

Validation of three predictive equations for basal metabolic rate in adults

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Abstract

Objective: To cross-validate three predictive set of equations for basal metabolic rate (BMR) developed by Schofield (Schofield database), Henry (Oxford database) and Cole (Oxford database) using mean values for age, weight, height and BMR of published studies.

Design: Literature review of studies published from 1985 to March 2002.

Setting: All studies selected used appropriate methods and followed conditions that met the criteria established for basal metabolism, were performed in healthy adults, and were not part of the Schofield or Oxford database.

Subjects: A total of 261 groups of men and women from 175 studies were selected and categorised in three age groups (18.5–29.9, 30.0–59.9, ≥ 60 years old) and three body mass index (BMI) groups (normal weight, overweight and obese).

Results: Linear regression and concordance correlation analysis showed that the three sets of equations had the same association and agreement with measured BMR, across gender, age, and BMI groups. The agreement of all equations was moderate for men and poor for women. The lowest mean squared prediction errors (MSPEs) were given by Henry equations in men and Cole equations in women. Henry and Cole equations gave lower values than Schofield equations, except for men over 60 years of age. Henry equations were the most accurate in men. None of the three equations performed consistently better in women.

Conclusion: These results support the use of Henry equations in men with a wide range of age and BMI. None of the proposed predictive equations seem to be appropriate to estimate BMR in women.

Keywords
Basal metabolism
Energy expenditure
Body mass index
Obesity
Undernutrition
Energy metabolism
Basal metabolic rate

Introduction

Since 1981, the Joint Food and Agricultural Organization/World Health Organization/United Nations University (FAO/WHO/UNU) Expert Consultation on Energy and Protein Requirements recommended expressing energy expenditure as multiples of basal metabolic rate (BMR)¹. The document *Energy and Protein Requirements*, published in 1985, reported several predictive equations for BMR developed by Schofield^{2–3}. However, most BMR values in the Schofield database were obtained from European and North American subjects (87%), and several reports have been published demonstrating that those equations overestimate BMR, particularly in some ethnic groups^{4–8}. Henry and Cole^{9–10} have developed new predictive equations, using a more extensive database than Schofield (Oxford database). Henry and Cole equations excluded the Italian subjects, who were over-represented in the Schofield database (47%) and have unusually high BMR values. Moreover, 38% of subjects in

the Oxford database are from developing countries⁹. Hence, the Oxford database has a broader geographical and ethnic representation than the Schofield database.

The purpose of this paper is to cross-validate those three predictive models (Schofield, Henry and Cole) in adults, using mean values for age, anthropometry and BMR of published studies. The analyses were performed in groups of individuals with a mean body mass index (BMI) in the normal range (18.5–25.0 kg m⁻²). Further analyses were done including groups of individuals with a mean BMI over 18.5 (normal weight, overweight, and obese groups).

Methods

A literature review was performed using MEDLINE database (National Library of Medicine, Bethesda, MD). The search covered the period from January 1985 to March 2002. The following keywords were used: basal metabolism, BMR, or resting metabolic rate, all limited to human subjects. Additional articles were obtained from the list of

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references of few papers. A total of 2286 articles were electronically transferred to ProCite 3.1 (Personal Bibliographic Software, Inc., Michigan), for reference management.

The exclusion criteria used to select papers for their analysis were:

1. Non-original papers, published twice or more for the same individuals. Consequently, I excluded review papers (320), letters to the editor (40), meta-analysis and compilations of several studies (18), and studies based on subjects whose results were published in other papers (45).
2. Studies that were part of the Oxford database (20). None of the papers were part of the Schofield database, since those papers were published prior to 1985.
3. Studies where the abstract said that BMR was not measured, or was measured exclusively in ill or burned persons, hospitalised or during administration of anaesthetic (1007).
4. Studies done exclusively on children or adolescents, obese persons, pregnant women, early post-partum, or athletes (210).
5. Studies that did not show data separating men from women, or did not report age, weight, or non-adjusted BMR of subjects (79).
6. Since the mean value of each age and gender group was used, it was decided to exclude from analysis studies with less than 10 individuals of a given age and gender (252).
7. Methods and environmental and subjects' conditions followed to measure BMR were carefully reviewed in each study to make sure that criteria for BMR were accomplished. Twenty-seven studies were excluded due to inappropriate methodology.

Excluding all articles that met any of the above criteria, plus another 86 articles that were not possible to obtain by the time the analysis was started, and five studies with BMR values considered as outliers by the Tukey method (median \pm twice the interquartile range)¹¹, a total of 175 studies remained for analysis. Several of those studies included more than one age and gender group, for example, men 18–30 and men 30–65. Table 1 summarises the number of groups of subjects in each gender, age and BMI category. Underweight groups were not included in the analysis due to the low number of groups available. The age groups selected for both sexes are the same used by Schofield *et al.* for the development of their predictive equations (Table 2). All references used in the analysis are listed in Annex 1.

Predictive equations

The Schofield equations were derived from 7173 individual BMR data (4809 men, 2364 women), 0–100 years of age, from 114 studies published between 1914

Table 1 Group of subjects in each gender, age and body mass index (BMI) category

Age (years)	BMI (kg m ⁻²)				All
	Underweight <18.5	Normal weight 18.5–25.0	Overweight 25.1–30.0	Obese >30.0	
Men					
18.0–29.9	5	50	9	2	61
30.0–59.9	0	19	16	9	44
≥ 60.0	0	8	17	0	25
All	5	77	42	11	130
Women					
18.0–29.9	2	49	4	4	57
30.0–59.9	1	38	12	9	59
≥ 60.0	0	7	5	3	15
All	3	94	21	16	131

and 1980 (Table 2)³. Peculiarities of this database are that 57% of men and 27% of women were from Italy; the Italian group appears to have a higher BMR kg⁻¹ body weight than any other Caucasian group; most studies used closed-circuit methods that usually lead to higher BMR values compared to open-circuit methods; and most of the studies were done in European and North American subjects, containing relatively few subjects from developing countries (13%).

The Henry equations were obtained from 10 502 individual BMR values (5794 men, 4708 women), 0–106 years of age, from 166 published (1914–2001) and unpublished studies (Oxford database)⁹. The Cole equations were also developed from this database (Table 2).

The Oxford database included only healthy subjects (malnourished or sick subjects were excluded), although overweight and obese subjects were not eliminated. It considers the Italian subjects of the Schofield database, although Henry did not include them to derive his equations. The Oxford and Schofield databases have 4039 data points in common (77 papers). However, 38% of subjects (4018) in the Oxford database lived in developing countries. The later database also included 53% of studies that used open-circuit calorimetry.

The Henry and Schofield equations assumed a linear association between BMR and weight. It is worth noting that weight reduces the total variation in BMR by 90–93% in children 0–3 years of age; however, as age increases, this total variation explained by weight decreases, being the lowest in the 30–60-year-old group (36 and 46% for men and women, respectively, by Schofield's equations and 51 and 57% by Henry's equations). Both authors, however, demonstrated that the inclusion of height in the equation did not improve its prediction ability significantly.

Cole developed another set of equations only for adults, 18–80 years old, which avoid any discontinuities between age groups¹². He used the Oxford database, as Henry did, but he did not exclude the Italian subjects. Cole's models predict ln BMR using age, ln weight and ln height as independent variables, adjusted for differences in mean

Table 2 Predictive equations for basal metabolic rate (BMR, MJ day⁻¹) applied in the analysis*

Age (years)	Schofield		Henry		Cole [†]	
	<i>n</i> **	Equations	<i>n</i> **	Equations	<i>n</i> **	Equations
Men	4809		5794			
0–2.9	162	0.249 × Wt – 0.127	277	0.255 × Wt – 0.141		
3.0–9.9	338	0.095 × Wt + 2.110	289	0.0937 × Wt + 2.15		
10.0–17.9	734	0.074 × Wt + 2.754	863	0.0769 × Wt + 2.43		
18.0–29.9	2879	0.063 × Wt + 2.896	2821	0.0669 × Wt + 2.28	1207	$e^{-0.1631 - 0.00255 \times \text{Age} + 0.4721 \times \ln \text{Wt} + 0.2952 \times \ln \text{Ht}}$
30.0–59.9	646	0.048 × Wt + 3.653	1010	0.0592 × Wt + 2.48		or
≥ 60.0	50	0.049 × Wt + 2.459				
60.0–69.9			270	0.0543 × Wt + 2.37		
≥ 70.0			264	0.0573 × Wt + 2.01	6425	$e^{-0.2630 - 0.00277 \times \text{Age} + 0.4877 \times \ln \text{Wt} + 0.3367 \times \ln \text{Ht}}$
Women	2364		4708			
0–2.9	137	0.244 × Wt – 0.130	215	0.246 × Wt – 0.0965		
3.0–9.9	413	0.085 × Wt + 2.033	403	0.0842 × Wt + 2.12		
10.0–17.9	575	0.056 × Wt + 2.898	1063	0.0465 × Wt + 3.18		
18.0–29.9	829	0.062 × Wt + 2.036	1664	0.0546 × Wt + 2.33	1030	$e^{-0.1934 - 0.00199 \times \text{Age} + 0.4764 \times \ln \text{Wt} + 0.0194 \times \ln \text{Ht}}$
30.0–59.9	372	0.034 × Wt + 3.538	1023	0.0407 × Wt + 2.90		or
≥ 60.0	38	0.038 × Wt + 2.755				
60.0–69.9			185	0.0429 × Wt + 2.39		
≥ 70.0			155	0.0417 × Wt + 2.41	3224	$e^{-0.0713 - 0.00209 \times \text{Age} + 0.4075 \times \ln \text{Wt} + 0.3540 \times \ln \text{Ht}}$

*Wt – weight (kg); Ht – Height (m).

**Sample size used for development of each regression model.

†First equation (restricted to 18–80 years of age, body mass index (BMI) 18.5–24.9 kg m⁻², published after 1950, using open-circuit calorimetry, and adjusted for study differences in mean BMR) was used in the analysis of subjects with mean BMI between 18.5 and 25.0. Second equation (restricted only to 18–80 years of age and adjusted for study differences in mean BMR) was used when overweight and obese subjects were included in the analysis.

BMR (also adjusted for age, weight, and height) between studies. Cole also created models limited to subjects with normal BMI (18.5–24.9 kg m⁻²), to those same subjects but from studies published after 1950 and all the above conditions plus restricted to open-circuit methods. Those conditions eliminated the Italian subjects, who were measured by a closed-circuit technique between the years 1936–1942. Cole's restricted model was applied to the analysis of a group of subjects with mean BMI between 18.5 and 25.0. The full model was used when overweight and obese subjects were also included in the analysis.

Analysis

All analyses were done using the mean values for BMR, age, weight, height, and BMI published in each article. Results are reported as mean ± SD. Linear regression analysis (to test for precision), concordance correlation (to test for accuracy)¹², and analysis of variance (to further test for accuracy) were used to compare predicted BMR by each set of equations with measured BMR and among each other. The best model was considered with the lowest mean squared prediction error (MSPR), a better indicator of how well the model predicts in another data set than standard error of the estimate (SEE)¹³.

Results

The first analysis was done in age and gender groups with a mean BMI between 18.5 and 25.0 kg m⁻². Table 3 contains characteristics of the groups of subjects included in this analysis. BMR was lower in women than in men.

The group of individuals over 60 years of age had a lower BMR than younger groups.

Linear regression and concordance correlation analysis revealed that the three sets of predictive equations had the same association and agreement with measured BMR, across gender and age groups (Table 4). Overall and stratified by age, concordance correlation coefficients were between 0.6 and 0.8 in men, meaning that all equations are moderately precise and accurate to predict BMR. In the case of women, all predictive equations had a poor association and agreement with measured BMR, particularly in the 30–59.9-year-old group (Table 4). The lowest MSPR was given by Henry's equations in men and Cole's equations in women.

BMR values predicted by the three equations, as expected, were highly correlated (*r* values between 0.92 and 1.00, Table 4). Schofield and Henry equations for men and women between 18.0 and 59.9 years old had correlation coefficients of 1 and their association with measured BMR were identical. However, the concordance coefficients between those two equations varied among 0.56 and 0.92, meaning that the association between them is a straight line, but one equation gives values that under or overestimate the values of the other. In this case, the Henry equations showed slightly lower predicted values than the Schofield equations, except for men over 60 years of age (Table 5).

Since all predictive equations resulted in the same precision and accuracy, analysis of variance was performed to test for accuracy only. Levene's test was done to verify for homogeneity of variances, showing that variances among groups were not different. This condition allows the use of analysis of variance.

Table 3 Characteristics of age and gender groups included in the analysis

Age (years)	Groups	Subject per group	Total n of subjects	Age (years)	Weight (kg)	Height (m)	Body mass index (BMI, kg m ⁻²)	Basal metabolic rate (BMR, MJ day ⁻¹)	BMR (kJ kg ⁻¹ per day)
Mean BMI between 18.5 and 25.0 kg m ⁻²									
Men									
18.0–29.9	50	10–192	1439	23.9 ± 3.0 (18.3–29.7)*	69.8 ± 7.0 (52.2–82.6)	1.76 ± 0.05 ^a (1.65–1.87)	22.5 ± 1.6 (19.0–25.0)	6.997 ± 0.636 ^a (5.387–8.499)	100.6 ± 6.6 ^a (86.0–115.6)
30.0–59.9	19	11–76	604	37.2 ± 6.0 (30.0–52.5)	69.3 ± 8.8 (51.6–80.3)	1.71 ± 0.07 ^b (1.56–1.81)	23.3 ± 1.7 (19.3–24.9)	6.826 ± 0.842 ^a (5.410–7.833)	98.9 ± 8.7 ^a (85.0–117.1)
≥ 60.0	8	10–89	256	71.6 ± 5.5 (63.0–82.0)	70.1 ± 7.4 (53.8–77.0)	1.72 ± 0.04 ^{ab} (1.66–1.77)	23.6 ± 2.0 (19.4–25.0)	6.012 ± 0.690 ^b (4.622–6.882)	85.7 ± 2.4 ^b (82.9–89.4)
All	77	10–192	2299	32.1 ± 15.2 (18.3–82.0)	69.7 ± 7.4 [†] (51.6–82.6)	1.76 ± 0.06 [†] (1.56–1.87)	22.8 ± 1.7 [†] (19.0–25.0)	6.852 ± 0.749 [†] (4.622–8.499)	98.6 ± 8.1 [†] (82.9–117.1)
Women									
18.0–29.9	49	10–114	1544	25.3 ± 2.9 (18.5–29.9)	56.7 ± 5.6 ^a (43.6–65.7)	1.62 ± 0.05 (1.49–1.71)	21.5 ± 1.3 ^a (19.0–23.9)	5.444 ± 0.491 ^{ab} (4.234–6.500)	96.4 ± 7.5 ^a (79.5–114.5)
30.0–59.9	38	10–293	1526	39.4 ± 8.6 (30.0–59.8)	60.4 ± 5.2 ^b (48.4–68.8)	1.62 ± 0.05 (1.49–1.70)	22.9 ± 1.3 ^b (19.0–25.0)	5.645 ± 0.420 ^a (4.982–6.670)	93.9 ± 9.0 ^a (77.6–110.2)
≥ 60.0	7	13–113	390	71.6 ± 11.7 (61.0–94.0)	61.0 ± 8.6 ^b (43.1–70.0)	1.58 ± 0.07 (1.44–1.64)	23.6 ± 1.4 ^b (20.8–25.0)	5.043 ± 0.635 ^b (3.688–5.477)	83.1 ± 6.0 ^b (69.9–87.4)
All	94	10–293	3460	34.4 ± 14.2 (18.5–94.0)	58.5 ± 5.9 (43.1–70.0)	1.62 ± 0.05 (1.44–1.71)	22.2 ± 1.5 (19.0–25.0)	5.495 ± 0.497 (3.688–6.670)	94.4 ± 8.7 (69.9–114.5)
Mean BMI ≥ 18.5 kg m ⁻²									
Men									
18.0–29.9	61	10–192	1917	24.3 ± 3.0 (18.3–29.7)	72.8 ± 9.5 ^a (52.2–103.0)	1.76 ± 0.05 ^a (1.65–1.87)	23.4 ± 2.8 ^a (19.0–35.0)	7.116 ± 0.658 ^a (5.387–8.740)	98.5 ± 8.0 ^a (75.4–115.6)
30.0–59.9	44	10–680	2264	38.2 ± 7.6 (30.0–57.0)	80.2 ± 13.7 ^b (51.6–108.7)	1.74 ± 0.06 ^b (1.56–1.81)	26.4 ± 3.8 ^b (19.3–34.5)	7.291 ± 0.825 ^a (5.410–8.981)	92.1 ± 9.9 ^b (75.1–117.1)
≥ 60.0	25	10–145	836	68.6 ± 4.7 (62.0–82.0)	75.3 ± 6.3 ^{ab} (53.8–87.0)	1.72 ± 0.03 ^b (1.64–1.77)	25.4 ± 1.8 ^b (19.4–28.7)	6.321 ± 0.490 ^b (4.622–6.900)	84.1 ± 4.1 ^c (73.5–91.3)
All	130	10–680	5017	37.5 ± 17.2 (18.3–82.0)	75.8 ± 11.1 [†] (51.6–108.7)	1.75 ± 0.05 [†] (1.56–1.87)	24.8 ± 3.3 (19.0–35.0)	7.023 ± 0.773 [†] (4.622–8.981)	93.6 ± 9.8 [†] (73.5–117.1)
Women									
18.0–29.9	57	10–181	1926	25.4 ± 2.9 (18.5–29.9)	61.0 ± 13.1 (43.6–104.6)	1.62 ± 0.05 (1.49–1.71)	23.0 ± 4.6 ^a (19.0–39.6)	5.631 ± 0.706 ^{ab} (4.234–7.900)	93.9 ± 9.7 ^a (69.3–114.5)
30.0–59.9	59	10–293	3271	39.7 ± 7.9 (30.0–59.8)	67.1 ± 13.3 (48.4–104.6)	1.62 ± 0.05 (1.49–1.70)	25.7 ± 4.9 ^b (19.0–41.9)	5.879 ± 0.616 ^a (4.742–7.854)	89.4 ± 11.8 ^a (61.1–110.2)
≥ 60.0	15	10–238	899	69.4 ± 8.4 (60.2–94.0)	67.7 ± 10.1 (43.1–84.3)	1.60 ± 0.05 (1.44–1.64)	26.3 ± 3.3 ^{ab} (20.8–32.1)	5.228 ± 0.555 ^b (3.688–6.009)	78.0 ± 6.8 ^b (69.3–87.4)
All	131	10–293	6096	36.9 ± 14.9 (18.5–94.0)	64.5 ± 13.2 (43.1–104.6)	1.62 ± 0.05 (1.44–1.71)	24.5 ± 4.8 (19.0–41.9)	5.697 ± 0.678 (3.688–7.900)	90.0 ± 11.5 (61.1–114.5)

*Mean ± SD (Min–Max), $P < 0.05$ among values with different letters.† Men different from women, $P < 0.05$.

Table 4 Comparison of measured and predictive basal metabolic rate (BMR) of subjects with mean body mass index (BMI) between 18.5 and 25.0 kg m⁻², using linear regression and concordance correlation (r_c) analysis

	Men						Women							
	n	r ²	r	SEE	MSPR	r _c mean ± SD	r _c CI	n	r ²	r	SEE	MSPR	r _c mean ± SD	r _c CI
	All	77	0.619	0.787	0.465	0.258	0.730 ± 0.052	0.629–0.831	94	0.398	0.631	0.387	0.148	0.551 ± 0.061
BMR/Schofield	77	0.659	0.812	0.440	0.199	0.766 ± 0.042	0.684–0.849	94	0.350	0.591	0.403	0.176	0.494 ± 0.065	0.367–0.621
BMR/Henry	72	0.662	0.814	0.442	0.207	0.739 ± 0.043	0.739–0.823	89	0.430	0.656	0.365	0.139	0.548 ± 0.059	0.433–0.664
BMR/Cole	50	0.600	0.775	0.406	0.248	0.631 ± 0.073	0.487–0.775	49	0.452	0.672	0.368	0.141	0.612 ± 0.082	0.451–0.773
18.0–29.9 years	50	0.600	0.775	0.406	0.161	0.737 ± 0.059	0.620–0.853	49	0.452	0.672	0.368	0.131	0.601 ± 0.077	0.449–0.752
BMR/Schofield	48	0.615	0.784	0.405	0.175	0.678 ± 0.058	0.563–0.792	49	0.432	0.657	0.374	0.140	0.533 ± 0.076	0.384–0.683
BMR/Henry	19	0.605	0.778	0.545	0.340	0.605 ± 0.103	0.403–0.808	38	0.105	0.324	0.403	0.158	0.227 ± 0.108	0.015–0.439
BMR/Cole	19	0.605	0.778	0.545	0.342	0.653 ± 0.113	0.431–0.876	38	0.105	0.324	0.403	0.241	0.188 ± 0.096	–0.000–0.378
30.0–59.9 years	17	0.549	0.741	0.582	0.324	0.640 ± 0.118	0.408–0.872	34	0.196	0.443	0.354	0.146	0.341 ± 0.122	0.102–0.581
BMR/Schofield	8	0.939	0.969	0.184	0.122	0.775 ± 0.082	0.615–0.935	7	0.677	0.823	0.395	0.146	0.666 ± 0.155	0.362–0.970
BMR/Henry	8	0.967	0.984	0.135	0.099	0.820 ± 0.053	0.715–0.924	7	0.659	0.812	0.406	0.137	0.711 ± 0.165	0.387–1.035
BMR/Cole	7	0.975	0.987	0.129	0.142	0.772 ± 0.092	0.591–0.953	6	0.873	0.934	0.276	0.096	0.824 ± 0.093	0.642–1.006
≥ 60.0 years	77	0.912	0.955	0.179	0.123	0.834 ± 0.026	0.783–0.884	94	0.953	0.976	0.069	0.032	0.847 ± 0.017	0.813–0.880
Schofield/Henry	72	0.910	0.954	0.182	0.097	0.850 ± 0.027	0.797–0.903	89	0.899	0.948	0.103	0.031	0.839 ± 0.026	0.789–0.889
Schofield/Cole	72	0.963	0.982	0.106	0.019	0.965 ± 0.008	0.950–0.980	89	0.958	0.918	0.087	0.008	0.950 ± 0.010	0.929–0.969
18.0–29.9 years	50	1.000	1.000	0.000	0.119	0.772 ± 0.006	0.761–0.783	49	1.000	1.000	0.000	0.017	0.922 ± 0.009	0.905–0.939
Schofield/Henry	48	0.964	0.982	0.084	0.096	0.766 ± 0.027	0.713–0.818	49	0.985	0.992	0.043	0.030	0.850 ± 0.026	0.800–0.901
Schofield/Cole	48	0.964	0.982	0.089	0.017	0.951 ± 0.011	0.929–0.972	49	0.985	0.992	0.038	0.004	0.975 ± 0.005	0.965–0.984
30.0–59.9 years	19	1.000	1.000	0.000	0.167	0.713 ± 0.032	0.650–0.776	38	1.000	1.000	0.000	0.056	0.563 ± 0.017	0.530–0.596
Schofield/Henry	17	0.947	0.973	0.123	0.104	0.786 ± 0.052	0.683–0.889	34	0.839	0.916	0.075	0.036	0.672 ± 0.042	0.554–0.791
Schofield/Cole	17	0.952	0.976	0.123	0.026	0.948 ± 0.026	0.898–0.998	34	0.839	0.916	0.090	0.013	0.873 ± 0.061	0.790–0.956
≥ 60.0 years	8	0.967	0.983	0.071	0.041	0.849 ± 0.056	0.740–0.959	7	0.997	0.998	0.021	0.010	0.954 ± 0.026	0.902–1.005
Schofield/Henry	7	0.925	0.962	0.113	0.088	0.731 ± 0.100	0.535–0.927	6	0.930	0.964	0.093	0.017	0.927 ± 0.049	0.831–1.022
Schofield/Cole	7	0.952	0.976	0.096	0.014	0.949 ± 0.043	0.866–1.033	6	0.951	0.975	0.091	0.020	0.925 ± 0.049	0.802–1.048

SEE – Standard error of the estimate; MSPR – Mean squared prediction error.

Table 5 contains the predicted BMR values using the Schofield, Henry and Cole equations, for each gender and age group. Overall, there were no differences among absolute values of measured BMR and predicted BMR by each method in men and women. However, predicted BMR by the Schofield equations was higher than predicted BMR by the Henry equations in men, and by the Henry and Cole equations in women. The only other difference found in men was in the 18–29.9-year-old group, where predicted BMR by the Schofield equations was greater than measured BMR. Conversely, predicted BMR by the Henry and Cole equations in women 30–59.9 years old resulted in lower than measured BMR.

The absolute and relative difference values among measured BMR and each predictive equation revealed that the Schofield equations overestimate BMR in men (3.7%), particularly in the 18–29.9-year-old group (4.6%), and the Henry equations underestimate BMR in women (1.8%), particularly in the 30–59.9-year-old group (4.6%, Table 5). Furthermore, Henry and Cole's equations gave consistently lower values than the Schofield equations, except for men over 60 years of age.

A second set of analysis included an overweight and obese group of subjects, according to their mean BMI values (25.1–30.0 and >30.0 kg m⁻², respectively). BMR decreased with age in both men and women (Table 3). Table 6 shows the linear regression and concordance correlation analysis when normal, overweight and obese groups were combined. The addition of the overweight and obese groups of men did not make any difference in the association and agreement found in the group of men with normal mean BMI alone. On the contrary, the association and agreement improved significantly when the overweight and obese groups of women were combined with normal BMI groups (Table 6 and Fig. 1).

The analysis of variance results when overweight and obese groups of subjects were included are presented in Table 5. When the overweight and obese groups of men were incorporated, the BMR overestimation by the Schofield equations was more evident and the Henry and Cole equations persisted as equally accurate. In the case of women, the BMR underestimation by the Henry equations in the 30–59.9-year-old age group disappeared (Table 5). The Henry and Cole equations continued giving lower values than the Schofield equations, except for men over 60 years of age.

Figure 2 shows the scatter plots among measured BMR and predicted BMR by the Schofield, Henry, and Cole equations in Caucasian (37 groups of men and 40 groups of women) and non-Caucasian (41 groups of men and 51 groups of women) subjects with BMI between 18.5 and 25.0. Non-Caucasian groups included African, Amerindian, Caribbean, Indian, Hispanic, Malaysian, Oriental, and Polynesian. Caucasian groups included White and Black American. All groups in which ethnicity

was not reported or various ethnic groups were included, were not considered here. Non-Caucasians had significantly lower BMR values than Caucasians (6.17 ± 0.68 and 7.12 ± 0.62 MJ day⁻¹ in men, and 5.18 ± 0.52 and 5.76 ± 0.44 in women, $P < 0.01$) and non-Caucasian values corresponded to most of the lowest BMR values (Fig. 2). Henry's equations fit better Caucasian and non-Caucasian groups than the Schofield and Cole equations in men.

Discussion

The main findings of this validation study were that, in men, the three sets of equations developed by Schofield, Henry, and Cole, are equally precise, but the Henry and Cole equations were more accurate, since Schofield's equations tend to overestimate BMR. For simplicity, this finding diminishes the significance of recommending the more complex equations developed by Cole, leaving the Henry equations as the best set of equations for men. This conclusion is valid for a group of subjects whose mean BMI classified them as normal weight, overweight, or obese. The degree of association and SEE were similar to the association and SEE reported by Schofield and Cole in their papers^{9–10}.

In women, the results are not that clear, probably related to the poor association and agreement found with all equations validated. As in previous reports^{3,9}, weight diminishes the total variation in BMR by 62–66% in men. In women, however, the total variation in BMR explained by weight was only 35–43%, and only 10–19% in the 30–60-year-old group. Apparently this poor association vanished when overweight and obese groups of subjects were included in the analysis. However, that circumstance is probably explained by a leverage effect of the upper data points corresponding to obese subjects (Fig. 1). More data is needed on obese women to clarify this point. None of the proposed predictive equations seem to be appropriate to estimate BMR from mean population weight values in women. The logarithmic transformation used in the Cole equations did not improve the prediction accuracy and precision.

The results obtained in women may also be accounted for by a non-linear association between weight and BMR, or weight not being the main variable that can explain BMR variation. A logarithmic transformation, as in Cole's equations, did not improve the prediction ability of the model. A suggestion to improve the model is conducting a piecewise regression¹³; in other words, allow the linear regression line to have a break-point. Observing Fig. 1 in more detail, it seems that the predicted values for women overestimated BMR in most cases when BMR was less than approximately 5.4 MJ day⁻¹. The break-point for the parameter used in the equations (body weight) can be determined by examining a scatter plot between BMR

Table 5 Measured and predictive basal metabolic rate (BMR): absolute values, and absolute and percent differences*

	Men				Women				
	18–29.9 years		30–59.9 years		18–29.9 years		30–59.9 years		All
	≥ 60.0 years	All	≥ 60.0 years	All	≥ 60.0 years	All	≥ 60.0 years	All	
Mean body mass index (BMI) between 18.5 and 25.0 kg m ⁻²									
BMR measured	6.997 ± 0.636 ^b	6.826 ± 0.842	6.012 ± 0.690	6.852 ± 0.749 ^{ab}	5.444 ± 0.491	5.645 ± 0.420 ^a	5.043 ± 0.635	5.495 ± 0.497 ^{ab}	
Schofield	7.293 ± 0.440 ^a	6.980 ± 0.421	5.895 ± 0.361	7.070 ± 0.599 ^a	5.551 ± 0.345	5.593 ± 0.175 ^a	5.072 ± 0.325	5.532 ± 0.313 ^a	
Henry	6.949 ± 0.468 ^b	6.583 ± 0.519	6.088 ± 0.378	6.769 ± 0.545 ^b	5.425 ± 0.304	5.359 ± 0.210 ^b	4.986 ± 0.380	5.366 ± 0.295 ^b	
Cole	7.008 ± 0.371 ^b	6.636 ± 0.492	6.145 ± 0.382	6.836 ± 0.484 ^{ab}	5.408 ± 0.253	5.422 ± 0.225 ^b	5.027 ± 0.417	5.387 ± 0.271 ^b	
BMR – Schofield	-0.296 ± 0.405 ^a	-0.154 ± 0.578	0.118 ± 0.352	-0.218 ± 0.462 ^a	-0.107 ± 0.364	0.053 ± 0.399 ^a	-0.029 ± 0.412	-0.036 ± 0.385 ^a	
BMR – Henry	0.048 ± 0.403 ^b	0.243 ± 0.545	-0.075 ± 0.326	0.083 ± 0.441 ^b	0.019 ± 0.365	0.286 ± 0.479 ^b	0.057 ± 0.395	0.130 ± 0.401 ^b	
BMR – Cole	-0.016 ± 0.423 ^b	0.097 ± 0.578	-0.159 ± 0.369	-0.003 ± 0.458 ^b	0.036 ± 0.377	0.158 ± 0.353 ^{ab}	0.041 ± 0.337	0.083 ± 0.366 ^{ab}	
BMR – Schofield (%)	-4.6 ± 6.1 ^a	-3.2 ± 9.2	1.4 ± 6.1	-3.7 ± 7.1 ^a	-2.4 ± 7.0	0.5 ± 7.0 ^a	-1.5 ± 9.6	-1.2 ± 7.3 ^a	
BMR – Henry (%)	0.3 ± 5.7 ^b	2.8 ± 8.0	-1.9 ± 6.2	0.7 ± 6.5 ^b	-0.1 ± 6.9	4.6 ± 6.9 ^b	0.3 ± 8.7	1.8 ± 7.3 ^b	
BMR – Cole (%)	-0.7 ± 6.1 ^b	0.6 ± 8.7	-3.4 ± 7.3	-0.7 ± 6.9 ^b	0.1 ± 7.1	2.5 ± 6.2 ^{ab}	-0.1 ± 8.1	1.0 ± 6.8 ^{ab}	
Schof – Henry (%)	4.8 ± 0.7 ^a	5.8 ± 1.8 ^a	-3.3 ± 1.2	4.2 ± 2.8 ^a	2.2 ± 0.6 ^a	4.2 ± 0.8 ^a	1.8 ± 1.3	3.0 ± 1.3 ^a	
Schof – Cole (%)	4.0 ± 1.3 ^b	4.4 ± 2.0 ^a	-4.8 ± 1.8	3.2 ± 3.0 ^a	2.5 ± 1.7 ^a	3.0 ± 1.7 ^a	-0.2 ± 2.8	2.5 ± 1.9 ^a	
Henry – Cole (%)	-0.8 ± 1.9 ^c	-1.7 ± 2.0 ^b	-1.4 ± 1.5	-1.1 ± 1.9 ^b	0.3 ± 1.1 ^b	-1.3 ± 1.7 ^b	-2.2 ± 2.0	-0.5 ± 1.7 ^b	
Mean BMI ≥ 18.5 kg m ⁻²									
BMR measured	7.116 ± 0.658 ^a	7.291 ± 0.825 ^a	6.321 ± 0.490	7.023 ± 0.773 ^{ab}	5.631 ± 0.706	5.879 ± 0.616	5.228 ± 0.555	5.697 ± 0.678	
Schofield	7.479 ± 0.597 ^b	7.503 ± 0.656 ^b	6.149 ± 0.307	7.232 ± 0.780 ^a	5.818 ± 0.812	5.821 ± 0.453	5.326 ± 0.386	5.763 ± 0.645	
Henry	7.147 ± 0.634 ^a	7.229 ± 0.809 ^a	6.414 ± 0.365	7.034 ± 0.723 ^{ab}	5.661 ± 0.715	5.633 ± 0.542	5.275 ± 0.447	5.604 ± 0.622	
Cole	7.032 ± 0.456 ^a	7.038 ± 0.673 ^a	6.281 ± 0.334	6.889 ± 0.596 ^b	5.575 ± 0.475	5.639 ± 0.464	5.276 ± 0.442	5.569 ± 0.475	
BMR – Schofield	-0.363 ± 0.457 ^a	-0.212 ± 0.502 ^a	0.172 ± 0.305 ^a	-0.209 ± 0.488 ^a	-0.187 ± 0.422 ^a	0.059 ± 0.448	-0.098 ± 0.323	-0.066 ± 0.437 ^a	
BMR – Henry	-0.031 ± 0.468 ^b	0.063 ± 0.525 ^b	-0.093 ± 0.295 ^b	-0.011 ± 0.462 ^b	-0.029 ± 0.383 ^{ab}	0.247 ± 0.462	-0.047 ± 0.311	0.093 ± 0.434 ^b	
BMR – Cole	0.084 ± 0.426 ^b	0.222 ± 0.463 ^b	0.046 ± 0.290 ^{ab}	0.122 ± 0.420 ^b	0.057 ± 0.388 ^b	0.223 ± 0.423	-0.024 ± 0.291	0.119 ± 0.403 ^b	
BMR – Schofield (%)	-5.4 ± 6.5 ^a	-3.5 ± 7.6 ^a	2.4 ± 5.0 ^a	-3.3 ± 7.2 ^a	-3.5 ± 7.4 ^a	0.5 ± 7.6	-2.4 ± 7.1	-1.6 ± 7.7 ^a	
BMR – Henry (%)	-0.7 ± 6.4 ^b	0.6 ± 7.4 ^b	-1.7 ± 5.1 ^b	-0.5 ± 6.5 ^b	-0.8 ± 6.9 ^{ab}	3.8 ± 7.7	-1.3 ± 6.5	1.2 ± 7.6 ^b	
BMR – Cole (%)	0.8 ± 5.8 ^b	2.6 ± 6.6 ^b	0.4 ± 5.0 ^{ab}	1.3 ± 6.0 ^b	0.4 ± 7.1 ^b	3.3 ± 7.0	-0.9 ± 6.1	1.5 ± 7.1 ^b	
Schof – Henry (%)	4.5 ± 0.8 ^a	3.9 ± 2.4 ^a	-4.3 ± 1.2 ^a	2.6 ± 3.7 ^a	2.6 ± 1.1 ^{ab}	3.4 ± 1.6 ^a	1.0 ± 1.3	2.7 ± 1.6 ^a	
Schof – Cole (%)	6.0 ± 1.8 ^b	6.0 ± 2.2 ^b	-2.1 ± 1.3 ^b	4.5 ± 3.7 ^b	3.6 ± 4.3 ^a	3.3 ± 1.9 ^b	0.9 ± 2.1	3.2 ± 3.3 ^a	
Henry – Cole (%)	1.6 ± 2.6 ^c	2.2 ± 2.9 ^c	2.1 ± 1.2 ^c	1.9 ± 2.5 ^a	1.1 ± 3.5 ^b	-0.0 ± 2.6 ^b	-0.2 ± 1.8	0.5 ± 3.0 ^b	

Comparisons were made separately for absolute values, absolute differences, percent differences among measured BMR and each predictive set of equations, and percent differences among predictive set of equations. *P < 0.05 among values with different letters within each gender and age group.

Table 6 Comparison of measured and predictive basal metabolic rate (BMR) in subjects with mean body mass index (BMI) over 18.5 kg m⁻² (includes overweight and obese subjects), using linear regression and concordance correlation (r_c) analysis

	Men						Women							
	n	r ²	r	SEE	MSPR	r _c mean ± SD	r _c CI	n	r ²	r	SEE	MSPR	r _c mean ± SD	r _c CI
All	130	0.644	0.803	0.463	0.280	0.774 ± 0.036	0.704–0.845	131	0.613	0.783	0.423	0.194	0.778 ± 0.035	0.710–0.846
BMR/Schofield	130	0.659	0.812	0.453	0.212	0.809 ± 0.030	0.750–0.869	131	0.609	0.780	0.426	0.196	0.770 ± 0.036	0.699–0.840
BMR/Henry	124	0.715	0.846	0.417	0.177	0.809 ± 0.027	0.756–0.862	125	0.668	0.817	0.396	0.159	0.786 ± 0.032	0.725–0.848
18.0–29.9 years	61	0.545	0.738	0.448	0.338	0.628 ± 0.072	0.488–0.769	57	0.731	0.855	0.370	0.209	0.821 ± 0.044	0.736–0.907
BMR/Schofield	61	0.545	0.738	0.448	0.216	0.737 ± 0.059	0.621–0.854	57	0.731	0.855	0.370	0.145	0.854 ± 0.037	0.782–0.926
BMR/Henry	59	0.600	0.775	0.425	0.181	0.714 ± 0.054	0.608–0.821	57	0.732	0.856	0.369	0.138	0.820 ± 0.039	0.744–0.896
30.0–59.9 years	44	0.630	0.794	0.508	0.291	0.743 ± 0.066	0.613–0.872	59	0.474	0.688	0.451	0.201	0.653 ± 0.070	0.516–0.790
BMR/Schofield	44	0.630	0.794	0.508	0.273	0.791 ± 0.058	0.678–0.905	59	0.474	0.688	0.451	0.271	0.625 ± 0.077	0.474–0.777
BMR/Henry	41	0.700	0.837	0.468	0.221	0.804 ± 0.052	0.701–0.906	54	0.555	0.745	0.427	0.197	0.715 ± 0.066	0.586–0.844
≥60.0 years	25	0.643	0.802	0.299	0.119	0.661 ± 0.096	0.473–0.849	15	0.678	0.823	0.327	0.107	0.754 ± 0.103	0.552–0.957
BMR/Schofield	25	0.642	0.801	0.300	0.092	0.749 ± 0.084	0.585–0.914	15	0.687	0.829	0.322	0.092	0.806 ± 0.091	0.628–0.985
BMR/Henry	24	0.690	0.831	0.285	0.094	0.734 ± 0.082	0.574–0.894	14	0.745	0.863	0.299	0.097	0.813 ± 0.095	0.627–0.998
All	130	0.899	0.948	0.249	0.100	0.913 ± 0.015	0.885–0.942	131	0.977	0.988	0.098	0.035	0.957 ± 0.006	0.946–0.969
Schofield/Henry	124	0.909	0.954	0.237	0.136	0.863 ± 0.019	0.824–0.901	125	0.896	0.947	0.213	0.077	0.895 ± 0.016	0.863–0.926
Schofield/Cole	124	0.948	0.974	0.165	0.041	0.952 ± 0.006	0.940–0.963	125	0.939	0.969	0.158	0.027	0.960 ± 0.005	0.950–0.970
18.0–29.9 years	61	1.000	1.000	0.000	0.112	0.869 ± 0.005	0.860–0.878	57	1.000	1.000	0.000	0.034	0.971 ± 0.005	0.962–0.980
Schofield/Henry	59	0.956	0.978	0.126	0.159	0.763 ± 0.030	0.704–0.823	57	0.967	0.983	0.149	0.140	0.857 ± 0.024	0.811–0.903
Schofield/Cole	59	0.956	0.978	0.134	0.046	0.922 ± 0.010	0.902–0.941	57	0.967	0.983	0.132	0.044	0.944 ± 0.008	0.928–0.960
30.0–59.9 years	44	1.000	1.000	0.000	0.098	0.913 ± 0.015	0.885–0.942	59	1.000	1.000	0.000	0.043	0.918 ± 0.011	0.896–0.939
Schofield/Henry	41	0.947	0.973	0.155	0.130	0.865 ± 0.025	0.816–0.914	54	0.944	0.972	0.112	0.028	0.944 ± 0.012	0.921–0.968
Schofield/Cole	41	0.947	0.973	0.191	0.054	0.950 ± 0.012	0.927–0.973	54	0.972	0.944	0.134	0.012	0.980 ± 0.006	0.969–0.990
≥60.0 years	25	0.968	0.984	0.056	0.077	0.734 ± 0.037	0.661–0.807	15	0.997	0.999	0.021	0.007	0.980 ± 0.008	0.964–0.996
Schofield/Henry	24	0.945	0.972	0.075	0.089	0.684 ± 0.039	0.608–0.761	14	0.951	0.975	0.092	0.011	0.968 ± 0.016	0.936–0.999
Schofield/Cole	24	0.961	0.980	0.075	0.006	0.972 ± 0.010	0.953–0.992	14	0.957	0.978	0.099	0.015	0.963 ± 0.017	0.930–0.996

SEE – Standard error of the estimate; MSPR – Mean squared prediction error.

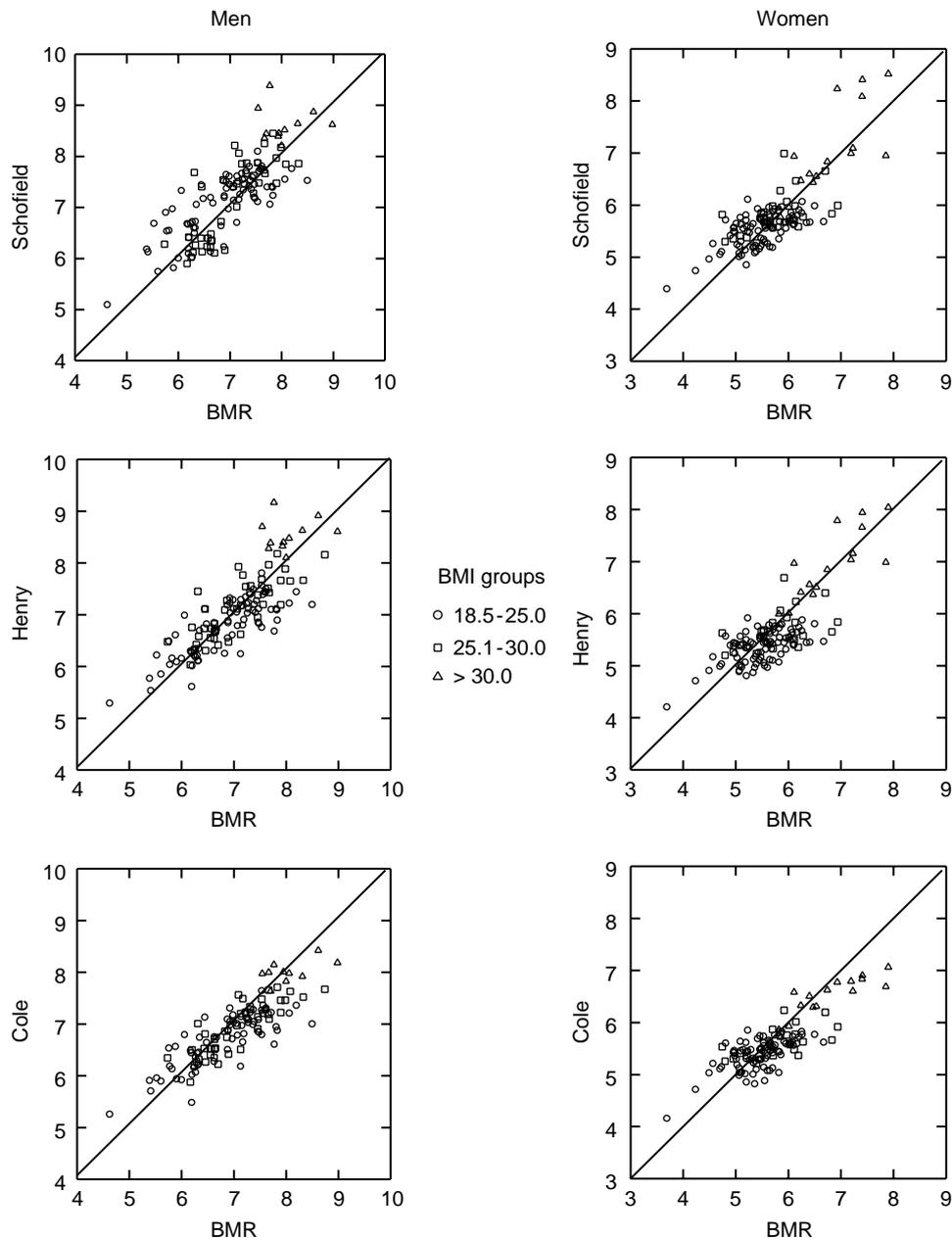


Fig. 1 Scatter plots among measured and predictive basal metabolic rate by each set of equations (Schofield, Henry and Cole) of group of subjects with mean body mass index (BMI) over 18.5 kg m⁻² (includes overweight and obese groups)

and body weight and fitting a locally weighted smoothing function to the data.

The Henry and Cole equations had a better concordance coefficient than Schofield's equations with any of them (confidence intervals do not intersect), probably because the former equations were generated from the same database.

A limitation of the study was that the validation exercise was conducted using mean values for age, anthropometry, and BMR rather than on individual data, due mainly to lack of individual data from all studies included in the analysis. Nevertheless, the use of BMR predictive equations is for

the estimation of energy requirements and recommendations, which were developed for their application in populations².

Figure 2 shows that most of the non-Caucasian group of subjects had the lowest BMR values. The previously reported overestimation of BMR by Schofield's equations in several ethnic groups, particularly from developing regions⁴⁻⁹, is also demonstrated in men with the present data.

In conclusion, although there were no differences in agreement among the three sets of equations, the accuracy of Henry's equations was better in men and of

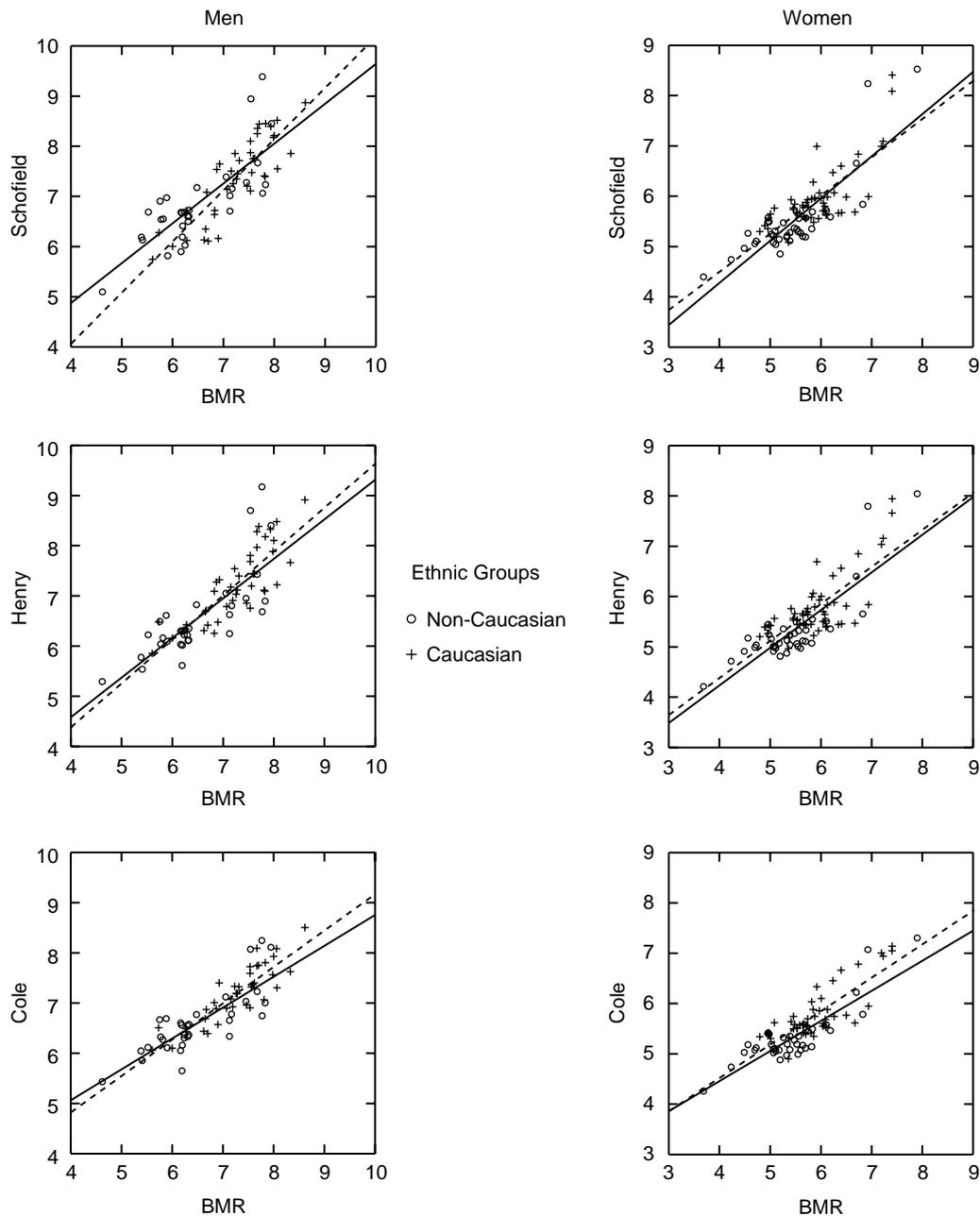


Fig. 2 Scatter plots among measured basal metabolic rate and Schofield, Henry, and Cole predictive equations for non-Caucasian (continuous fit line) and Caucasian (dotted fit line) group of subjects with mean body mass index (BMI) between 18.5 and 25.0 kg m⁻²

Schofield's equations in women. Furthermore, the MSPR was lowest for Henry's equations in men and Cole's equations in women. These results support the use of Henry's equations in men. The inconsistency in women might be related to the poor association between predictive and measured BMR.

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