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1 **Plausible self-reported dietary intakes in a residential facility are not**
2 **necessarily reliable.**

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19 Running Head : Misreporting of energy intakes

20 **Conflicts of interest**

21 The authors declare no conflict of interest.

22 **Abstract**

23 **BACKGROUND/OBJECTIVES** Comparing reported energy intakes to estimated energy
24 requirements as multiples of Basal Metabolic Rate ($E_{in}:BMR$) is an established method of
25 identifying implausible food intake records. The present study aimed to examine the validity
26 of self-reported food intakes believed to be plausible.

27 **SUBJECTS/METHODS** One hundred and eighty men and women were provided with all
28 food and beverages for two consecutive days in a residential laboratory setting. Subjects self-
29 reported their food and beverage intakes using the weighed food diary method (WDR).
30 Investigators covertly measured subjects' actual consumption over the same period. Subjects
31 also reported intakes over four consecutive days at home. Basal Metabolic Rate was
32 measured by indirect calorimetry.

33 **RESULTS** Average reported energy intakes were significantly lower than actual intakes
34 (11.2MJ/d and 11.8MJ/d respectively, $p < 0.001$). Two-thirds (121) of the WDR were under-
35 reported to varying degrees. Only five of these were considered as implausible using an
36 $E_{in}:BMR$ cut-off value of $1.03 \times BMR$. Under-reporting of food and beverage intakes, as
37 measured by the difference between reported and actual intake, was evident at all levels of
38 $E_{in};BMR$. Reported energy intakes were lower still (10.2MJ/d) while subjects were at home.

39 **CONCLUSION** Under-recording of self-reported food intake records was extensive but very
40 few under-reported food intake records were identified as implausible using energy intake to
41 BMR ratios. Under-recording was evident at all levels of energy intake.

42

43 **Key words:** Misreporting, under-reporting, under-eating, dietary intake.

44

45 **Introduction**

46 Almost all dietary intake measurements are self-reported and therefore prone to distortion by
47 subjects inaccurately or incompletely reporting their diets. Based on the fundamental
48 principles of energy balance, it is now generally accepted that under-reporting, or
49 misreporting, of food intake is widespread if not universal (1-4). Many subjects in diet
50 surveys misreport their food intake to an extent that may distort the relationships between diet
51 and health that inform policy decisions (e.g. 5).

52 Aside from technical errors in the recording of food intake (such as inadequate descriptions
53 of foods, accuracy of food weighing scales or unclear instructions given to participants) the
54 misreporting of food intake can be considered as having two components. Firstly participants
55 choose different foods from normal when they are aware that their diet is being monitored
56 (the observation effect), either to report a diet that they believe is closer to the recommended,
57 or for convenience as some foods and meals are simply easier to weigh than others (6).
58 Secondly participants fail to record all of the foods that they actually consume, either
59 consciously or accidentally (the recording effect) (7).

60 It is usually assumed that misreporting of food intake is biased more towards reporting lower
61 rather than higher energy intakes, and there is indirect evidence to support this when reported
62 energy intakes are compared against energy expenditure (see below). More direct evidence is
63 harder to find, although weight stable obese subjects under-reported energy intake from a
64 buffet meal, whereas normal weight subjects accurately reported intakes (8). Perhaps
65 unsurprisingly weight restored patients with anorexia nervosa over-reported energy intake in
66 the same study (8). When a measure of true food intake is available for periods of a day or
67 two-weeks, group average reported energy intakes are lower than actual energy intakes, and
68 most individuals under-report their food intake, although a small number do over-report (7,
69 9).

70 When direct observation of food intake is not possible, the most widely used methods of
71 identifying individuals suspected of reporting low energy intakes are the Goldberg cut-off
72 method and by comparison to energy expenditure through indirect calorimetry, *viz.* the
73 doubly labelled water technique (10). A major problem is that these methods rely on
74 measures of energy expenditure that are imperfect, or estimates of energy expenditure based
75 on assumptions about levels of physical activity and regression equations to estimate BMR.

76 The Goldberg cut-off method aims, statistically, to identify subjects who report implausibly
77 low energy intake to BMR ratios either for long-term habitual intake (cut-off 1) or for intake
78 over the measurement period (cut-off 2)(11). The cut-off values are based on the assumption
79 that subjects are in energy balance and that their energy requirements have been accurately
80 estimated, with the cut-off value being adjusted to account for the uncertainty in estimating
81 BMR and the duration of the diet recording period. Predicting BMR can be difficult,
82 especially so in the obese as common regression methods over-estimate BMR at higher body
83 weights (12), and assumptions have to be made about physical activity levels. Subsequent
84 recommendations were made that measurements or estimates of individual physical activity
85 levels are necessary (13). In addition higher reported intakes may also be affected by
86 misreporting and higher intakes are more likely in those with higher activity levels.
87 Furthermore, most subjects tend to be in a negative energy balance (as estimated by change in
88 body weight) when completing food intake records (14-16).

89 The use of energy intake to BMR ratios to identify low reported energy intakes has also been
90 compared to that of using biomarkers of diet, the most widely used being the ratio of urinary
91 to dietary nitrogen (17), a method that is also not without its limitations. Thus, self-reported
92 dietary intakes have been compared to indirect measures of energy expenditure (as an indirect
93 measure of energy intake assuming energy balance), or indirect measures of protein intake (as
94 an indirect measure of energy intake). What is missing, and is needed, is a direct, precise and
95 concurrent measure of food intake against which to test the ability of energy intake to BMR
96 ratios to identify misreporting of energy intake.

97 We have previously developed and validated a “gold standard” method of measuring food
98 intake, and used it to quantify the nature and extent of misreporting of diet in the laboratory,
99 albeit under conditions that were as close to free-living as practicable *i.e.* in a residential
100 metabolic facility (7). This gold standard method, the laboratory weight intake (LWI) allows
101 a direct comparison to be made between food intake reported by subjects and their actual
102 food intake. The current study aimed to assess the validity of self-reported weighed food
103 intake records completed in a laboratory setting and that would be considered plausible using
104 the criterion of reported energy intake to BMR ratios. Effects of recording food intake under
105 more usual, real world, diet survey conditions on reported energy intake were then
106 considered.

107 **Methods and Materials**

108 **Study design**

109 **Subjects**

110 One hundred and eighty, apparently healthy, men and women were recruited from the
111 Aberdeen area. The real purpose of the study was, necessarily, not explained to the subjects
112 and they were informed that it was to examine the relationships between diet and lifestyle.

113 **Recruitment and ethics**

114 Prospective volunteers were invited to the Human Nutrition Unit (HNU) of the Rowett
115 Institute of Nutrition and Health where all procedures involved in the study and any
116 discomfort or risk they may have posed were explained. This study was conducted according
117 to the guidelines laid down in the Declaration of Helsinki and all procedures involving human
118 subjects were approved by the Joint Ethical Committee of the Grampian Health Board and
119 the University of Aberdeen. Written informed consent was obtained from all subjects.

120 **Protocol**

121 Each subject was studied using a randomized cross over design for two consecutive days in
122 the laboratory and four consecutive days in their natural environment (home). The days of the
123 week on which subjects completed the measurements was balanced between the laboratory
124 and home phases.

125 **Laboratory phase**

126 Subjects each completed a one-day maintenance period (at home) during which they were
127 provided with a fixed diet designed to maintain energy balance estimated at 1.6 and 1.5 times
128 BMR for men and women respectively. For the following two days (one week-day and one
129 weekend-day, randomized to Friday and Saturday or Sunday and Monday) subjects were
130 resident at the HNU where food intake was covertly quantified on a daily basis by the
131 investigators, using a previously described LWI method (7).

132 Each subject was provided with an individual larder and had *ad libitum* access to variety of
133 familiar foods, and food intake was continuously and covertly monitored and quantified by

134 trained staff. All food items were weighed by research staff before they were placed into each
135 subject's personal larder. Each subject received bottled water for drinking, and their own
136 individual kettle, in order to allow an estimate of water consumption. Full verbal and written
137 instructions regarding the kitchens including information on waste and packaging, and use of
138 kettles and water were given to each subject. Subjects were instructed not to throw any waste
139 away including packaging of food items and peelings, and uneaten food from meals. Every
140 kitchen contained a special bin for all waste and packaging, with all waste items being
141 individually wrapped. Subjects were also instructed not to wash any dishes.

142 An investigator entered the kitchen each morning before the subject awoke and re-weighed
143 all food items, any leftovers including peelings, and packaging found in the subjects'
144 individual bins. This enabled accurate estimates of 24-hour food intake to be calculated.
145 Subjects were unaware of this procedure, and this constituted the "gold standard" against
146 which to compare self-reported food intakes (7). Each subject was asked to weigh and record
147 all food items eaten and all fluids drunk using the Weighed Dietary Record (WDR) method
148 (18). Full written and verbal information on how to carry this out was given at the beginning
149 of the study.

150 Thus, the LWI was investigator measured actual food intake, and the WDR was food intake
151 as self-reported by subjects during the residential stay in the laboratory (WDR-L). The
152 difference between the LWI and WDR-L was therefore the reporting effect (the difference
153 between what subjects actually ate and reported eating). The observation effect (change in
154 diet) as a result of the subject being aware that their diet was being evaluated was not
155 measured and would have been an additional source of misreporting error (7).

156 **Home phase**

157 The five-day home study consisted of a one-day maintenance, with the same maintenance
158 diet as during the laboratory phase, and two weekdays and two weekend days (randomized to
159 Thursday – Sunday or Saturday – Tuesday) within the subject's natural environment (i.e. at
160 home). Subjects were asked to complete a four-day WDR (WDR-H) on days two-five using
161 the same procedure as during the laboratory phase.

162

163 **Dietary analysis**

164 Dietary data for all methods were analysed using Diet 5 (Robert Gordon University,
165 Aberdeen), a computerized version of McCance and Widdowson composition of foods, and
166 supplements (19).

167 **Basal Metabolic Rate**

168 Respiratory exchange was measured using a ventilated hood system (Deltatrac II, MBM-200,
169 Datex Instrumentarium Corporation, Helsinki) under standardized conditions in subjects who
170 were fasted for 12 hours from the previous night. BMR was calculated using the equations of
171 Elia and Livesy (20).

172 **Anthropometry**

173 Body weight was measured on each morning of the study when subjects were resident in the
174 HNU, and at the start and end of the WDR-H period when subjects were at home, using a
175 digital platform scale (DIGI DS-410 CMS Weighing Equipment, London) to the nearest 0.01
176 kg after voiding and before eating. Subjects were weighed in dressing gowns of a known
177 weight and body weight was then corrected back to nude.

178 Height was measured to the nearest 0.5cm before subjects started the study using a portable
179 stadiometer (Holtain Ltd., Crymych, Dyfed, Wales).

180 **Statistics**

181 The cut-off value for weighed intake records and measured BMR was calculated as
182 $1.03 \times \text{BMR}$ for the two-day WDR-L and $1.10 \times \text{BMR}$ for the four-day WDR-H following the
183 method of Goldberg et al. (1991). All analyses were performed using Statistical Package of
184 Social Sciences software (SPSS Inc., Chicago, IL, USA; Version 21.0.0.1). T-tests were used
185 for comparison of the reporting effect (WDR-L - LWI) between groups of male and female,
186 and lean and overweight subjects. Pearson's correlations were used to assess the strength of
187 the relationship between energy intake and energy requirements. Differences were accepted
188 as statistically different at the 5% level.

189 **Results**

190 **Table 1** gives the age, height, weight, BMI and BMR of the subjects. Mean daily absolute
191 energy intakes, and energy intake relative to BMR from subjects' self-reported food intakes
192 (WDR-L) were significantly lower than those from the LWI (**table 2**). Both actual (LWI) and
193 reported energy intakes (WDR-L) were positively correlated with BMR ($r = 0.487$, $P < 0.001$
194 and $r = 0.516$, $P < 0.001$ respectively).

195 < TABLE 1 NEAR HERE >

196 < TABLE 2 NEAR HERE >

197 The reporting effect (WDR-L - LWI) was significantly greater in males than it was in females
198 ($p = 0.025$). There was no significant difference in the reporting effect between lean ($BMI \leq$
199 $25\text{kg}\cdot\text{m}^{-2}$) and overweight ($BMI > 25\text{kg}\cdot\text{m}^{-2}$) subjects ($p=0.539$).

200 Six subjects (3.3%) reported energy intakes that were below the Goldberg cut-off value of
201 $1.03 * BMR$. Of these, five had actual energy intake that were less than $1.03 * BMR$.

202 Mean change in body weight over the two-days was significantly different from zero for
203 males ($+0.21\text{kg}$, $P = 0.001$) and all subjects combined ($+0.09\text{kg}$, $P = 0.025$), but not for
204 females (-0.02kg , NS).

205 **Figure 1** shows the difference in mean daily energy intake calculated from each subjects'
206 self-reported food intake and that calculated from the investigator measured intake (WDR-L -
207 LWI). Values less than zero show those subjects who under-reported their food intake (67%
208 of subjects), and values greater than zero show those subjects who over-reported their food
209 intake (33% of subjects). The appropriate cut-off value ($1.03*BMR$) is shown by the vertical
210 line, values to the left of this line would be considered as implausible measures of the food
211 consumed over the two-day recording period, whereas values to the right would be
212 considered as acceptable. The same data are presented in **figure 2** but with the WDR-L
213 expressed as a percentage of the LWI for each subject.

214 < FIGURE 1 NEAR HERE >

215 < FIGURE 2 NEAR HERE >

216 Self-reported energy intakes during the home phase (WDR-H) were significantly lower than
217 the WDR-L energy intakes (table 2). Few people (20 or 11%) who reported implausible
218 energy intakes ($< 1.10 * \text{BMR}$) during the home phase of the study had also reported energy
219 intakes that were less than the LWI during the laboratory phase (figure 3). Almost half (101
220 or 56%) of the participants who under-reported energy intake in the laboratory reported
221 plausible levels of energy intake at home.

222 < FIGURE 3 NEAR HERE >

223 Mean change in body weight over the four-day WDR-H period was similar to the WDR-L
224 period with males gaining a small, and borderline statistically significant, amount of weight
225 (+0.14kg, $P = 0.057$). Change in weight for females and all subjects combined was not
226 significantly different from zero (-0.08kg and +0.03kg respectively).

227

228 **Discussion**

229 This study explored whether plausible reports of energy intake, as determined by energy
230 intake to BMR ratios, are always valid and accurate under residential laboratory conditions.
231 Low reported energy intakes – those that would normally be considered implausible - can be
232 valid, and of greater concern is that the majority of plausible food intake records are under or
233 over-reported to varying degrees. It is not simply a case of too lenient a cut-off values.
234 Increasing it does not solve the problem of misreporting, which is a continuous trait that is
235 not easily accounted for by categorical cut-offs. Mis-reporting of food intake under free-
236 living conditions appears to be greater than in the laboratory.

237 In a prior study, when a different group of subjects recorded their food intake they changed
238 their diet such that energy intake decreased by 5.3% (the observation effect), the difference
239 between what they ate and what they reported was a further decrease in energy intake of
240 5.1% (the reporting effect) (7). In the current study the reporting effect was a similar 3.8% of
241 actual energy intake.

242 The prevalence of low energy reporting as determined using an energy intake to BMR cut-off
243 value was only 5% in our previous study and 3% in the current study (and 18% when subjects
244 were at home), considerably lower than the average of 33% (range 14% to 39%) reported by
245 Poslusna *et al.* (10) in a review of misreporting of energy intakes, and when considering
246 weighed food records. It appears, therefore, that subjects in both studies, reported more
247 complete food records, or at least higher energy intakes, than is typical during free-living
248 studies. It is quite possible that the residential nature of the study, with fewer of the usual
249 day-to-day distractions, increased the completeness of food recording. It is also likely that
250 subjects were in positive energy balance over the two-days residential stay as the nature of
251 the protocol meant that subjects were sedentary whereas the average observed energy intake
252 was $1.82 \times \text{BMR}$. This is higher than the estimated physical activity level of $1.78 \times \text{BMR}$ of
253 groups judged to be more active than average (21). This is supported by the small, but
254 statistically significant average change in body weight, although using change in body weight
255 as an estimate of change in energy balance over such a short period is only an approximation.
256 Therefore, reported energy intakes were more likely to be above the misreporting cut-off than
257 would be expected, as any misreporting was from a level that was probably higher than
258 habitual. Even when low energy reporting was much less than usual there was still a large

259 discrepancy between the numbers of people identified as reporting implausible levels of
260 energy intakes and actually misreporting food intake.

261 Under-reporting, and even over-reporting, were evident in both plausible and implausible
262 food records, not just below or near the low-energy reporting cut-off value. Under-reporting
263 of 12MJ/d was seen in one subject with a reported energy intake of almost 3*BMR (subject X
264 in figure 1). In contrast another subject accurately reported an energy intake that was less
265 than half of BMR (subject Y in figure 1).

266 Most studies report an association between BMI and misreporting; subjects with higher BMIs
267 being more likely to be classified as low-energy reporters, or a positive correlation between
268 BMI and the difference between energy intake calculated from reported food intake and
269 either estimated energy requirements or measured energy expenditure (10). An effect of BMI
270 on the degree of misreporting was not apparent in the current study, or our previous study (7).
271 The few studies that have used a covertly measured food intake as the reference have shown
272 mixed results - either no effect of BMI on the degree of misreporting (9, 22), that obese
273 subjects are more accurate in reporting their food intake than are overweight or lean subjects
274 (23), or less accurate (8). Most of these studies have used diet recalls completed after the
275 covert food intake measurement rather than concurrent measures thereby introducing a
276 further source of uncertainty into the dietary intake method since the recall method relies on
277 the ability and motivation of subjects to remember what was eaten. The difference in the
278 apparent effect of BMI on the degree of misreporting when using estimated energy
279 requirements compared to actual food intake may reflect a difficulty in estimating energy
280 requirements in individuals with higher BMIs. BMR is often estimated using well established
281 linear regression equations (24, 25). These equations tend to overestimate BMR at higher
282 body weights because the increase in BMR with body weight is curvilinear. Increases in
283 metabolically active fat-free-mass and metabolically less-active fat-mass do not occur at a
284 linear rate as body weight increases (12). Overestimating BMR will lower the ratio of
285 reported energy intake to BMR, and result in subjects with higher BMIs being more likely to
286 be identified as low-energy-reporters than are lean subjects. Additionally, the Schofield
287 equations underestimate BMR at lower body weights (25) resulting in leaner subjects being
288 more likely to have reported energy intake to BMR ratios within the plausible range.
289 However, the overweight and obese are still more likely to be classified as low-energy-
290 reporters than are the “normal” weight after accounting for differences in body composition

291 by estimating BMR from estimated fat-free-mass (26). Therefore the difference in prevalence
292 of misreporting between the lean and overweight may still exist, but might not be as great as
293 is generally reported.

294 It has been argued that removing subjects who report implausibly low energy intakes
295 introduces bias into any analyses (10), because subjects with higher energy requirements are
296 also likely to under-report their food intake. The current study supports this.

297 Reported energy intakes were lower over the home phase than the residential phase, possibly
298 because the residential environment of the HNU encouraged more complete food records, or
299 the home environment hindered record keeping – or both. It is also possible that subjects
300 altered their behaviour when in the HNU, which resulted in higher than habitual energy
301 intakes. Food and drink were provided free to the subjects, and they probably had more time
302 to prepare and eat meals than they would have had at home.

303 That so few subjects reported low energy intakes during both the home and laboratory phases
304 suggests that people cannot be classified as consistently plausible reporters or consistently
305 implausible reporters. Furthermore, misreporting of food intake is continuous and is not
306 resolved with categorical cut-offs.

307 Plausible records that are invalid present difficulties for intervention and epidemiological
308 studies, to the extent that some have argued that reliance on self-reported dietary intakes
309 should be discontinued (27).

310 **Limitations**

311 The results of this study, and therefore the conclusions drawn from it, are subject to a number
312 of limitations.

313 Actual, and reported, energy intakes were higher during the laboratory phase than would be
314 expected for sedentary subjects, and it is likely that the cut-off value would have identified
315 more subjects with low reported energy intakes had subjects been studied in their natural
316 environment. This would, however, have precluded an accurate measure of true food intake.
317 A lack of a covert and objective measure of food intake during the home phase of the study is
318 an unavoidable limitation.

319 In the present study energy expenditure was not measured during the time that subjects were
320 completing the food records. However, energy intake when subjects were resident in the
321 HNU was measured under identical conditions to a previous study where measured energy
322 intake matched measured energy expenditure (7).

323 **Summary**

324 Comparing reported energy intakes to estimates of energy expenditure has become an
325 established method to identify implausible food intake records. We have previously shown
326 that low-energy reporting, when compared to the gold standard Laboratory Weighed Intake
327 method, occurs at all levels of energy turn-over (7). In this study we demonstrated that
328 misreporting occurs at all levels of energy intake and found that the many plausible records
329 of energy intake were inaccurate to variable degrees. The method of using energy intake to
330 BMR ratios probably introduces bias by only excluding misreporters with low reported
331 energy intakes and retaining misreporters with higher reported energy intakes. It may also
332 have given researchers, and readers of the literature, a false confidence in the completeness of
333 dietary data.

334

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337 Standards Agency, UK.

338

339 **Conflicts of interest**

340 The authors declare no conflict of interest.

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Figure legends.

Figure 1. Difference in mean daily energy intake calculated from each subjects' self-reported food intake and that calculated from the investigator measured intake (WDR-L - LWI) against estimated energy requirements. WDR, weighed dietary record - laboratory. LWI, laboratory weighed intake.

Section A; Subjects identified as low energy reporters by the Goldberg method, but with valid/over reports of energy intake.

Section B; Subjects identified as acceptable reporters by the Goldberg method, but with valid/over reports of energy intake.

Section C; Subjects identified as low energy reporters by the Goldberg method, and under reported energy intake.

Section D; Subjects identified as acceptable reporters by the Goldberg method, and with valid/over reports of energy intake.

Figure 2. Reporting effect against estimated energy requirements. WDR-L, weighed dietary record - laboratory. LWI, laboratory weighed intake.

Section A; Subjects identified as low energy reporters by the Goldberg method, but with valid/over reports of energy intake.

Section B; Subjects identified as acceptable reporters by the Goldberg method, but with valid/over reports of energy intake.

Section C; Subjects identified as low energy reporters by the Goldberg method, and under reported energy intake.

Section D; Subjects identified as acceptable reporters by the Goldberg method, and with valid/over reports of energy intake.

Figure 3. Reported energy intake during the home phase of the study relative to BMR against reported energy intake relative to actual energy intake during the residential phase of the study. WDR-H, weighed dietary record – home. WDR-L, weighed dietary record - laboratory. LWI, laboratory weighed intake.

Table 1 : Baseline characteristics of participants by sex, age and BMI group. (Mean values with their st

Sex	BMI Category kg/m ²	n	Age (Years)		Height (m)		Weight (kg)	
			Mean	SD	Mean	SD	Mean	SD
Females	20-25	47	41.6	12.9	1.65	0.06	60.2	5.9
Females	>25	48	45.0	11.8	1.62	0.05	75.4	9.1
Males	20-25	32	39.8	12.8	1.76	0.08	69.5	6.9
Males	>25	53	42.3	11.8	1.78	0.07	89.4	10.7

BMI: Body Mass Index. BMR: Basal Metabolic Rate

andard deviations)

BMR (MJ/d)		BMI (kg/m ²)	
Mean	SD	Mean	SD
5.5	0.8	22.3	1.8
6.0	0.8	28.6	3.0
6.7	1.3	22.4	1.4
7.6	1.0	28.3	2.8

Table 2 : Average daily energy intake and energy intake relative to BMR over the WDR-L and WDR

	LWI		WDR-L		P (WDR-L and LWI)
	MJ/d	SE	MJ/d	SE	
Energy					
Females	9.6	0.28	9.2	0.24	0.007
Males	14.2	0.44	13.3	0.38	<0.001
All	11.8	0.3	11.2	0.27	<0.001
Energy/BMR					
Females	1.68	0.05	1.62	0.04	0.011
Males	1.98	0.06	1.85	0.05	<0.001
All	1.82	0.04	1.73	0.03	<0.001

LWI: Laboratory Weighed Intakes, WDR-L: Weighed Dietary Record Lab., WDR-H: Weighed Dietar

t-H measurement periods		
WDR-H		P (WDR-H and WDR-L)
MJ/d	SE	
8.5	0.20	<0.001
12.1	0.34	<0.001
10.2	0.23	<0.001
1.49	0.03	<0.001
1.67	0.04	<0.001
1.57	0.03	<0.001

y Record Home. BMR: Basal Metabolic Rate.





