research.[10] Reliability/agreement of REE estimations was conceptualised in accordance with 'GRRAS' guidelines.[12] For every equation, variability was calculated using intraclass correlation (ICC) and Bland–Altman (BA) analysis estimates and their 95% CI through one-way analysis of variance for measured REE within the four sex/ethnicity by race subgroups. Informed by the work of Nunnally,[16] ICC was classified as: $0 \leq \text{ICC} \leq 0.4$ = poor; $0.4 < \text{ICC} \leq 0.75$ = moderate; $0.75 < \text{ICC} \leq 0.9$ = good; $\text{ICC} > 0.9$ = excellent. Similar to previous studies,[6,17] estimation accuracy was defined as a percentage difference between estimated and measured REE of < 10. As a result of the skewed distribution of measured REE, median regression (based on the whole-body variables weight and height plus sex, race/ethnicity and age) was used for developing a local estimation equation. Based on easier application at clinical (grass-roots) level in a low- to middle-income country and a higher ICC, this approach was deemed superior to when logarithmically transformed data were regressed against the whole-body variables. Reliability/agreement between REE as measured and estimated with the new equation was again determined with ICC and the BA method. A leave-one-out preliminary-validation was employed: for each case, the median regression for estimating REE was fitted to the data set after omitting that particular case. $p < 0.05$ was considered statistically significant.

The study was approved by the University of Pretoria's Faculty of Health Sciences Research Ethics Committee and all participants were required to provide their written informed consent.

# RESULTS

## Description of sample

For the final sample of 328 subjects, a complete and credible dataset was available (Table 1). The data from 10 subjects were excluded from the original group of 338 (for five subjects, the self-reported race/ethnicity was

**TABLE 1** Sex, race/ethnicity and obesity class distribution of sample ($N = 328$).

| | Race/ethnicity | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Black | | | | White | | | | |
| Sex | Healthy weight,[a] n (%) | Over-weight,[b] n (%) | Obesity,[c] n (%) | Total, n (%) | Healthy weight,[a] n (%) | Over-weight,[b] n (%) | Obesity,[c] n (%) | Total, n (%) | Total n (%) |
| F | 31 (9.4) | 12 (3.7) | 39 (11.9) | 82 (25.0) | 77 (23.5) | 20 (6.1) | 29 (8.8) | 126 (38.4) | 208 (63.4) |
| M | 11 (3.4) | 29 (8.8) | 7 (2.1) | 47 (14.3) | 27 (8.2) | 40 (12.3) | 6 (1.8) | 73 (22.3) | 120 (36.6) |
| Total | 42 (12.8) | 41 (12.5) | 46 (14.0) | 129 (39.3) | 104 (31.7) | 60 (18.4) | 35 (10.6) | 199 (60.7) | 328 (100.0) |

Abbreviations: BMI, body mass index; F, female; M, male.

[a]BMI < 25 kg m$^{-2}$.

[b]BMI 25–29.9 kg m$^{-2}$.

[c]BMI ≥ 30 kg m$^{-2}$.

TABLE 2 Anthropometry and body composition of sample ($N = 328$).

| | | Black ($n = 129$) | | | White ($n = 199$) | | | Race/ethnicity difference, $p$ value[b] |
|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | 95% CI[a] | Mean | SD | 95% CI[a] | |
| Age (years) | F | 32.1 | 11.7 | (29.7–34.5) | 30.5 | 11.7 | (28.6–32.4) | 0.312 |
| | M | 38.9 | 8.3 | (35.8–42.1) | 36.8 | 10.2 | (34.2–39.3) | 0.291 |
| Weight (kg) | F | 77.0 | 21.0 | (73.0–80.9) | 70.6 | 20.1 | (67.4–73.8) | 0.014 |
| | M | 81.0 | 15.2 | (75.8–86.2) | 84.4 | 11.8 | (80.2–88.6) | 0.322 |
| Height (m) | F | 1.6 | 0.1 | (1.6–1.6) | 1.7 | 0.1 | (1.7–1.7) | <0.001 |
| | M | 1.7 | 0.1 | (1.7–1.8) | 1.8 | 0.1 | (1.7–1.8) | <0.001 |
| BMI (kg m$^{-2}$) | F | 29.7 | 8.1 | (28.3–31.1) | 25.6 | 7.5 | (24.4–26.7) | <0.001 |
| | M | 27.0 | 4.5 | (25.1–28.9) | 25.8 | 3.1 | (24.3–27.3) | 0.326 |
| FFM (kg) | F | 46.9 | 7.0 | (45.2–48.5) | 47.9 | 6.6 | (46.6–49.2) | 0.347 |
| | M | 61.4 | 8.4 | (59.2–63.5) | 66.8 | 9.0 | (65.0–68.5) | <0.001 |
| FFMI (kg m$^{-2}$) | F | 18.0 | 2.3 | (17.5–18.5) | 17.3 | 2.2 | (16.9–17.7) | 0.025 |
| | M | 20.5 | 2.2 | (19.8–21.1) | 20.4 | 2.3 | (19.9–20.9) | 0.91 |
| FM (kg) | F | 30.1 | 15.3 | (27.4–32.9) | 22.6 | 14.8 | (20.4–24.8) | <0.001 |
| | M | 19.7 | 8.2 | (16.0–23.3) | 16.8 | 6.0 | (13.9–19.7) | 0.233 |
| FMI (kg m$^{-2}$) | F | 11.7 | 6.0 | (10.7–12.7) | 8.2 | 5.5 | (7.4–9.1) | <0.001 |
| | M | 6.6 | 2.6 | (5.2–7.9) | 5.1 | 1.8 | (4.1–6.2) | 0.113 |
| %BF | F | 36.8 | 9.8 | (35.0–38.7) | 29.6 | 9.6 | (28.1–31.1) | <0.001 |
| | M | 23.8 | 6.1 | (21.4–26.2) | 19.3 | 5.1 | (17.4–21.2) | 0.004 |

Abbreviations: BMI, body mass index; CI, confidence interval; F, female; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; M, male; %BF, percentage body fat.

[a]95% Confidence interval around the mean.

[b]Welch two-sample $t$ test.

neither Black nor White and, for one Black and four White males, the measured REE was not credible as determined by outlier analysis [box and whiskers plot; data not shown]). The anthropometric and body composition characteristics of the final sample are summarised in Table 2.

Table 2 shows that Black females had a significantly higher weight, BMI, FFMI, FM, FMI and %BF but a lower height, than White females. In the case of males, the height and FFM of Black subjects were significantly lower, while %BF was higher than in White males.

## Measured REE of Black versus White adults

Table 3 shows that the unadjusted (measured) REE of White males was significantly higher than that of the Black counterparts ($p < 0.001$). This difference was not found among women. However, when adjusted for age along with FFMI alone or FFMI plus FMI, the difference between the race/ethnicity groups was highly significant for males and females alike. Age together with FFM or height as covariate resulted in a statistically significant difference between the two race/ethnicity groups in males only. Age with FFM and FM together as covariates resulted in a statistically significant difference between the two race/ethnicity groups in females only. In all comparisons (i.e., unadjusted and adjusted, females and males), the percentage difference in REE was negative, indicating higher REE in White compared to Black subjects. The values ranged from just over 2% (unadjusted REE of females) to approximately 14% (males adjusted for FFMI plus FMI).

Table 4 shows that the unadjusted REE of Black and White subjects differed significantly regardless of sex and obesity class. The percentage difference was larger for the subjects with obesity

## Estimated versus measured REE

In Table 5, the reliability/agreement in terms of ICC and BA mean difference of 30 sets of equations estimating REE is displayed for males and females, Black and White subjects as subgroups (see Supporting information, Table S1 with REE estimation equations and Table S2

**TABLE 3** Median of measured REE (kJ day$^{-1}$) of Black and White adults ($N = 328$).

| REE | | | Black | | White | | Race/ethnicity difference | |
|---|---|---|---|---|---|---|---|---|
| | | | Median | 95% CI[a] | Median | 95% CI[a] | %[b] | *p* value[c] |
| Unadjusted | | F | 6085 | (5668–6502) | 6224 | (5960–6488) | −2.2 | 0.557 |
| | | M | 7325 | (7049–7601) | 8216 | (7854–8578) | −10.8 | <0.001 |
| Adjusted for age plus: | FFM | F | 6272 | (6080–6464) | 6384 | (6238–6531) | −1.8 | 0.313 |
| | | M | 7495 | (7245–7745) | 8001 | (7692–8310) | −6.3 | 0.019 |
| | FFMI | F | 6034 | (5792–6276) | 6527 | (6361–6693) | −7.6 | <0.001 |
| | | M | 7147 | (6824–7470) | 8060 | (7662–8457) | −11.3 | <0.001 |
| | FFM plus FM | F | 6062 | (5881–6243) | 6626 | (6462–6791) | −8.5 | <0.001 |
| | | M | 7458 | (7075–7842) | 7987 | (7595–8378) | −6.6 | 0.082 |
| | FFMI plus FMI | F | 5974 | (5718–6230) | 6601 | (6393–6810) | −9.5 | <0.001 |
| | | M | 7063 | (6717–7410) | 8220 | (7810–8630) | −14.1 | <0.001 |
| | Height (m) | F | 6103 | (5830–6376) | 6345 | (6055–6634) | −3.8 | 0.257 |
| | | M | 7596 | (7264–7929) | 8151 | (7769–8531) | −6.8 | 0.024 |

Abbreviations: CI, confidence interval; F, female; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; M, male; REE, resting energy expenditure.

[a]95% Confidence interval around the median.

[b]([Black – White]/White) × 100.

[c]Welch two-sample *t* test.

**TABLE 4** Mean measured REE (kJ day$^{-1}$) of Black and White subjects who are obese and non-obese ($N = 328$).

| Sex | | Black | | White | | Race/ethnicity difference | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Nonobese | | Obese | |
| | | Nonobese | Obese | Nonobese | Obese | %[a] | *p* value[b] | %[a] | *p* value[b] |
| F | n | 43 | 39 | 97 | 29 | −8.9 | 0.0013 | −13.8 | 0.0001 |
| | REE | 5454 | 7047 | 5990 | 8182 | | | | |
| | 95% CI[c] | (5200–5708) | 6721–7373) | (5804–6175) | (7719–8645) | | | | |
| M | n | 40 | 7 | 67 | 6 | −10.8 | 0.0019 | −16.8 | 0.0247 |
| | REE | 7097 | 7545 | 7960 | 9078 | | | | |
| | 95% CI[c] | (6773–7421) | (6984–8107) | (7589–8331) | 7583–10574) | | | | |

Abbreviations: CI, confidence interval; F, female; M, male; REE, resting energy expenditure.

[a]([Black – White]/White) × 100.

[b]Welch two-sample *t* test.

[c]95% Confidence interval around the mean.

with references for REE estimation equations). Regardless of the model (i.e., whole-body anthropometry or body composition), the reliability of the sets of equations varied from 'consistently poor' (ICC ≤ 0.4 across subgroups) for four sets of equations, or 'consistently moderate' (0.4 < ICC < 0.75) for two sets, to 'mixed' (two different classifications of reliability across the subgroups) and 'very mixed' (three different classifications for the four subgroups) for each of 13 sets. No set of equations performed 'consistently good' (ICC > 0.75 for all four subgroups). In fact, no single equation had an ICC ≥ 0.75 (i.e., good reliability) for men, regardless of race/ethnicity. On the other hand, four equations (De Lorenzo; Johnstone; Lazzer; WHO [age]) were classified as 'good' for females across the two race/ethnicity groups. However, for all of these, the reliability classification for the two male subgroups differed, resulting in a 'very mixed' reliability of these equations across the subgroups. In ten cases, 'good' reliability between an estimation equation and measured REE was

TABLE 5 Reliability/agreement of estimated REE[a] of Black and White adults by sex

| Model | Sets of estimation equations:Author, alphabetically(see Supporting information, Tables S1 and S2) (REE unit) | Sex | Black | | | | White | | | | Race/ethnicity difference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bland–Altman analysis | | | | Bland–Altman analysis | | | |
| | | | Mean REE (kJ) (95% CI)[b] | ICC(95% CI)[b] | Mean difference (kJ) (95% CI)[b] | Limits of agreement (95% CI)[b] | Mean REE (kJ) (95% CI)[b] | ICC (95% CI)[b] | Mean difference (kJ) (95% CI)[b] | Limits of agreement (95% CI)[b] | %[c] | p value[d] |
| **Whole body** | Bernstein (kcal) | F | 5275 (5127–5423) | 0.34 (0.14–0.53) | 962 (793–1130) | (−574 to 2498) | 5086 (4966–5205) | 0.09 (0.00–0.26) | 1433 (1270–1596) | (−420 to 3286) | 3.7 | 0.051 |
| | | M | 5899 (5703–6094) | 0.03 (0.00–0.32) | 1293 (1033–1554) | (−479 to 3066) | 6441 (6284–6598) | 0.00 (0.00–0.23) | 1642 (1327–1957) | (−1100 to 4346) | −8.4 | <0.001 |
| | Black (MJ) | F | 6247 (6093–6401) | 0.70 (0.60–0.81) | −36 (−206 to 135) | (−1600 to 1517) | 6132 (6007–6256) | 0.62 (0.51–0.73) | 362 (206–519) | (−1400 to 2138) | 1.9 | 0.252 |
| | | M | 7290 (7086–7493) | 0.54 (0.33–0.74) | −125 (−369 to 118) | (−1800 to 1532) | 7689 (7526–7853) | 0.34 (0.13–0.54) | 363 (50–675) | (−2300 to 3040) | −5.2 | 0.003 |
| | BMI (kcal) | F | 6416 (6266–6566) | 0.71 (0.60–0.82) | −204 (−372 to −36) | (−1700 to 1327) | 5972 (5851–6093) | 0.56 (0.45–0.68) | 522 (360–684) | (−1300;2362) | 7.4 | <0.001 |
| | | M | 7523 (7324–7721) | 0.29 (0.03–0.55) | −359 (−622 to −95) | (−2200 to 1438) | 7439 (7280–7598) | 0.17 (0.00–0.39) | 613 (287–939) | (−2200 to 3404) | 1.1 | 0.519 |
| | De Lorenzo (kJ) | F | 6513 (6326–6700) | 0.79 (0.71–0.87) | −301 (−442 to −160) | (−1600 to 983) | 6326 (6174–6476) | 0.77 (0.70–0.84) | 169 (34–303) | (−1400 to 1692) | 3.0 | 0.126 |
| | | M | 7500 (7253–7747) | 0.48 (0.26–0.70) | −336 (−602 to −69) | (−2200 to 1481) | 7894 (7695–8092) | 0.40 (0.21 0.59) | 159 (−152 to 469) | (−2500 to 2818) | −5.0 | 0.015 |
| | Harris–Benedict, 1919 (kcal) | F | 6435 (6262–6607) | 0.74 (0.64–0.84) | −223 (−376 to 68) | (−1600 to 1193) | 6251 (6112–6390) | 0.68 (0.58–0.77) | 243 (94–393) | (−1500;1941) | 2.9 | 0.103 |
| | | M | 7453 (7225–7680) | 0.50 (0.28–0.71) | −289 (−565 to −13) | (−2200 to 1592) | 7870 (7688–8053) | 0.42 (0.23–0.61) | 182 (−128 to 492) | (−2500 to 2839) | −5.3 | 0.005 |
| | Harris–Benedict, 1984 (kcal) | F | 6478 (6311–6646) | 0.72 (0.62–0.82) | −267 (−424 to −110) | (−1700 to 1163) | 6328 (6192–6463) | 0.68 (0.59–0.78) | 167 (16–317) | (−1500 to 1872) | 2.4 | 0.170 |
| | | M | 7452 (7231–7673) | 0.50 (0.28–0.71) | −288 (−560 to −16) | (−2100 to 1563) | 7848 (7670–8025) | 0.41 (0.21–0.60) | 204 (−106 to 515) | (−2500 to 2864) | −5.0 | 0.006 |
| | Henry (W, H, A–MJ) | F | 6085 (5919–6252) | 0.75 (0.66–0.85) | 126 (−30–283) | (−1300 to 1551) | 6006 (5872–6141) | 0.66 (0.56–0.76) | 488 (347–629) | (−1100 to 2089) | 1.3 | 0.467 |
| | | M | 7212 (6992–7432) | 0.53 (0.32–0.74) | −48 (−305 to 209) | (−1800 to 1701) | 7622 (7446–7799) | 0.33 (0.12–0.53) | 430 (114–745) | (−2300 to 3134) | −5.4 | 0.004 |
| | Henry (W, A–MJ) | F | 6208 (6021–6395) | 0.80 (0.72–0.88) | 3 (−144 to 150) | (−1300 to 1342) | 5977 (5826–6128) | 0.70 (0,61–0,79) | 517 (385–649) | (−977 to 2011) | 3.9 | 0.059 |
| | | M | 7302 (7054–7549) | 0.50 (0.28–0.71) | −137 (−414 to 140) | (−2000 to 1749) | 7589 (7390–7787) | 0.34 (0.14–0.55) | 464 (151–776) | (−2200 to 3141) | −3.8 | 0.075 |
| | Huang *et al.* (kcal) | F | 5979 (5809–6148) | 0.81 (0.74–0.89) | 233 (98–367) | (−992 to 1457) | 5803 (5666–5940) | 0.63 (0.52–0.73) | 691 (560–823) | (−801 to 2184) | 3.0 | 0.113 |
| | | M | 7447 (7224–7671) | 0.46 (0.23–0.69) | −283 (−533 to −33) | (−2000 to 1420) | 7731 (7551–7910) | 0.29 (0.08–0.50) | 321 (4–639) | (−2400 to 3041) | −3.7 | 0.053 |
| | Korth (kJ) | F | 6491 (6319–6663) | 0.73 (0.63–0.83) | −280 (−440 to −119) | (−1700 to 1182) | 6438 (6300–6577) | 0.72 (0.64–0.81) | 56 (−90–202) | (−1600 to 1713) | 0.8 | 0.636 |
| | | M | 8049 (7822–8275) | 0.22 (0.00–0.49) | −885 (−1100 to −634) | (−2600 to 820) | 8501 (8320–8683) | 0.32 (0.11–0.52) | −449 (−764 to −134) | (−3100 to 2251) | −5.3 | 0.002 |
| | Lazzer (MJ) | F | 6388 (6193–6583) | 0.83 (0.76–0.90) | −176 (−313 to −39) | (−1400 to 1070) | 6308 (6150–6465) | 0.79 (0.72–0.85) | 187 (58–316) | (−1300 to 1651) | 1.3 | 0.528 |
| | | M | 7557 (7300–7814) | 0.48 (0.26–0.70) | −393 (−657 to −129) | (−2200 to 1406) | 8123 (7917–8330) | 0.39 (0.20–0.59) | −71 (−389 to 247) | (−2800 to 2653) | −7.0 | 0.001 |
| | Livingston and Kohlstadt (kcal) | F | 6133 (5990–6275) | 0.73 (0.62–0.83) | 79 (−82–240) | (−1400 to 1544) | 5916 (5802–6031) | 0.55 (0.43–0.67) | 578 (422–733) | (−1200 to 2340) | 3.7 | 0.021 |
| | | M | 7215 (7027–7403) | 0.49 (0.28–0.72) | −51 (−299 to 197) | (−1700 to 1641) | 7429 (7278–7580) | 0.25 (0.03–0.46) | 623 (311–935) | (−2100 to 3299) | −2.9 | 0.082 |

(Continues)

TABLE 5 (Continued)

| Model | Sets of estimation equations:Author, alphabetically(see Supporting information, Tables S1 and S2) (REE unit) | Sex | Black: Mean REE (kJ) (95% CI)[b] | Black: ICC(95% CI)[b] | Black: Bland–Altman analysis: Mean difference (kJ) (95% CI)[b] | Black: Bland–Altman analysis: Limits of agreement (95% CI)[b] | White: Mean REE (kJ) (95% CI)[b] | White: ICC (95% CI)[b] | White: Bland–Altman analysis: Mean difference (kJ) (95% CI)[b] | White: Bland–Altman analysis: Limits of agreement (95% CI)[b] | Race/ethnicity difference: %[c] | Race/ethnicity difference: p value[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mifflin-St Jeor et al. (kcal) | F | 6058 (5892–6224) | 0.75 (0.66–0.85) | 153 (−5–311) | (−1300 to 1592) | 5959 (5825–6093) | 0.63 (0.52–0.73) | 535 (389–682) | (−1100 to 2197) | 1.7 | 0.359 |
| | | M | 7086 (6867–7305) | 0.52 (0.31–0.73) | 78 (−171 to 328) | (−1600 to 1777) | 7472 (7297–7648) | 0.28 (0.07–0.49) | 580 (267–893) | (−2100 to 3263) | −5.2 | 0.007 |
| | Müller (W, A–MJ) | F | 7077 (6875–7278) | 0.65 (0.52–0.78) | −865 (−988 to 743) | (−2000 to 252) | 6755 (6592–6917) | 0.82 (0.76–0.88) | −260 (−381 to −140) | (−1600 to 1107) | 4.8 | 0.015 |
| | | M | 8374 (8108–8640) | 0.00 (0.00–0.29) | −1200 (−1500 to −943) | (−3000 to 606) | 8501 (8287–8714) | 0.22 (0.00–0.44) | −449 (−778 to −119) | (−3300 to 2374) | −1.5 | 0.465 |
| | Müller (BMI–MJ) | F | 7278 (7054–7503) | 0.57 (0.42–0.71) | −1100 (−1200 to −932) | (−2300 to 158) | 6979 (6798–7160) | 0.77 (0.71–0.85) | −485 (−607 to −363) | (−1900 to 897) | 4.3 | 0.042 |
| | | M | 8573 (8277–8869) | 0.00 (0.00–0.29) | −1400 (−1700 to −1100) | (−3500 to 633) | 8682 (8444–8920) | 0.21 (0.00–0.43) | −630 (−959 to −300) | (−3500 to 2195) | −1.3 | 0.573 |
| | Owen et al. (kcal) | F | 5634 (5504–5763) | 0.59 (0.45–0.73) | 578 (421–734) | (−849 to 2004) | 5443 (5338–5547) | 0.32 (0.16–0.48) | 1051 (897–1206) | (−705 to 2808) | 3.5 | 0.024 |
| | | M | 7128 (6957–7299) | 0.46 (0.23–0.68) | 36 (−218 to 290) | (−1700 to 1767) | 7272 (7135–7409) | 0.15 (0.00–0.37) | 780 (460–1101) | (−2000 to 3529) | −2.0 | 0.198 |
| | Schofield (WHO) (kcal) | F | 6322 (6141–6504) | 0.75 (0.66–0.85) | −111 (−275 to 53) | (−1600 to 1382) | 6125 (5979–6272) | 0.73 (0.64–0.81) | 369 (231–506) | (−1200 to 1931) | 3.2 | 0.097 |
| | | M | 7550 (7311–7790) | 0.43 (0.19–0.66) | −386 (−649 to −123) | (−2200 to 1405) | 7824 (7632–8016) | 0.34 (0.14–0.55) | 228 (−87–544) | (−2500 to 2934) | −3.5 | 0.081 |
| | Schofield (W, H, A–kcal) | F | 6277 (6100–6454) | 0.77 (0.68–0.86) | −66 (−223 to 92) | (−1500 to 1366) | 6111 (5968–6254) | 0.72 (0.64–0.81) | 387 (251–524) | (−1200 to 1927) | 2.7 | 0.152 |
| | | M | 7551 (7318–7785) | 0.43 (0.20–0.67) | −387 (−647 to −127) | (−2200 to 1384) | 7826 (7639–8014) | 0.35 (0.15–0.55) | 226 (−87–539) | (−2500 to 2911) | −3.5 | 0.072 |
| | WHO/FAO (W, A–kcal) | F | 6804 (6562–7047) | 0.79 0.71–0.87) | −593 (−723 to −462) | (−1800 to 594) | 6411 (6216–6607) | 0.87 (0.83–0.91) | 83 (−33–199) | (−1200 to 1397) | 6.1 | 0.014 |
| | | M | 7051 (6731–7371) | 0.49 (0.27–0.71) | 113 (−170 to 396) | (−1800 to 2041) | 7258 (7001–7515) | 0.23 (0.01–0.45) | 794 (477–1111) | (−1900 to 3510) | −2.9 | 0.322 |
| | WHO/FAO (W, H, A–kcal) | F | 6360 (6181–6539) | 0.78 (0.70–0.87) | −148 (−299 to 3) | (−1500 to 1229) | 6179 (6035–6323) | 0.75 (0.68–0.83) | 315 (183–447) | (−1200 to 1811) | 2.9 | 0.123 |
| | | M | 7498 (7262–7735) | 0.45 (0.23–0.68) | −334 (−591 to −77) | (−2100 to 1417) | 7787 (7597–7976) | 0.35 (0.15–0.55) | 266 (−47–578) | (−2400 to 2947) | −3.7 | 0.062 |
| **Body composition** | Bernstein (body composition–kcal) | F | 4976 (4819–5134) | 0.25 (0.05–0.46) | 1235 (1075–1395) | (−219 to 2689) | 4950 (4823–5077) | 0.12 (0.00–0.29) | 1544 (1396–1692) | (−134 to 3222) | 0.5 | 0.798 |
| | | M | 5922 (5714–6130) | 0.04 (0.00–0.32) | 1242 (999–1486) | (−415 to 2900) | 6320 (6153–6486) | 0.00 (0.00–0.23) | 1733 (1411–2055) | (−1000 to 4491) | −6.3 | 0.004 |
| | Cunningham (body composition–kcal) | F | 5778 (5630–5927) | 0.57 (0.42–0.72) | 433 (254–612) | (−1200 to 2064) | 5870 (5750–5989) | 0.49 (0.35–0.62) | 625 (462–787) | (−1200 to 2465) | −1.6 | 0.347 |
| | | M | 7088 (6892–7283) | 0.57 (0.38–0.77) | 77 (−162 to 315) | (−1500 to 1700) | 7573 (7416–7730) | 0.30 (0.09–0.51) | 479 (152–806) | (−2300 to 3283) | −6.4 | <0.001 |
| | Huang et al. (body composition–kcal) | F | 5925 (5746–6103) | 0.81 (0.74–0.89) | 287 (156–418) | (−903 to 1477) | 5700 (5556–5844) | 0.60 (0.49–0.71) | 794 (667–922) | (−651 to 2240) | 3.9 | 0.055 |
| | | M | 7250 (7014–7485) | 0.51 (0.30–0.72) | −86 (−339 to 168) | (−1800 to 1642) | 7470 (7281–7659) | 0.26 (0.05–0.48) | 582 (263–902) | (−2200 to 3320) | −2.9 | 0.153 |
| | Johnstone et al. (body composition–kJ) | F | 6401 (6195–6607) | 0.82 (0.75–0.89) | −190 (−329 to −50) | (−1500 to 1080) | 6274 (6108–6440) | 0.80 (0.73–0.86) | 220 (95–346) | (−1200 to 1643) | 2.0 | 0.345 |
| | | M | 7295 (7022–7567) | 0.55 (0.35–0.75) | −130 (−399 to 138) | (−2000 to 1699) | 7717 (7498–7935) | 0.39 (0.19–0.58) | 336 (12–659) | (−2400 to 3112) | −5.5 | 0.018 |

TABLE 5 (Continued)

| Model | Sets of estimation equations:Author, alphabetically(see Supporting information, Tables S1 and S2) (REE unit) | Sex | Black | | | | White | | | | Race/ethnicity difference | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Bland–Altman analysis | | | | Bland–Altman analysis | | | |
| | | | Mean REE (kJ) (95% CI)[b] | ICC(95% CI)[b] | Mean difference (kJ) (95% CI)[b] | Limits of agreement (95% CI)[b] | Mean REE (kJ) (95% CI)[b] | ICC (95% CI)[b] | Mean difference (kJ) (95% CI)[b] | Limits of agreement (95% CI)[b] | %[c] | *p* value[d] |
| | Korth (body composition–kJ) | F | 6298 (6120–6475) | 0.71 (0.60–0.81) | −86 (−256 to 84) | (−1600 to 1464) | 6407 (6264–6550) | 0.69 (0.59–0.78) | 87 (−64–239) | (−1600 to 1803) | −1.7 | 0.347 |
| | | M | 7865 (7631–8100) | 0.40 (0.15–0.64) | −701 (−953 to −448) | (−2400 to 1019) | 8447 (8258–8635) | 0.35 (0.15–0.56) | −394 (−728 to −61) | (−3300 to 2464) | −6.9 | <0.001 |
| | Lazzer (body composition–MJ) | F | 6095 (5872–6318) | 0.88 (0.83–0.93) | 117 (−5–239) | (−994 to 1227) | 5816 (5636–5996) | 0.72 (0.64–0.81) | 678 (563–792) | (−622 to 1978) | 4.8 | 0.057 |
| | | M | 3000 (2705–3295) | 0.00 (0.00–0.29) | 4164 (3882–4446) | (2245–6083) | 3338 (3102–3575) | 0.00 (0.00–0.23) | 4714 (4393–5035) | (1962–7466) | −10.1 | 0.079 |
| | Mifflin-St Jeor et al. (body composition–kcal) | F | 5586 (5451–5721) | 0.45 (0.28–0.63) | 626 (441–810) | (−1100 to 2304) | 5669 (5560–5778) | 0.36 (0.21–0.51) | 825 (657–993) | (−1100 to 2728) | −1.5 | 0.347 |
| | | M | 6780 (6601–6959) | 0.48 (0.26–0.70) | 384 (150–619) | (−1200 to 1981) | 7223 (7080–7366) | 0.19 (0.00–0.41) | 829 (504–1155) | (−2000 to 3621) | −6.1 | <0.001 |
| | Müller (body composition–MJ) | F | 7021 (6833–7209) | 0.65 (0.53–0.78) | −809 (−932 to 687) | (−1900 to 305) | 6751 (6600–6903) | 0.81 (0.74–0.87) | −257 (−379 to −135) | (−1600 to 1123) | 4.0 | 0.029 |
| | | M | 8300 (8052–8548) | 0.02 (0.00–0.31) | −1100 (−1400 to −877) | (−2900 to 629) | 8439 (8240–8639) | 0.24 (0.02–0.46) | −387 (−717 to −57) | (−3200 to 2442) | −1.7 | 0.390 |
| | Müller (body composition & BMI–MJ) | F | 7014 (6785–7243) | 0.61 (0.48–0.75) | −803 (−966 to −639) | (−2300 to 683) | 6774 (6590–6959) | 0.74 (0.66–0.82) | −280 (−427 to −133) | (−1900 to 1384) | 3.5 | 0.109 |
| | | M | 7343 (7041–7645) | 0.30 (0.04–0.56) | −179 (−534 to 196) | (−2700 to 2375) | 7635 (7392–7877) | 0.04 (0.00–0.27) | 418 (12–823) | (−3100 to 3894) | −3.8 | 0.139 |
| | Owen *et al.* (body composition–kcal) | F | 5256 (5111–5400) | 0.29 (0.09–0.48) | 956 (771–1140) | (−722 to 2634) | 5339 (5223–5455) | 0.20 (0.04–0.37) | 1155 (988–1323) | (−748 to 3058) | −1.6 | 0.377 |
| | | M | 6933 (6742–7123) | 0.55 (0.35–0.75) | 231 (−9–472) | (−1400 to 1867) | 7434 (7281–7587) | 0.28 (0.07–0.49) | 618 (290–946) | (−2200 to 3429) | −6.7 | <0.001 |

Abbreviations: A, age in years; BMI, body mass index; CI, confidence interval; F, female; H, height (m); h, height (cm); ICC, intra-class correlation; M, male; REE, resting energy expenditure; kJ = kcal × 4.2; W, weight (kg)

[a]Compared to measured, unadjusted REE.

[b]95% Confidence interval around the mean.

[c]([Black −White]/White) × 100.

[d]Welch two-sample *t* test.

noted in Black subgroups, whilst this was the case for seven White subgroups. Similarly, the table shows considerable variability in terms of agreement (based on mean differences and limits of agreement in the BA analyses) between estimated and measured REE within the race/ethnicity groups and sexes.

In almost all cases, the race/ethnicity difference in the estimation of REE, when expressed as a percentage, was below 10. Among the women, the percentage difference between the race/ethnicity group tended to be positive. Conversely, the percentage difference in estimated REE between Black and White men tended to be negative and larger than the corresponding value for women. The latter concurs with the observation that 14 of all the equations identified a statistically significant ($p < 0.05$) difference in estimated REE between Black and White males. Seven other equations indicated a significant race/ethnicity difference in REE for females. Eight equations identify the race/ethnicity difference in either males or females.

## Local estimation equation

The following estimation equation emerged from our data:

[a] Sex: 1 if male; 0 if female.

[b] Race/ethnicity: 1 if Black; 0 if White.

[c] Sex-race/ethnicity interaction: 1 if male and Black; 0 if otherwise.

[d] Age in years.

[e] Weight (kg).

[f] Height (m).

The validation of the equation resulted in an ICC = 0.79 (95% CI = 0.75–0.83; $R^2$ = 89.7%).

A BA comparison (Figure 1) of the average measured REE (kJ day$^{-1}$) of the sample and the local estimation equation for REE (kJ day$^{-1}$) of South African adults resulted in a mean difference of −27 (95% CI = −123 to 69) with limits of agreement ranging between −1800 and 1731 kJ.

Figures 2 and 3 illustrate the BA comparison of the average measured REE (kJ day$^{-1}$) of the sample and the two estimation equations (Harris–Benedict and WHO [age-based]) generally used to calculate the for REE (kJ day$^{-1}$) of South African adults (the mean difference with limits of agreement are indicated in Table 5).

# DISCUSSION

Self-report of energy intake and physical activity are fraught with challenges,[18] particularly among people with obesity. As a result, the international trend is towards objectively measured energy expenditure when determining energy (im)balance or energy requirements.[5] In this respect, the measurement of REE, for example with indirect calorimetry, is usually recommended, rather than estimation.[1,2,5,6,14] In resource-limited settings such as South Africa, the availability and affordability of the equipment for measuring REE and body composition are considerable challenges. Hence, reliance on estimation equations based on the whole-body level remains the pillar, especially in clinical and community settings. Furthermore, Landes *et al.*[19] doubt the impact of indirect calorimetry on patient outcome.

The REE, as measured and when adjusted for age together with various anthropometric and body composition indices of Black and White males, differed statistically significantly ($p \leq 0.001$) and the mean difference was deemed clinically meaningful (>10%). The absence of a statistically significant difference in measured REE between Black and White females may be related to the differences in their body composition because, when corrected for (Table 3), in most cases the difference became highly significant ($p < 0.001$). When

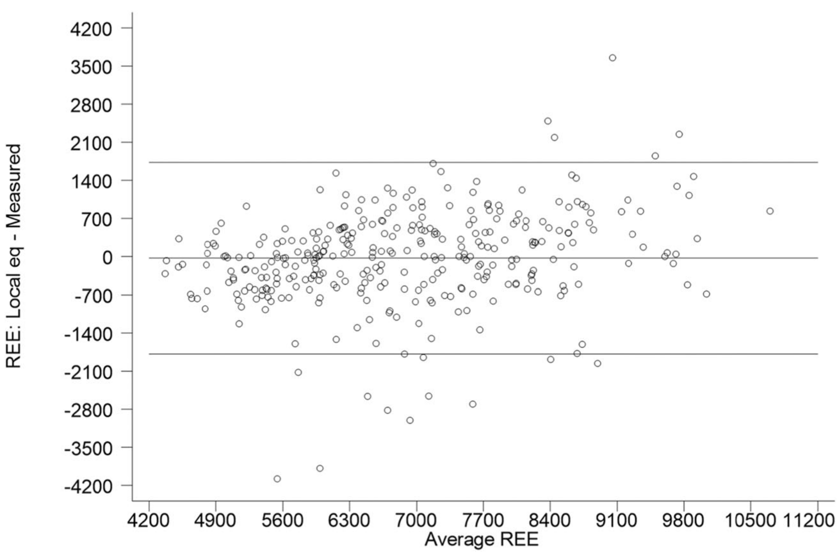


**FIGURE 1** Bland–Altman analysis of measured resting energy expenditure (REE) (kJ day$^{-1}$) of the sample and local estimation equation for REE (kJ day$^{-1}$) of South African adults

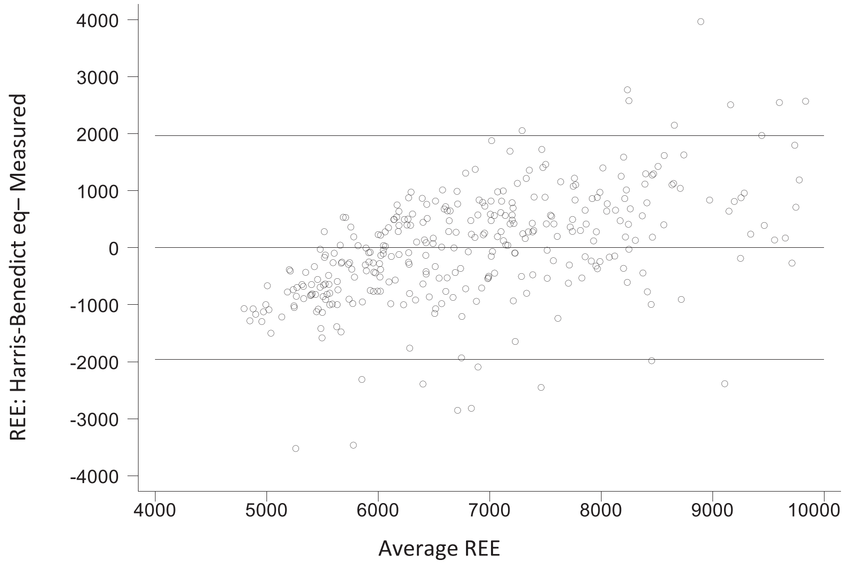


FIGURE 2 Bland–Altman analysis of measured resting energy expenditure (REE) (kJ day$^{-1}$) of the sample and Harris-Benedict estimation equation for REE (kJ day$^{-1}$) of South African adults

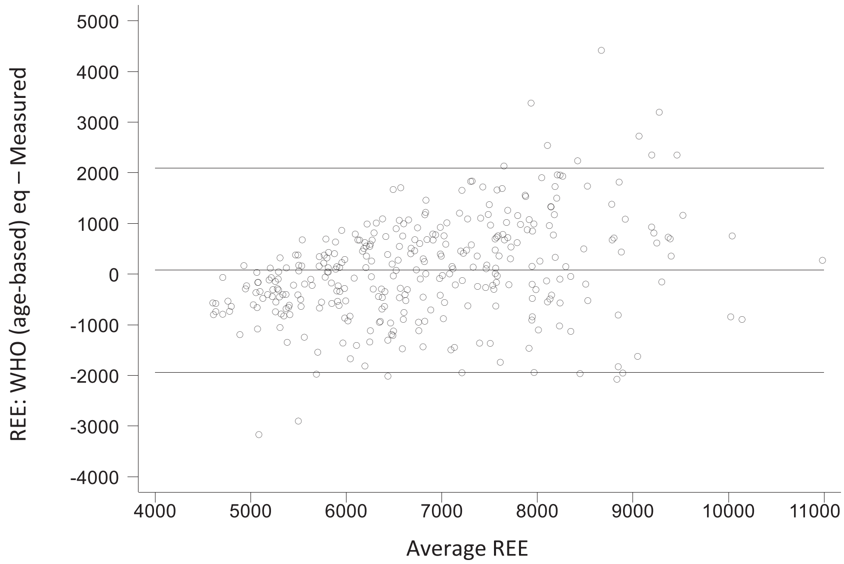


FIGURE 3 Bland–Altman analysis of measured resting energy expenditure (REE) (kJ day$^{-1}$) of the sample and WHO (age-based) estimation equation for REE (kJ day$^{-1}$) of South African adults

adjusted for FFM, differences in the REE remained relatively unchanged. However, when adjusted for FFMI, the REE of Black females was significantly ($p < 0.001$) lower than of White females. It could therefore be argued that, despite their shorter stature, the higher FFM per unit of height in Black women may have contributed to their measured REE. In addition, Black females had a significantly higher FM ($p < 0.001$) than White counterparts. Even though FM is less metabolically active than FFM,[5] it contributed to their measured REE, hence the increase in REE differences when adjusted for FFM + FM and FFMI + FMI. Shook *et al.*[20] have reported similar findings. Their percentage difference, when translated to a mean absolute difference in unadjusted REE (282 and 985 kJ for females and males, respectively), is smaller than the range of 150–300 kcal (630−1260 kJ) reported by Amen-Ra *et al.*[21] when REE was adjusted for common confounders including body fat.

The race/ethnicity difference in measured REE was apparent irrespective of the subjects' obesity class and sex (Table 4), expanding the findings of Olivier *et al.*[10] beyond females. Our data do, however, suggest that the magnitude of the difference is larger among subjects with obesity. The critical review of Heymsfield *et al.*[22] aimed to unravel the significant race/ethnicity differences in the relationship between BMI and adiposity. Race/ethnic groups may vary in body shape and composition at a constant BMI. The lower fat percentage in Black than White subjects may therefore partly explain their lower REE and the bigger difference in the group with obesity noted in our study. Heymsfield *et al.*[22] further reported that differentiating between the environmental versus inherited effects on body shape and composition remains a challenge. However, a cross-sectional study in adults does not take into consideration different environmental exposures earlier in life. The South African history of socio-economic disparities along race/ethnicity and, for example, the shorter statures among the Black subjects in our study (Table 2), suggest that the 'nature–nurture' interplay, including persisting effects of early malnutrition,[23] requires more disentanglement. As mentioned in the Introduction, overweight/obesity and childhood stunting are both public health concerns in the country. In addition to biology, genetic and behavioural factors are an inherent part of an integrated approach to the aetiology of obesity.[24]

Many equations for predicting REE have been developed and evaluated.[25–29] These equations may be based on the whole body, tissue-organ, cellular and molecular level,[13] or for specific populations, defined by health status or otherwise.[1,30,31] Heymsfield *et al.*[31] have argued that equations that are based on the tissue-organ model are more likely to agree with measured REE as the proportion of 'active protoplasmic mass', and not just FFM, significantly affects REE.[3,5] Such an emerging approach would only be useful for developing countries if the equipment to assess it is more affordable and feasible than indirect calorimetry. The development of indirect calorimetry devices that are accurate, easy to use and affordable (by standards of industrialised countries) is underway.[14]

In the meantime, countries such as South Africa have to rely on estimation equations, despite the documented limitations of using equations in populations dissimilar to those from which the equations were derived.[1] In this regard, ethnicity is one of the variables singled out in the performance of the Harris–Benedict equation,[32] which is commonly used in South Africa. The equations analysed in our study were either on the whole-body anthropometry and/or the body composition level (Table 5) and were tested in apparently healthy adults. Contrary to expectation, equations on the body composition level did not necessarily outperform those based on whole-body variables only. Similarly, the performance did not follow a race/ethnicity pattern for males or females alike. Broadly speaking, for women, the estimations of REE were higher for the Black women, whereas, for men, the estimations tended to be higher for the White subjects. Nonetheless, for women, regardless of race/ethnicity the agreement between measured REE and the prediction thereof was good for the equations from WHO (age-based), Lazzer (whole body), de Lorenzo and Johnstone (FFM-based). Of these, only the WHO equation is commonly used in South Africa across sexes and race/ethnic groups. It follows that no single equation can be recommended for Black and White adults (females and males), particularly not on the individual nor clinical level. The conflicting findings previously reported in respect of prediction accuracy of estimation equations are thus also reflected in our study. Hasson *et al.*[26] previously reported that the accuracy of four REE equations (Harris–Benedict, Mifflin-St Jeor, Owen, and WHO/Food and Agriculture Organization/United Nations University) varied 'dramatically' when their data set was stratified by sex, BMI, age and race/ethnicity. Anjos *et al.*[25] also noted that the equations they investigated in Brazilian adults did not perform satisfactorily across sexes and age categories.

The purpose and target group for which an estimation equation is to be used are important considerations. No individual equations showed *excellent* reliability (when compared with measured REE) for any subgroup. Furthermore, *good* reliability was not achieved in all four sub-groups for any set of equations. If required for research (i.e., groups of people), some of the individual equations may be considered for certain subgroups. If the equations are the basis for energy prescriptions for individuals, then considerable error should be anticipated. In over half of the equations, the difference in the measured, unadjusted REE between Black and White males was reflected. Because the unadjusted REE did not differ significantly between Black and White women, it was not surprising that only three equations (albeit different to those for males) pointed out a race/ethnicity difference.

Frankenfield[17] and Landes *et al.*[19] have noted better prediction accuracy of equations among adults with healthy BMI, suggesting obesity-class-specific prediction equations, as was done by Müller *et al.*[33] and Orozco-Ruiz *et al.*[29] Which weight (e.g., actual, ideal or adjusted) to use remains, however, an unresolved issue.[1] Our data do, however, show that the % difference between Black and White subjects was larger for those with obesity.

The present study must be interpreted with some caution. Not all predictors of REE were objectively controlled for. We attempted to describe physical activity of our subjects by using the International Physical Activity Questionnaire (IPAQ)[34] but abandoned this because of challenges expressed by our participants. To some extent, this supports the reservations related to self-reports of the components of energy balance.[18] The study by Shook *et al.*,[20] however, highlighted cardiorespiratory fitness as partly explaining race/ethnicity differences among Black and White women in America. Self-report of diabetes and HIV were exclusion criteria in our study but cannot be completely ruled out because if the high prevalence of undiagnosed morbidity and/or sensitivity related to disclosure. Martin *et al.*[35] considered diabetes, especially when uncontrolled,[36] in addition to race as important when predicting REE. Even though Ashcraft and Frankenfield[15] identified the Quark RMR as an accurate and reliable instrument, the perfect measurement of REE is still debated.[1,7,37] In addition, the prediction and comparability of body composition data across studies and different body composition models/methods poses challenges, particularly in racially diverse, resource-limited settings.[21,38,39]

To our knowledge, this is the first study in (South) Africa that includes such a population and sample size objectively measuring REE. We took into account sex, age, body composition and height when determining race/ethnicity differences in measured REE. Similarly, the large number of estimation equations that were analysed and the development and preliminary validation of a new equation for groups of (South) Africans in a resource-limited setting are unique. Expanding the investigation to other race/ethnicities and formal cross-validation of the equation in a different study group are recommended. Anthanont and Jensen[40] found that adults with low, compared to those with high, basal metabolic rates did not gain more weight, thereby concurring with the earlier review of Luke *et al.*,[41] who argued that increased weight gain among Black individuals is unlikely to be related to lower REE. Nonetheless, Amen-Ra *et al.*[21] and at least the move towards personalised nutrition in clinical settings[1] suggest accounting for related factors, including race/ethnicity, when considering an energy prescription for the management of obesity. It is hoped that our new equation will serve this purpose. In research and public health, resource-limited settings, awareness of race/ethnicity differences in REE may pave the way for purposefully integrated investigation of the role of lifelong nutrition and environmental versus genetic factors in this regard. The recently reported genomic diversity of Black South Africans[42] adds to the research challenge ahead.

# CONCLUSIONS

Black South African adults have lower measured REE than their White counterparts, irrespective of obesity class and sex. When adjusted for age and body composition variables, these differences increased for males and females. General non-population-specific equations did not perform well in estimating the measured REE for Black and White adults (females and males). Considering local resource limitations to measure REE, a new estimation equation relying on whole-body parameters shows promise to more accurately estimate energy requirements of the diverse South African population.

## AUTHOR CONTRIBUTIONS

Adeline Pretorius collected data, contributed to data analysis, interpreted the data and completed the writing of the manuscript. Monique Piderit collected data and contributed to data analysis and interpretation. Piet Becker performed the statistical analysis of the data. Friede Wenhold designed the study, interpreted the data and drafted the manuscript. All authors read and approved the final version of the manuscript submitted for publication.

## ACKNOWLEDGEMENTS

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## CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

## TRANSPARENT PEER REVIEW

The lead author affirms that this manuscript is an honest, accurate and transparent account of the study being reported. The lead author affirms that no important aspects of the study have been omitted and that discrepancies from the study as planned have been explained.

## DATA AVAILABILITY STATEMENT

The datasets used and analysed during the current study are deposited in the University of Pretoria Research Data Storage Repository and are available from the corresponding author/institution upon reasonable request.

## ETHICAL STATEMENT

The study was approved by the University of Pretoria, Faculty of Health Sciences Research Ethics Committee (Certificate: 263/2014). Written informed consent was obtained. No incentives were offered, yet transport costs to the assessment venue were paid on request. Each participant received a personalised printed summary of his/her anthropometric status and a risk warning or recommendation/referral, where applicable.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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