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Weight Loss and Calorie Restriction at 50% Fasting Rate

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Abstract: In planning a diet with the purpose of weight loss, a doctor will invariably need to cut back calories consumed by the patient. As a rule of thumb, 3500 cal/lb is the calories eliminated for loss of one pound of body weight. This work is a pilot study to see the relation between the calorie deficit and the rate of weight loss in humans. A random search was made for data points and the search was stopped when the average fasting rate was about 50% and N = 51 data points were found. Water loss enters in and people have different metabolisms, so the 3500 figure has an uncertainty of about 20%. The author performed the literature search, in addition to adding his own data and he came up with a new value of 3511 cal/lb. This result originates from calorie restriction data on an otherwise normal diet in terms of the proportion of fat, carbohydrate and protein. The well-known result of 3500 cal/lb agrees with data from diets at a 50% fasting rate. Evidently the 3500 cal/lb figure holds throughout the entire fasting range.

Key words: Energy intake, linear model, fasting, calorie restriction, rate of weight loss

INTRODUCTION

In this paper the author has attempted to lay out a strategy for looking at diet to test the well-accepted figure of D = 3500 cal/lb as being the value for the loss of one pound of body weight from calorie-driven weight loss. A linear equation is employed where the calorie deficit is directly proportional to the rate of weight loss per day. The acceptable data is used in the linear equation and gives a value very close to the well-known value for N = 51 diets for a fasting rate of 50%, where normal eating is zero fasting rate and complete fasting is fasting rate = 1.0. It has been noted (Thomas *et al.*, 2010) that energy intake during weight loss is difficult and costly to measure accurately. I found looking at N = 51 diets where weight data and calorie intake were available enables calculation of D, given that one can get the normal calorie intake by equations involving the RMR (resting metabolic rate) and estimates for F_A (the activity factor). The normal calorie intake, C_o, was obtained by the formula $C_o = (RMR)(F_A)$. The literature search employed in this study was done at random, but a more extensive study could be done with more time and money.

MATERIALS AND METHODS

Data was gathered from the biomedical literature. Acceptable data could be used in a linear model for dietary energy intake, where the calorie deficit is directly proportional to the rate of weight loss. The calorie deficit is the number of calories consumed below the maintenance calories at the beginning of the characteristic linear period of weight loss for the individual. The data is: (sex, height and weight) or (sex, weight and age). This is because two effective predictive equations for the RMR, or resting metabolic rate, use either of those two groups of parameters. Unacceptable data occurred where the weight was not accurate (e.g., only to nearest kilogram), the age was given as a range (not as a mean), or the men and women were grouped together and their weights or ages were averaged between the sexes. Also, if it is not clear what were the calories eaten, that would constitute incomplete data. It was necessary to go through twenty papers to get the six papers with the diets to do this study. The author performed a literature search by getting individual papers through separate searches on Pub Med and garnering others from the references section of relevant papers. An effort was made to have an equal number of men's and women's diets and have an equal number of diets above and below the point where the normalized calorie deficit $f = (C_o - C_e)/C_o$ was 0.5 (see Supplement). When this was achieved, the search for data points was over. All good data points were included in the calculations. The assumption was, no matter how the papers were gathered, the resulting total of N = 51 diets would give a statistically significant value for D and the value turned out to be very close to the accepted value. This study is an example of how a more exhaustive study might be done by showing how the data can be worked up.

There are four different calculations first, of the four different cases for Dk and one other calculation showing one example of how the activity factors for obese men and women were got. See Tables 1 and 2 for data and sources.

Five sample calculations (Nos. are numbered data points 1-20 in Table 1, 2).

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Table 1: Data I for calculation of cal/kg

No.	Ref.	NASOP, Patient I.D.	Age (Years)	$(dW/dt)_0$ (kg/day)	W_0 (kg)	RMR (cal/day)
1	(Blondhein *et al.*, 1981)	1F, #1	n/a	-0.195	89.8	1558.87a
2	(Blondhein *et al.*, 1981)	1F, #1	n/a	-0.183	82.9	1514.80a
3	(Blondhein *et al.*, 1981)	1M, #10	n/a	-0.296	133.1	2049.89a
4	(Blondhein *et al.*, 1981)	1M, #10	n/a	-0.306	126.1	2000.28a
5	(Benedict, 1915)	1M, Levanzin	40	-0.30718	50.526	1364.56/1.05b
6	(Benedict, 1915)	1M, Succi LONDON 1890	n/a	-0.21667	45.795	1434.10/1.05a
7	(Benedict, 1915)	1M, Succi ZURICH 1896	n/a	-0.30429	63.4	1558.86/1.05a
8	(Volek *et al.*, 2004)	13F	34.0	-2.01/28	76.2	1464.63b
9	(Sharman *et al.*, 2004)	15M	33.2	-5/42	109.1	2038.29b
10	(Welle *et al.*, 1984)	6F	31	-1.8/7	87.5	1499c
11	(Ball *et al.*, 1967)	1F	39	-0.220	103.5	1672.86b
12	(Blondheim and Kaufmann, 1965)	1F, #1	n/a	-0.106	94.22	1486.85a
13	(Blondheim and Kaufmann, 1965)	1F, #2	n/a	-0.194	89.15	1544.79a
14	(Blondheim and Kaufmann, 1965)	1F, #3	n/a	-0.209	93.31	1535.23a
15	(Blondheim and Kaufmann, 1965)	1F, #4	n/a	-0.173	85.34	1511.42a
16	(Blondheim and Kaufmann, 1965)	1F, #1	n/a	-0.143	90.7	1464.37a
17	(Blondheim and Kaufmann, 1965)	1F, #2	n/a	-0.200	81.0	1492.73a
18	(Blondheim and Kaufmann, 1965)	1F, #4	n/a	-0.225	77.8	1463.27/1.05a
19	d	1M	34	-0.2227463	91.172	1738.09a
20	d	1M	34	-0.04325197	78.698	1649.69a

Points 5, 6, 7 and 18 are for (Ce = 0): RMR reduced by factor 1.05 (Blondheim and Kaufman, 1965).

a RMR calculated by equations of Hume (1966) and Cunningham (1980).

b RMR calculated by equations of Livingston and Kohlstadt (2005).

c RMR determined (Welle *et al.*, 1984) by indirect calorimetry. Dk $(dW/dt)_0$ = - (Co - Ce)

d John H. Jennings' data (from Dr. Michael Lesser's files). NASOP = No. and Sex of Patients: M = male, F = female

Table 2: Data II for calculation of cal/kg: (calculated) measured

No.	Dk Cal/kg	Height (ht) Centimeters	FA Activity factor	Ce cal/day eaten	BMI W (kg)/ $(ht (m))^2$ kg/m^2	Beginning weight = W (used for BMI) kilograms
1	6289.93	(157.1)	1.3	800	37.3	92.0 not equal to Wo
2	9121.56	(157.1)	1.3	300	37.3	92.0 not equal to Wo
3	4948.84	(169.6)	1.3	1200	47.5	136.6 not equal to Wo
4	6537.14	(169.6)	1.3	600	47.5	136.6 not equal to Wo
5	6557.56	170.7	1.55	0	n/a	n/a
6	9770.61	170 (est.)	1.55	0	n/a	n/a
7	7562.44	170 (est.)	1.55	0	n/a	n/a
8	9270.65	(160.4)	(1.32)	1243 a	29.6	76.2 = Wo
9	7435.26	(178.3)	(1.27)	1709.35 b	34.3	109.1 = Wo
10	5742.72	n/a	1.3	472	n/a	n/a
11	6248.72	n/a	1.3	800	n/a	n/a
12	8800.99	146	1.3	1000	n/a	n/a
13	6227.97	156	1.3	800	n/a	n/a
14	5721.53	152	1.3	800	n/a	n/a
15	6733.21	155	1.3	800	n/a	n/a
16	12787.97	146	1.3	75	n/a	n/a
17	9702.78	156	1.3	40	n/a	n/a
18	8051.81	155	1.3	0	n/a	n/a
19	5016.22	167.6	1.5	c	n/a	n/a
20	8173.14	167.6	1.5	d	n/a	n/a

a Co = 1931 cal/day, by measurement of RMR and estimation of FA.

b Co = 2594.5 cal/day, by measurement of RMR and estimation of FA.

c (Co - Ce) / Co = 3/7, Co = 2607.14 = (RMR) (FA).

d (Co - Ce) / Co = 1/7, Co = 2474.53 = (RMR) (FA).

Note: For data points Nos. 8 and 9, W = Wo, but for Nos. 1-4, W is not equal to Wo. See Table 1 for sources of data (references)

Sample calculation 1 is the example for Points 1-4, 6, 7 and 12-18.
Sample calculation 2 is the example for Points 8, 9.
Sample calculation 3 is the example for Points 5, 11.
Sample calculation 4 is the example for Points 19, 20. (The RMR for Point 10 was determined by indirect calorimetry).
Sample calculation 5 applies to Points 8, 9.

No. 4 from data (Blondhein *et al*., 1981):
Male patient, obese, patient #10
BMI = 47.5 = beginning W (kg) / (ht (m))^2 = (136.6)/(ht (m))^2
Therefore ht = 169.6 cm
W_o = 126.1 kg, weight at beginning of linear period of weight loss (from the graph).
$(dW/dt)_o$ = -0.306 kg/day, the slope is given
Using the Hume (1966) formula for the lean body mass (LBM) for men:
LBM = 0.3281 (126.1) + 0.33929 (169.6) - 29.5336 = 69.38 kg
Then, using the Cunningham (1980) formula for the resting metabolic rate (RMR) for either sex:
RMR = 501.6 + 21.6 (69.38) = 2000.28 cal/day F_A = activity factor = 1.3 (obese)
C_o = (RMR) (F_A) = (2000.28) (1.3) = 2600.37 cal/day
Daily calorie allotment was C_e = 600 cal/day
Dk = - Calorie deficit/Rate of weight loss = - (C_o - C_e) / $(dW/dt)_o$
Dk = (2600.37 - 600) / (0.306) = 6537.14 cal/kg

No. 8 from data (Volek *et al*., 2004) 13 overweight women: There are two diets, one low-fat and the other very low-carbohydrate and are averaged to give a picture of a reduced normal diet. For the low-fat diet, C_e = 1243 cal/day and for the low-carbohydrate diet, C_e = 1288 cal/day. The average diet is 1265.5 cal/day.
"Energy levels were assigned to the nearest 200 kcal increment based on resting energy expenditure using indirect calorimetry...and appropriate activity factors" (Volek *et al*., 2004) to get the baseline energy requirement, set at 1931 cal/day, averaged over the 13 women. The appropriate activity factor in this case was 1.32, calculated in sample calculation 5 below:
Low-fat diet $(dW/dt)_o$ = -1.06 kg/28 days
Very low-carbohydrate $(dW/dt)_o$ = -2.96 kg/28 days
Average rate of weight change is -((1.06 + 2.96) / 2) / 28 kg / day = -0.07179 kg/day
For the 13 women, Dk = (1931 - 1265.5) / 0.07179 = 9270.65 cal/kg

No. 11 from data (Ball *et al*., 1967) a 39 year old obese woman:
W_o = 103.5 kg C_e = 800 cal/day $(dW/dt)_o$ = - 0.220 kg/day
Using the Livingston and Kohlstadt (2005) equation gives:
RMR = 248 (103.5)$^{0.4356}$ - (5.09) (39) = 1672.86 cal/day
F_A = 1.3 (for obese women) So, C_o = 1672.86 x 1.3
Dk = ((1672.86) (1.3) - 800)/0.220 = 6248.72 cal/kg

No. 20 from John H. Jennings (see fasting data from Dr. Michael Lesser):
Male, 34 years old, fasting one day per week
W_o = 78.698 kg
f = fraction of week fasted = (C_o - C_e) / C_o = 1/7
ht = 167.6 cm $(dW/dt)_o$ = -0.04325197 kg/day
Using the Hume (1966) formula:
LBM = 0.3281 (78.698) + 0.33929 (167.6) - 29.5336 = 53.15 kg
Then using the Cunningham (1980) formula:
RMR = 501.6 + 21.6 (53.15) = 1649.69 cal/day
F_A = 1.5 because the individual was fairly active
C_o = 1649.69 x 1.5 = 2474.53 cal/day
Dk = (2474.53) x (1/7) / 0.04325197 = 8173.14 cal/kg

Sample calculation for back-calculation of activity factor for No. 8 from data in Volek *et al*. (2004) 13 obese females:
W_o = 76.2 kg C_o = 1931 cal/day derived from indirect calorimetry and appropriate activity factors averaged over the 13 women
RMR estimated by the Livingston and Kohlstadt equation (Livingston and Kohlstadt, 2005) for females,
Average age = 34.0 years
RMR = 248 (76.2)$^{0.4356}$ - (5.09) (34) = 1464.63 cal/day = C_o/F_A
1931/1464.63 = 1.318 therefore 1.32 = F_A

Since for No. 9, the 15 obese males, the activity factor was so close (1.273), both were averaged for obese subjects to get 1.3 for all the obese subjects. This was because the studies for data points 8 and 9 had similar protocols and it was simpler to round the activity factor to 1.3 for both cases. (Activity factors are inexact in the first place and the BMI varied a bit between the two).

Equations used for the calculations:
C_o = (RMR) (F_A) = cal/day
Maintenance calorie intake = Resting metabolic rate x activity factor
Dk = - calorie deficit/rate of weight loss = - (C_o - C_e) / $(dW/dt)_o$ = calories/kg
C_o = Maintenance calorie intake at beginning of linear portion of weight loss
C_e = Daily calories eaten at beginning of linear weight loss period
Where k = 2.2046225 lb/kg and D is in calories/lb
The equations from Hume (1966) for lean body mass (LBM), men and women are as follows:
W_o is in kg, ht is in cm and LBM is in kg.

Men
LBM = 0.32810 (W_o) + 0.33929 (ht) - 29.5336

Women
LBM = 0.29569 (W_o) + 0.41813 (ht) - 43.2933

The Cunningham (1980) equation for RMR, resting metabolic rate is:
LBM is in kg and RMR is in cal/day.

RMR = 501.6 + 21.6 (LBM)

Livingston and Kohlstadt (2005) give non-linear equations for RMR with values for a, p and y that differ between the sexes.
The weight W_o is in kg and the age A is in years.
Notice that the weight is raised to the power P.

$$RMR = a (W_o)^P - y A$$

For men a = 293, P = 0.4330 and y = 5.92
For women a = 248, P = 0.4356 and y = 5.09.

Note on the suitability of the data for this calculation:
To show the scatter of the data in the (DK,f) plane, the following statistics were done.
They show that the data points are fairly well scattered above and below the point where
f = 0.5. [$f = (C_o - C_e) / C_o$ = fasting rate]: f(avg) is approx. 0.5 and [d(Dk)/d f] is small.
Dk = 8168.97 - 829.57 f and f = 0.5167 ± 0.2393
This shows that the value for D is for 52% fasting rate and there is little bias of D with respect to the fasting rate.

Data from Doctor's files: Personal fasting data from John H. Jennings, age 34, height 5'6" from April 12, 1985 to January 24, 1986. Raw data were in pounds from the scale of Dr. Michael Lesser, 181 Vicente Road. Berkeley, CA 94705. These data were collected mostly while John H. Jennings was at a stay in Bonita House, Berkeley, California. The two sets of raw data were originally collected in pounds and days.

Data set 1			Data set 2		
Day	Weight (lb)	(kg)	Day	Weight (lb)	(kg)
Three successive days/week water only fast			One day/week water only fast		
t	L	W	t	L	W
0	201	91.172 = Wo	56 (0)	173.5	78.698 = Wo
28	186.3	84.50	77 (21)	172	78.02
56	173.5	78.70	109 (53)	169.3	76.79
			116 (60)	167.2	75.84
			151 (95)	163	73.94
			168 (112)	162.7	73.80
			196 (140)	160.5	72.80
			208 (152)	160.7	72.89
			224 (168)	158.3	71.80
			236 (180)	158.3	71.80
			243 (187)	155.7	70.62
			251 (195)	154.7	70.17
			287 (231)	150	68.04

Linear regression results for each data set: L is in pounds and W is in kilograms.

Data set 1 $f = 3/7 = (C_o - C_e)/C_o$ = fasting rate
L = -0.4910714 t + 200.6833 dL/dt = -0.4910714 lb/day
r = -0.9992 dW/dt = -0.2227463 kg/day

Data set 2 $f = 1/7 = (C_o - C_e)/C_o$ = fasting rate
L = -0.09535427 t + 173.6842 dL/dt = -0.09535427 lb/day
r = - 0.989 dW/dt = -0.04325197 kg/day

The starting point for each fast is, of course, taken to be (0, 201) for the three-day fasting period and (56, 173.5) for the one-day fasting period.

RESULTS

Doctors may assume that the figure D = 3500 cal/lb (Wishnofsky, 1958) or 3524 cal/lb (Kozusko, 2001) is an exact value in calculating diet weight loss. A review on this topic is by Hall (2008). This author performed library research on various diets and found that D is uncertain by 20%, in other words, D = 3511±703 cal/lb, for a (N = 51) study. The figure for kilograms is Dk = 7740±1550 cal/kg where k = 2.20462 lb/kg. If a doctor advises a patient to cut out a number of calories per day, the calorie-driven weight loss may vary as much as twenty percent above or below the 3511 figure. As mentioned before, the medical literature was scoured for data on weight loss for calorie restriction in otherwise normal diets of various levels of calorie restriction (up to total fasting) and simple statistics revealed the above uncertainty. Unusual very-low carbohydrate diets were not counted among the data, or they were compensated for, to have instead diets with normal proportions of carbohydrates where water retention tends to mask the loss of body fat (Blondheim *et al*., 1967). The loss of hydrophilic carbohydrate in the diet releases water in the same way as fasting. An initial rapid weight loss is described in Blondheim and Kaufmann (1965) that comes at the beginning of fasting and calorie restriction, and it is followed by the characteristic linear period of weight loss, and their paper clarified the thinking for this study. The critical point in weight loss is the point where it becomes linear with time and that is the point used in the calculation.

Summary of the results: The value for Dk for each of the 20 data points and the frequency for each data point can be found in Tables 1 and 2.
Note: Because of their short heights (146-156 cm), the subjects #1 - #4 in data points 12 through 18 in the Blondheim and Kaufmann (1965) article were assumed to be female.
N = 51 22 males 29 females
Dk = 7740.32±1548.87 cal/kg
Dk = result ± population standard deviation
The best literature value for D is 7770 cal/kg (Kozusko, 2001), which differs by 0.4%.

DISCUSSION

The sources of data are listed in Table 1 and the results are in Table 2. The equations used in the calculations are included and five sample calculations are presented. The activity factor for obese women and men was put at 1.3, according to estimates made in the multiple-subject studies by Volek *et al.* (2004) and Sharman *et al.* (2004), which had similar protocols. The weight loss rates for the two diets in Volek and Sharman were averaged to give pictures of normal diets and the daily calories eaten were averaged and both averages were used in each case to calculate values for D. The activity factor for John H. Jennings, the author, was put at 1.5 and his data is presented in Data from Doctor's files. For the total fasters Succi and Levanzin in Benedict (1915), the activity factor was set to 1.55. The RMR, the resting metabolic rate, for total fasters was reduced by 5%, according to measurements made by Blondheim and Kaufmann (1965). Data from the fourteen unacceptable studies were excluded because of the reasons aforementioned, but all acceptable data points found were included in the calculation of D and its uncertainty.

The equation used is a simple relation $Dk(dW/dt)_o = -(C_o - C_e)$, where $(dW/dt)_o$ is the weight loss rate at the beginning of the linear weight loss period, C_o is the daily maintenance calorie intake and C_e is the actual number of daily calories eaten. D was calculated by using the data for the weight loss rate and the calorie deficit, $(C_o - C_e)$, from the literature at the linear portion of weight loss. The average normalized calorie deficit $f = (C_o - C_e)/C_o = 0.52$ (see Supplement). C_o was evaluated either by taking it from the data in the reference or using predictive equations for RMR from Livingston and Kohlstadt (2005) or Cunningham (1980). A standard equation in nutrition is $C_o = (RMR)(F_A)$, where RMR is the resting metabolism rate and F_A is the activity factor. (For women the activity factor is generally a bit lower and the overall activity factor ranges from 1.2 to about 1.9). The RMR was either measured or calculated. If the sex, weight and height are available, the formulas by Cunningham (1980) and Hume (1966) are used to calculate RMR. If the sex, weight and age are known, then the equations from Livingston and Kohlstadt (2005) are used to calculate RMR. There were a total of 22 men's diets and 29 women's diets and some of the studies were averages of men or women, but the linearity of the simple relation allows calculation of D from those kinds of studies. It was necessary that the men and women had been averaged separately in the studies by Volek *et al.* (2004), Sharman *et al.* (2004) and Welle *et al.* (1984), which they were. Other data came from studies by Ball *et al.* (1967) and Blondhein *et al.* (1981) in addition to the important data from Blondheim and Kaufmann (1965). This information would be of use to physicians who are concerned with what to expect for weight loss.

Conclusion: The results in this article are well-known, but this is evidently the first time the results have been derived on the basis of diet for 50% fasting rate. The number of 3500 cal/lb is corroborated here and the uncertainty of 20% may not be surprising, because it is known there is some scatter in the value for the resting metabolism rate for normal humans and water retention/loss is also an issue in calorie restriction. What is given here is direct proof, for 50% fasting rate, that diets will give a variability of 20% in weight loss. The value is 3511 cal/lb or 7740 cal/kg and it appears that this figure applies across the whole fasting range.

Practical application: The value for D, the calories per pound to lose weight, is well-known at 3500 cal/lb. What I have done in this paper is establish that the same value applies when a human is fasting at a 0.5 rate, where normal eating is zero fasting and complete starvation is fasting = 1.0.

Nomenclature:

BMI	=	Body mass index
C_e	=	Calories eaten in one day
C_o	=	Maintenance calorie intake
$(C_o - C_e)$	=	Calorie deficit
D	=	Calories per pound
Dk	=	Calories per kilogram
FA	=	Activity factor
ht	=	Height
k	=	Pounds per kilogram
RMR	=	Resting metabolic rate
W	=	Beginning weight for BMI
W_o	=	Weight at beginning of linear period of weight loss
$(dW/dt)_o$	=	Rate of weight loss at beginning of linear period

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