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24-HOUR METABOLISMS OF SEDENTARY PEOPLE

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In affluent societies the penalties of over-nutrition and under-exercise are manifest in a rising death-toll from degenerative-vascular and metabolic diseases. A great deal of information is available on the composition of diets and the 24-hour dietary intakes of such populations, but little is known of the 24-hour metabolisms and the patterns of activity of the members of their more sedentary sections. As a first step in this direction, a time-study and measurement of metabolism was made of the various daily activities of a sample of male and female 2nd-year medical students. These metabolic studies were complemented by a survey of the dietary intake of the same individuals.

METHODS

Measurement of Metabolisms

Each student made an estimate for an average weekday of the time spent in sleeping, sitting, standing, walking, and climbing stairs. At the medical school the cloakrooms and toilets are in the basement and the lecture theatres, dissection hall and laboratories are spread over one floor in such a manner that some time is spent in walking between lectures, laboratory practicals, and dissections.

A 5-minute collection of expired air was made by conventional Douglas-bag techniques for sitting, standing and walking and a shorter collection for climbing stairs. The students were enjoined to carry out these various activities at their usual pace. Analysis of aliquot samples of expired air was carried out in the standard manner the laboratory uses (Cook *et al.*[1]). No measurements were made during sleep, but energy metabolisms were calculated from standard Aub-DuBois tables taking age and sex into account. Resting metabolisms were repeated on different days to test the reproducibility of measurements. The means are 330·3 and 320·8 ml./min. and standard deviations 74·84 and 87·38 ml./min. They are not significantly different; the correlation coefficient of first and second measurements is 0·69 which is significant at the 5% level.

Estimation of Calorie Intakes

The students had previously recorded their daily food intakes as part of a class exercise 2 weeks before their individual oxygen consumptions were measured. This was done in the following way:

A class demonstration was held at which average helpings of various foods were weighed and measured, and the use of food tables was explained. Each student was provided with tables compiled mainly from those of McCance and Widdowson,[2] and Fox and Goldberg.[3] They were then asked to estimate, and record in detail, the amounts of each kind of food consumed daily for a period of 5 consecutive days. From these figures the mean daily intake of carbohydrates, fats, proteins and calories was calculated. One member of the group (E.J.S.) weighed all his food over this period. During the period in which oxygen consumptions were measured, the students were asked to repeat their food-intake recording, but this time each one was provided with scales. They were requested to weigh all food consumed, thereby giving more accurate figures than the previous estimated ones. Because E.J.S. had weighed his food initially, he was not asked to repeat the recording. Food consumption over the two 5-day periods is shown in Table I.

TABLE I. FOOD CONSUMPTION OVER TWO 5-DAY PERIODS

Student	*Calories*		*CHO*		*Protein*		*Fat*	
	1st	*2nd*	*1st*	*2nd*	*1st*	*2nd*	*1st*	*2nd*
E.J.S.	5118	—	535	—	174	—	227	—
M.E.M.	1541	1530	139	144	46	63	65	78
J.M.P.	1520	1879	173	172	63	79	56	82
P.A.M.	1774	1523	212	186	65	53	74	63
D.S.	1599	1687	172	236	48	53	60	59
M.C.	3715	2142	439	290	113	72	155	74
J.C.E.	2384	2109	218	203	98	72	104	80
B.R.	2049	2056	236	240	72	86	88	75
E.H.S.	3088	3272	269	388	131	133	119	132

RESULTS

Time and Metabolism spent in Sedentary and Active Pursuits

In Table II are given the measured rates of oxygen consumptions and times spent on each of the 5 main activities. From these values the caloric costs and total 24-hour metabolisms have been calculated.

There are small individual differences in the estimated times spent in sleeping, sitting, standing, etc. but these differences are relatively small. There are, however, large differences between individuals in the oxygen consumptions, which appear to be related to the gross body weights of the individuals.

From these data graphs of the percentages of time and of metabolism spent in sedentary, standing and active procedures have been drawn up (Fig. 1). From this it is clear that 72% of the students' time is spent in sleeping and sitting, 20% in standing and only 8% at a high level of activity. Because of the large differences in metabolism resulting from these activities the percentages of the 24-hour metabolism in these 3 categories are 53% in sleeping and sitting, 25% in standing and 22% in walking and climbing stairs.

Influence of Gross Body Weight on Energy Metabolism

To test these relationships, oxygen consumptions for each of the various activities are plotted against gross body weights and the correlation coefficients between oxygen consumption and gross body weights calculated for each. These are given in Figs. 2 - 6.

TABLE II. MEASURED OXYGEN CONSUMPTIONS OF SUBJECTS FOR VARIOUS TASKS AND CALCULATED METABOLISMS

Student	*O_2 cons. Litre/min.*	*O_2 cons. Litre/hour*	*Calories per hour*	*Time (hours)*	*Total Calories*	
	0·2364	14·184	68·7924	8·40	577·86	Sleeping
E.J.S. (Male)	0·3717	22·302	108·1647	9·00	973·48	Sitting
173·25 lb.	0·5429	32·574	157·9839	4·70	742·52	Working at bench
5 ft. 11¼ inches	0·9100	54·600	264·8100	1·30	344·25	Walking
Sur. Area 1·97 m²	1·6490	98·940	479·8590	0·60	287·92	Climbing stairs
					2926·03	
	0·2100	12·60	61·110	8·00	488·88	Sleeping
M.E.M. (Female)	0·2289	13·734	66·6099	9·00	599·49	Sitting
145·0 lb.	0·3715	22·290	108·1065	5·00	540·53	Working at bench
5 ft. 6¾ inches	0·8286	49·716	241·1226	1·75	421·96	Walking
Sur Area 1·75 m²	1·3246	79·476	385·4586	0·25	96·36	Climbing stairs
					2147·22	
	0·2285	13·68	66·348	8·4	557·32	Sleeping
J.M.P. (Male)	0·2999	17·994	87·2709	9·0	785·44	Sitting
155·0 lb.	0·3502	21·012	101·9082	4·7	478·97	Working at bench
5 ft. 11½ inches	0·6968	41·808	202·7688	1·3	263·60	Walking
Sur. Area 1·90 m²	1·4397	86·382	418·9527	0·6	251·37	Climbing stairs
					2336·70	
	0·192	11·52	55·87	8·50	474·90	Sleeping
P.A.M. (Female)	0·2524	15·144	73·4484	8·50	624·31	Sitting
115·0 lb.	0·3256	19·536	94·7496	5·00	473·72	Working at bench
5 ft. 6 inches	0·5523	33·138	160·7193	1·50	241·08	Walking
Sur. Area 1·61 m²	1·0961	65·766	318·9651	0·50	159·48	Climbing stairs
					1973·49	
	0·224	13·44	65·184	7·00	456·29	Sleeping
D.S. (Female)	0·3039	18·234	88·4349	10·00	880·43	Sitting
171·75 lb.	0·2752	16·512	80·0832	5·00	400·42	Working at bench
5 ft. 5¼ inches	0·9833	58·998	286·1403	1·50	429·21	Walking
Sur. Area 1·86 m²	1·7022	102·132	495·3402	0·50	247·67	Climbing stairs
					2414·02	
	0·216	12·96	54·43	7·00	381·01	Sleeping
M.C. (Male)	0·3374	20·244	98·1834	10·50	1030·93	Sitting
143·75 lb.	0·4645	27·870	135·1695	4·50	608·26	Working at bench
5 ft. 9½ inches	0·7035	42·210	204·7185	1·50	307·08	Walking
Sur. Area 1·80 m²	1·7648	105·888	513·5568	0·50	256·78	Climbing stairs
					2584·06	
	0·2892	17·352	84·1572	11·00	925·73	Sleeping
J.C.E. (Male)	0·4689	28·134	136·4499	7·00	955·15	Sitting
251·75 lb.	0·8242	49·452	239·8422	4·00	959·37	Working at bench
6 ft. 2½ inches	1·3475	80·850	392·1225	1·50	588·18	Walking
Sur. Area 2·41 m²	3·2293	193·758	939·7263	0·50	469·86	Climbing stairs
					3898·29	
	0·2064	12·384	60·0624	8·50	510·53	Sleeping
B.R. (Male)	0·2817	16·902	81·9747	10·00	819·75	Sitting
139·5 lb.	0·3964	23·784	115·3524	4·00	461·41	Working at bench
5 ft. 6½ inches	0·7602	45·612	221·2182	1·00	221·22	Walking
Sur. Area 1·72 m²	1·2493	74·958	374·7900	0·50	187·40	Climbing stairs
					2200·31	
E.H.S. (Male)	0·2472	14·832	71·9352	7·50	539·51	Sleeping
172·0 lb.	0·3697	22·182	107·5827	8·00	860·66	Sitting
6 ft. 3¼ inches	0·5604	33·624	163·0764	7·00	1141·53	Working at bench
Sur. Area 2·06 m²	0·9724	58·344	282·9684	1·25	353·71	Walking
	1·6163	96·978	470·3433	0·25	117·59	Climbing stairs
					3013·00	

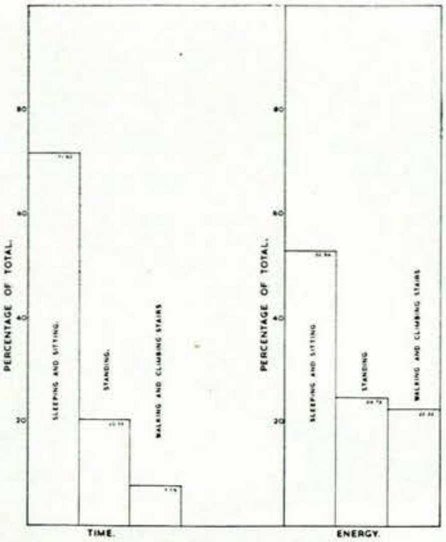

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Fig. 1. Percentages of time in 24 hours and of energy expenditure employed on sleeping and sitting—sedentary activities—and in standing and in walking and climbing stairs.

For sitting, the relationships and correlation for both gross body weight and DuBois' surface area are given in Figs. 2 and 3. Both parameters correlate highly with oxygen consumption. Surface area correlates at 0·93 compared with 0·92 for gross body weight.

The correlations of oxygen consumptions with gross body weights are 0·89 for standing, 0·90 for walking and 0·99 for climbing up and down stairs. In each case oxygen consumptions are correlated more highly with gross body weights than with surface areas. In the heaviest task, where the student carries his or her body weight upstairs against

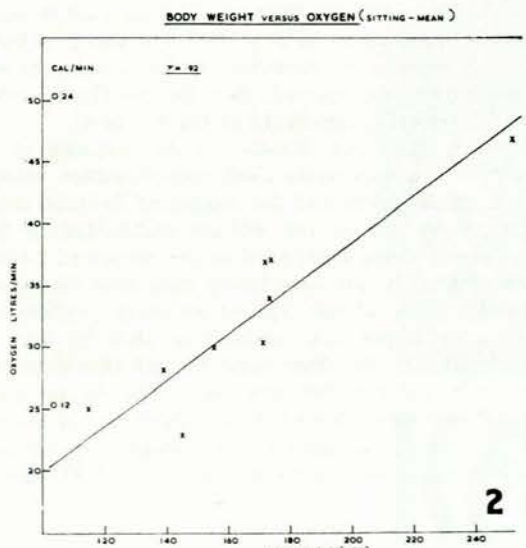

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Fig. 2. Oxygen consumptions, in litres/min., of 9 subjects plotted against gross body weights, with correlation coefficients and regression lines fitted to data, for sitting. y = ·0139 + ·0018 x.

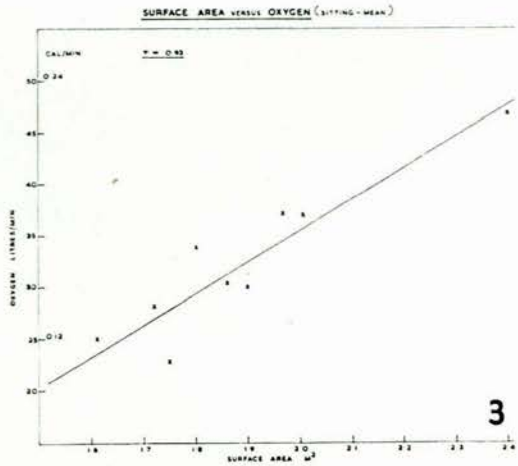

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Fig. 3. Oxygen consumption, in litres/min., of 9 subjects plotted against their surface areas, with correlation coefficients and regression lines fitted to the data, for sitting. y = −·2235 + ·2932 x.

gravity, the correlation of oxygen consumptions with gross body weights is much higher than with surface areas, 0·99 compared with 0·91. The very marked effect of weight on energy metabolism is well brought out by considering two

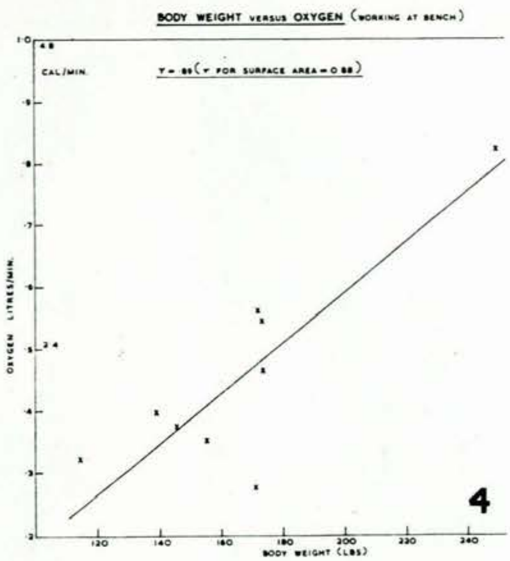

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Fig. 4. Oxygen consumption, in litres/min., of 9 subjects plotted against gross body weights, with correlation coefficients and regression lines fitted to the data, for standing at a bench. y = −·2109 + ·0040 x.

individuals at the extremes of body weight walking upstairs. The 116-lb. female consumed 1·096 litres oxygen/min. or 53·66 cal./min.; the 251-lb. male's consumption was 3·23 litres oxygen/min. or 156·62 cal./min. The male's weight was double that of the female but his metabolism was 3 times greater.

Average Metabolism

With such high correlation between oxygen consumption and gross body weight, it is obvious that the 24-hour

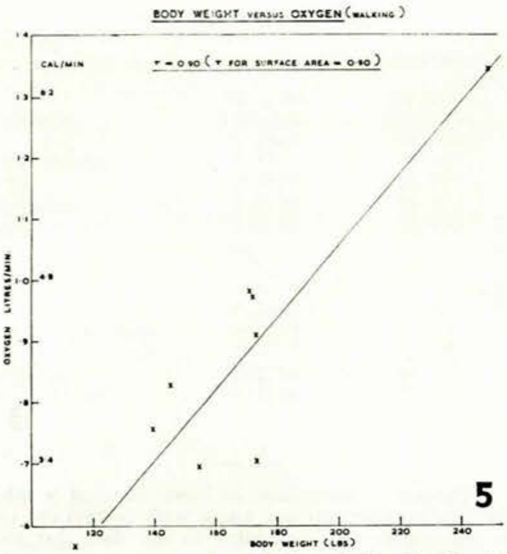

Fig. 5. Oxygen consumption, in litres/min., for 9 subjects plotted against gross body weights, with correlation coefficients and regression lines fitted to the data, for walking. $y = -{\cdot}0992 + {\cdot}0057\,x$.

metabolism would be highly correlated with gross body weight. The graph is given in Fig. 7 and has a correlation coefficient of 0·92. Although it will be obvious from these

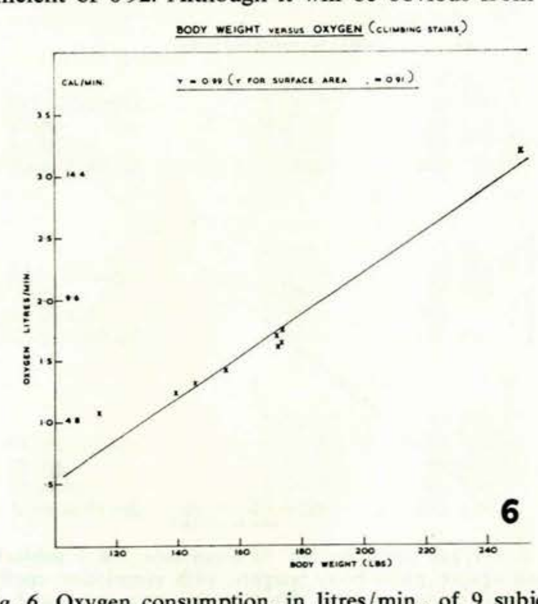

Fig. 6. Oxygen consumption, in litres/min., of 9 subjects plotted against gross body weights, with correlation coefficients and regression lines fitted to the data, for climbing stairs. $y = -1{\cdot}1847 + {\cdot}0171\,x$.

results that it is meaningless to talk of the 24-hour metabolism without specifying the gross body weights of the individuals, it is common practice to give an average figure. For this group the average caloric cost of daily living is 2,544 calories per 24 hours. For the 6 males it is 2,780 calories per day.

Relationship between Metabolism and Caloric Intake

In Table III are given the 24-hour measured metabolism

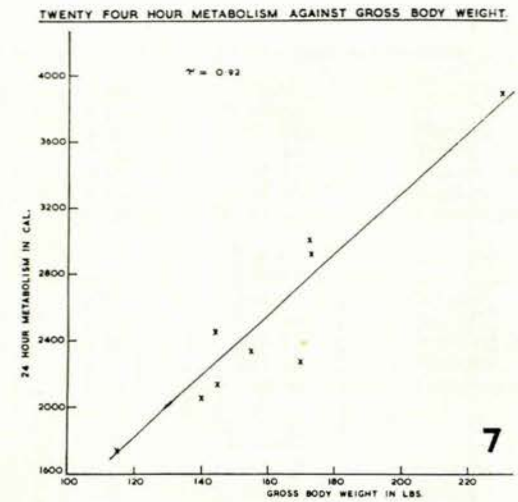

Fig. 7. Calculated 24-hour metabolisms plotted against gross body weights with correlation coefficients and regression lines fitted to experimental data.

and the 24-hour caloric intake calculated from the quantities of food consumed and caloric values in food-tables.

TABLE III. COMPARISON OF 24-HOUR CALORIE INTAKES WITH 24-HOUR METABOLISMS

Student	*Calorie intake* (1)	*Metabolisms* (2)	*2—1*
E.J.S.	5118	2926	−2192
M.E.M.	1535	2147	+612
J.M.P.	1700	2336	+636
P.A.M.	1645	1973	+328
D.S.	1646	2414	+769
M.C.	2928	2584	−344
J.C.E.	2245	3900	+1655
B.R.	2052	2200	+148
E.H.S.	3182	3013	−169
			Mean + 160 Cal./day

The correlation coefficient between 24-hour calorie intake and 24-hour metabolism is r = 0·44 for the 9 subjects, which is not significant. However, if the 2 subjects with anomalous results are omitted, then the correlation coefficient is 0·73, which is significant at the 5% level.

These facts stand out: Firstly, in the majority of the subjects there is a reasonably close approximation between the 24-hour metabolism and the calculated 24-hour caloric intake. Secondly, all of the women underestimate their 24-hour caloric intake compared to the measured 24-hour metabolism. Thirdly, the very heavy man, who claims that he eats only 2,245 calories against an energy expenditure of 3,900 calories per day, assured us that he was not dieting himself. On the other hand, the tall thin man, who expends 2,926 calories per day, says that he is always hungry and eats throughout the day, stepping out between lectures for subsistence (this is corroborated by his associates in the class). He claims he eats about 5,000 calories per day.

DISCUSSION

Relationship between Metabolism and Gross Body Weights

Tables have been given for the calorie costs of a wide variety of activities by Passmore and Durnin[4] and by

Spitzr and Hettinger,[5] and by Droese[6] for housewives. Curiously, in some instances these tables do not give the weights of the individuals. Our study has shown the very close dependence of the calorie costs of the daily activities upon gross body weight. Only for sitting at rest was the correlation between oxygen consumption and surface area ($r = 0{\cdot}93$) greater than that between oxygen consumption and gross body weight ($r = 0{\cdot}92$). In all other instances the correlation with gross body weight is the greater, and in most instances the correlation coefficients are 0·9 or above, which is significant at the 5% level. The calorie costs quoted in the tables are therefore of very limited application for estimating the probable energy expenditure of an individual unless he happens to be of the same weight as the mean of the individuals for which the caloric cost is given. Unfortunately, as the mean body weights of the individuals are not given, this comparison cannot always be made.

This important relationship between oxygen consumption and gross body weight does not appear to have been given the importance it deserves in the physiological literature on metabolism. Mahadeva *et al.*[7] draw attention to this relationship for walking and climbing on and off a step and give regression lines for these two activities. Wyndham *et al.*[8] also give regression lines for oxygen consumptions plotted against gross body weights for stepping on and off a stool at three different rates and they show differences between Bantu and Europeans in mechanical efficiency for this activity.

Unfortunately, on these meagre data it is not possible to allow for differences in gross body weights by applying a simple factor to the calorie costs given in the tables, because the slopes of the regression lines relating oxygen consumption to gross body weights increase with the heaviness of the activity. This point is brought out in Table IV, in which calorie costs for a 100-lb., 175-lb. and 250-lb. person are compared at rest, standing, walking and climbing up stairs (the values are taken from Figs. 2 - 6).

TABLE IV. COMPARISON OF METABOLISMS OF LIGHT, MEDIUM AND HEAVY INDIVIDUALS AT REST, STANDING, WALKING AND CLIMBING STAIRS

Activity	*Individuals of Different Weight*			
	100 lb. cal./min	*175 lb. cal./min*	*250 lb. cal./min*	*△Cal./min. per 100 lb. wt.*
Rest	0·9	1·6	2·3	0·9
Standing	1·0	2·4	3·8	1·9
Walking	2·2	4·4	6·5	2·9
Climbing stairs	2·5	8·6	14·5	8·2

These results make it clear that the usefulness of the tables of caloric costs would be greatly enhanced if the data were given in relation to:

(a) a man of standard weight, say 70 kg., with a factor for calculating the slope of regression lines relating metabolism to gross body weight for each level of activity; or

(b) as a regression line expressing the mathematical equation for the relationship between metabolism and gross body weight.

The same criticism holds for the method of expressing 24-hour metabolisms and, therefore, for comparing the 24-hour metabolisms of men engaged on various tasks. Edholm *et al.*[9] give a daily energy expenditure of 3,464 calories per day for cadets in training. Garry *et al.*[10] calculated the 24-hour metabolism of coal miners in Fife at 3,660 calories per day and 2,800 for clerks. The average 24-hour metabolisms for the 9 students in our studies is 2,480 calories per day and for the 6 males, average weight 173 lb., it is 2,780 calories per day. These various 24-hour metabolisms are not strictly comparable because the weights of the population differ.

The calculated 24-hour metabolisms of the 9 subjects of this study were shown to be correlated closely with gross body weight ($r = 0{\cdot}92$). In order to increase their useful application 24-hour metabolisms should be given as a regression line or equation relating metabolism to gross body weight for different occupations and NOT as at present, as a mean value and a standard deviation without any reference to the dependence of 24-hour metabolism upon gross body weight. Neglect of this relationship can lead to errors of some magnitude in calculating the dietary needs of workmen. For example, the average Bantu mine labourer in the South African gold mines weighs 130 lb. (Ward and Fleming[11]). If he led the sedentary life of a medical student his daily calorie requirements would be 1,980 calories per day compared with 2,440 calories per day of the 160-lb. Caucasian. This difference is increased when one considers heavier tasks such as mining. Garry *et al.*[10] give a figure of 3,660 calories per day for Scottish coal miners. Assuming the Bantu miner works as hard, then his 24-hour metabolism would be about 3,000 calories per day. In a recent dietary survey by Fleming[12] the Native mine labourer was found to consume about 3,000 calories per day. The regulations laid down for the caloric value of the mine-compound diet for each Bantu is in excess of 4,000 calories per day. This value is based, partly, upon Moss's figure[13] of 4,500 calories per day. It does not seem to have been appreciated that Moss's figure should be reduced very considerably to allow for the very big differences in gross body weight of Bantu and Caucasians. Some mines still attempt to feed in excess of 4,000 calories per day and, in consequence, there is a high refuse content in the pig-bins.

In drawing up the calorie requirements of populations the Food and Agricultural Organization (FAO) publications on nutrition[14, 15] Nos. 5 and 15 of 1950 and 1957 respectively recognize the dependence of 24-hour metabolism upon gross body weight. They propose an equation:

$$E = 152 \quad W^{0{\cdot}73}$$

(where E is calories per 24 hours and W is kilogram body weight) for calculating the 24-hour metabolisms of men engaged on moderate activity. Use of the exponent 0·73 for activity seems extraordinary when it is commonly used in calculating the basal metabolisms of individuals of different gross body weights. Large errors are involved in the use of such a hypothetical equation, which has not been tested experimentally. They are demonstrated in Fig. 8, in which the measured 24-hour metabolisms of the 9 subjects of this study are related to gross body weight by a linear equation of the form:

$$y = -140 + 16{\cdot}2\ x$$

(where y = 24-hour metabolism in calories, and x = gross body weight in lb.). Drawn in the figure are lines for the

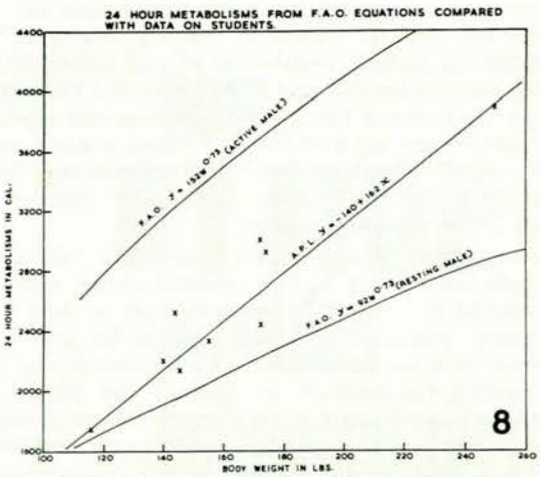

Fig. 8. Comparison of regression lines of 24-hour metabolisms from the calculated data on the 9 subjects; and from the FAO equation for resting males and for active males.

hypothetical FAO male from the equations $E = 152\ W^{0.73}$ for moderate activity and $E = 92\ W^{0.73}$ for basal metabolism. The use of the exponent 0·73 for both basal state and moderate activity points to a conceptual gap in thinking on the relationship between metabolism and gross body weight. As our data have shown in this paper, the slope of the regression line relating metabolism to gross body weight increases with the heaviness of the activity. A revision of the FAO equation along these lines would make it more generally applicable to practical work situations.

Activity and Metabolism of Medical Students

These studies show that the average medical student leads a very sedentary existence. 72% of the day and 53% of the 24-hour metabolism is spent in sleeping or sitting down. These figures exceed those given by Garry *et al.*[10] for clerks in the Fife coalfields. This sedentary life is forced upon the medical student by a curriculum that is overburdened with teaching. It has been demonstrated that the incidence of degenerative vascular disease is high in this section of the population. A strong case might therefore be made for introducing a compulsory daily period of physical education into the medical curriculum. This is standard practice in some of the universities in the USA.

Correlation between Calorie Intakes and Energy Metabolisms

In the majority of the subjects the 24-hour calorie intakes were similar to the 24-hour energy metabolisms. For 7 of the 9 subjects the correlation coefficient between the two measurements was 0·73, which is significant at the 5% level. Durnin and Brockway[16] analysed similar data on 78 individuals from various authors and report a correlation coefficient of 0·69.

In 2 cases there were wide differences between the calorie intakes and energy metabolisms. One was the 250-lb. male who estimated his calorie intake at 2,245 cal./day and expends 3,900 cal./day. The other, a male of 172 lb. weight, maintains he eats about 5,000 cal./day and has an energy metabolism of 2,960 cal./day. These two men are adamant in their assertion that the food-consumption records are representative of their average daily eating behaviour. They were not changing weight over this period. This seems to rule out the probability that in these two individuals the daily intake and output energy figures did not correlate but over a longer period, say a week, a balance would be achieved. Edholm[17] had shown in his survey of the energy intake and output of military cadets that the daily correlation was poor in these measurements. We are left with the possibility that these two men, for purposes best known to themselves, did not weigh their food accurately, or that the 24-hour balances in certain, especially overweight, individuals do not obey the first law of thermodynamics. This does not seem likely, because Bushkirk[18] in a study of obese women showed that an important factor is that they are less active than their leaner sisters.

The 3 females recorded a smaller calorie intake than energy metabolism. One possible explanation is that the females do not eat a midday meal during the week for fear of gaining weight whereas the males seem to respond more readily to hunger at midday. In the weekend, however, on home cooking, the females may eat more fully. Careful study of their weights might show a weekly cycle of loss of weight during the week and gain over the weekend. It was not possible to get the subjects to continue the study over the weekend to check this suggestion.

SUMMARY

Metabolisms of 9 medical students were measured by indirect calorimetry, and the time spent on their daily activities was recorded. 72% of the students' time is spent in sleeping or sitting and only 8% at a high level of activity; 53% of the 24-hour metabolism is used for sleeping and sitting and 22% in walking and climbing stairs. Very high correlations, of 0·9 and higher, were found between metabolism and gross body weight for each of the activities measured and therefore 24-hour metabolisms are also closely correlated with gross body weights. Tables of metabolism for daily activities which do not include this relationship are of very limited value. The FAO publications, recognizing this important relationship give a simple formula (Metabolism $E = 152\ W^{0.73}$) for calculating metabolisms of a man engaged on moderate work. Use of the exponent 0·73, which is applicable to basal metabolisms, is open to criticism when used to compute metabolisms for working men.

The calorie intake was determined from weights of food ingested and food tables, and in 7 of 9 subjects it correlated well with the 24-hour metabolisms computed from indirect calorimetry and time-studies. Two men showed large discrepancies and the possible reasons for these are discussed.

OPSOMMING

Metabolisme is deur middel van die indirekte kalorimetriese metode gemeet en die tydsbesteding aan die daaglikse aktiwiteite van 9 mediese studente is aangeteken. Slaap en sit het 72% van die tyd beslaan en gedurende slegs 8% van hul tyd was hul baie aktief. Slaap en sit het egter 53% van die metabolisme vir 24-uur betrek, terwyl loop en klim (van trappe bv.) 22% van die metabolisme vir 24-uur betrek het. Vir elk van die gemete aktiwiteite is baie hoë

korrelasies, van omtrent 0·9 en hoër, gevind tussen metabolisme en totale liggaamsgewig, en daarom is daar 'n noue korrelasie tussen 24-uur metabolisme en totale liggaamsgewig. Tabelle van metabolismes vir daaglikse aktiwiteite, wat nie verband hou met hierdie verhouding nie, is van baie min waarde. Die FAO-publikasies erken hierdie belangrike verhouding en voorsien 'n eenvoudige formule (Metabolisme $E = 152\ W^{0.73}$) vir die berekening van die metabolisme vir 'n persoon wat besig is met matige werk. Die gebruik van die eksponent 0·73, wat toepasbaar is op basale metabolismes, word egter gekritiseer wanneer dit gebruik word vir die berekening van metabolismes van werkende persone.

Die kalorie inname is bereken deur voedseltabelle te gebruik vir die gewig van voedsel wat ingeneem is. Die resultate van sewe van die 9 studente het goed ooreengestem met die berekende 24-uur metabolismes d.m.v. die indirekte kalorimetriese metode en tydstudies. Twee studente het egter groot afwykings getoon en die moontlike redes hiervoor word bespreek.

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