THE OXYGEN CONSUMPTION OF FASTING WHITE MICE

By J. E. DAVIS and H. B. van DYKE

(*From the Lasker Foundation for Medical Research and the Department of Medicine, the University of Chicago, Chicago, and the Department of Pharmacology, Peiping Union Medical College, Peiping, China*)

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A method for measuring the oxygen consumption of small animals was described in a previous article (1). It was shown that this method permitted not only the direct measurement of the oxygen consumed but also the elimination of periods during which the animal was active. These points were illustrated by experiments on fasting white mice, whose oxygen consumption for the quiet-relaxed-awake state was found to average 37.5 liters of oxygen per kilo of body weight of mouse per 24 hours. As this figure was lower than most hitherto reported, it was arranged to have the oxygen consumption of a series of mice determined in Chicago by the authors with this method, and checked in the Nutrition Laboratory of the Carnegie Institution of Washington at Boston by its skilled workers with the method developed there (2). Seven male mice were used for this comparison, four (Mice 1, 3, 5, 19) of a litter born November 14, 1931, and three (Mice 8, 9, 13) of a litter born December 23, 1931. In both places they were kept at an environmental temperature of about 28° before as well as during the metabolism determination. In both places, also, several determinations were made on each mouse 17 to 24 hours after its last access to food.

The data obtained by the Chicago method are shown in Tables I and II. Table I shows the data for a typical determination by the Chicago method. It should be noted that Table I does not account for the full time the mouse was in the metabolism chamber, but only that portion during which its behavior was for the most part quiet. Before the mouse became quiet, oxygen was admitted and no readings were attempted; only when the mouse became quiet was the apparatus closed and readings made. Only

TABLE I

Oxygen Consumption of Mouse 13, June 8, 1932, Determined by Chicago Method

Weight, 27.5 gm.; temperature, 28.0°; barometric pressure corrected, 717.8 mm.; time away from food, 18 hrs.

Time	State of mouse	O_2 consumption		
		Per 5 min.	Per period	Per kilo per 24 hrs.
min.		*cc.*	*cc.*	*liters*
0	Quiet-relaxed-awake			
5	"	4.2		
10	"	4.1		
15	"	4.3		
20	Turning and scratching	5.0		
25	" " "	5.6		
0	Quiet			
5	"	4.5		
10	Turning	5.0		
15	Sleeping	3.4		
20	"	3.2		
25	"	3.2		
30	"	3.1	12.9 per 20 min., sleeping	29.2* for sleeping state
35	Turning and scratching	5.0		
0	Quiet-relaxed-awake			
5	"	4.2		
10	"	4.3		
15	Sleeping	3.3		
20	Quiet-relaxed-awake	3.9		
25	"	4.1		
30	"	4.2	20.7 per 25 min., quiet-relaxed-awake	37.3* for quiet state

* Liters of oxygen (S.T.P.) consumed per kilo per 24 hours: (*a*) for sleeping state $= \frac{12.9}{1000} \times \frac{60 \times 24}{20} \times \frac{1000}{27.5} \times \frac{273}{301} \times \frac{717.8}{760} = 29.2$; (*b*) for quiet-relaxed-awake state $= \frac{20.7}{1000} \times \frac{60 \times 24}{25} \times \frac{1000}{27.5} \times \frac{273}{301} \times \frac{717.8}{760} = 37.3$.

those readings which corresponded to similar states of the mouse and remained consistent for successive 5-minute periods were taken for calculation of the oxygen consumption. Two such longer periods were obtained for Mouse 13, one of 20 minutes for the sleeping state, and one of 25 minutes for the quiet-relaxed-awake state, the former giving an oxygen consumption value of 29.2

TABLE II

Oxygen Consumption of Each of Seven Fasting White Mice Determined in Chicago by Authors, with Their Method

Mouse No.	Date	Weight	Barometric pressure, corrected	O_2 per kilo per 24 hrs.	
				Sleeping	Quiet-relaxed-awake
	1932	*gm.*	*mm.*	*liters*	*liters*
1	July 5	27.3	718.1		38.1
	" 7	27.0	713.5		38.0
	" 11	26.0	724.7		37.9
	" 27	26.0	717.3		41.8
3	June 13	27.0	715.4	26.5	40.0
	" 27	26.5	712.2		39.9
	July 8	27.3	717.2	28.1	38.4
5	June 16	31.0	716.6		39.3
	" 28	32.3	720.0	29.6	36.9
	" 30	31.5	712.6	28.9	39.0
8	" 9	29.3	717.4		36.3
	" 17	30.2	717.7	31.2	40.1
	" 29	31.7	714.0	28.5	38.8
	July 25	31.0	716.7	28.5	37.4
9	June 11	26.8	723.1		38.2
	" 25	27.0	713.4	27.3	39.2
	July 9	26.5	720.5	29.5	39.4
13	" 18	28.0	721.0	25.5	35.8
	June 8	27.5	717.8	29.2	37.3
	July 6	29.3	719.1		36.1
19	June 10	28.0	719.7		39.5
	" 23	29.8	721.8		39.6
	July 12	29.0	722.3	26.6	37.5
	" 29	30.5	720.9		39.5
Average....................................				28.3	38.5

liters, and the latter of 37.3 liters per kilo of body weight per 24 hours. The oxygen consumption values of all the mice are shown in Table II. The average for the sleeping state was 28.3 liters; for the quiet-relaxed-awake state 38.5. It will be observed that

TABLE III

Oxygen Consumption of Each of Six Fasting White Mice Determined in Boston by Nutrition Laboratory Workers, with Method Developed There

Mouse No.	Date	Weight	Surface*	Duration of period	O_2 per kilo per 24 hrs.	Calories† Per kilo per 24 hrs.	Calories† Per sq.m. per 24 hrs.	Time active
	1932	*gm.*	*sq.cm.*	*min.*	*liters*			*per cent*
1	Apr. 27	25.41	78	8.3	50.3	236	768	
				8.6	50.6	237	773	
				9.5	50.7	238	774	
				9.2	55.3	260	846	
				12.5	44.5	208	679	
5	" 28	28.17	83	9.3	45.8	215	729	
				8.8	44.1	207	702	
				10.5	47.5	223	756	
				10.4	55.3	259	880	
				10.4	57.0	267	907	
13	" 25	24.20	75	11.0	80.0	375	1210	
				11.3	50.7	238	767	
				12.3	53.8	252	813	
				11.8	53.4	250	807	
				12.0	54.7	256	827	
				12.0	55.1	258	833	
	May 4	23.96	75	14.4	41.9	196	626	
				10.4	53.5	251	800	
				9.0	62.4	292	934	
1	Apr. 12	24.58	76	55.6	47.7	224	725	10
				53.0	42.2	199	644	15
8	" 15	26.33	80	31.1	41.1	193	634	15
				43.4	35.9	168	553	3
				24.6	33.6	158	519	5
				42.8	38.1	179	588	2
				51.8	38.5	181	595	2
9	" 11	24.11	75	61.0	59.7	280	900	35‡
				74.8	51.9	243	782	23‡
				60.1	52.0	245	786	18‡
19	" 16	24.75	76	30.6	48.2	226	737	23‡
				17.1	40.5	190	618	12
				32.4	42.2	198	644	3
Average.					40.0	188	613	

* $S = 9.0 \times W^{\frac{2}{3}}$.

† Computed from the oxygen consumption with the caloric value indicated by the actually determined respiratory quotient.

‡ Values corresponding to activities over 15 per cent are not included in the average.

the drop due to change of state is 26.5 per cent, which is greater than that usually attributed to sleep. It may well be that these states of the mouse have not been correctly described, and that what appeared to be a quiet-relaxed-awake state was in reality not one of perfect relaxation but of some tension; more, perhaps, than characterizes animals that show a smaller difference between the sleeping and awake states. The average, 38.5 liters per kilo of body weight, for what appeared to be the quiet-relaxed-awake state was but slightly higher than the value of 37.5 liters previously reported.

Table III shows the determinations made on six of the same mice in the Nutrition Laboratory at Boston. It will be observed that these determinations were made about 3 months before those of Table II, and that consequently the weights of the mice were less. Table III is divided into two parts, the first part containing those determinations in which activity was not measured, the second part those determinations in which activity was measured. The activity as recorded in the last column was measured in terms of duration only. Mouse 1 was active 10 per cent of the time in the first period and 15 per cent of the time in the second, but the oxygen consumption for the first period was greater than for the second. This was no doubt due to an intensity factor which was not measured and which must have been much greater in the first than in the second period. However, the purpose of the activity measurement was merely to illustrate somewhat roughly the effect of activity, and it may be observed that the oxygen consumption values corresponding to activity durations of 18 to 35 per cent were all greater than those corresponding to activity durations of 2 to 15 per cent. Therefore, it would seem safe to conclude regarding those cases in the first part of Table III where activity was not recorded that the lower oxygen consumption values corresponded to a lesser degree of activity either during or just before the period than did the higher values. None of the values in the first part of Table III was used in calculating the average and only the nine values in the second part that corresponded to recorded activity durations of 15 per cent or less. The average of these nine determinations was 40.0 liters of oxygen per kilo per 24 hours, which was but slightly higher than the Chicago average, 38.5. The four lowest of these oxygen consumption values, namely 35.9, 33.6, 38.1, and 38.5 for Mouse 8, corresponded to the lowest recorded activities, namely 3, 5, 2, and 2 per cent, respectively, and were of the same order as the four values, 36.3, 40.1, 38.8, and 37.4, obtained for the same mouse by the Chicago method in which activity was entirely eliminated. It will be observed that the second of the former four values, 33.6, corresponding to an activity duration of 5 per cent, is less than any of the latter four for the quiet state involving no activity. It is probable that the behavior of a mouse during any one determination was characterized by states of quiet, sleep, and activity, the proportions of which varied from determination to determination, and that in the partly quiet, partly active, partly sleeping state of this mouse the activity was more than compensated by the sleep so that the value obtained lay between that for the quiet and that for the sleeping state. If the mouse had slept throughout, it would probably have given a value approaching 28.3, obtained for the sleeping state by the Chicago method. Values as low as this were later found in the Boston Laboratory on a different group of mice, each of which, after being without food from 18 to 43 hours, showed a lowering of rectal temperature (determined by the thermoelectric method) of from 1.6–3.5°. A somewhat smaller lowering of rectal temperature (determined by a clinical thermometer), namely 0.5–1.5°, was also later found in the Chicago laboratory on some of the jointly investigated and other mice after being without food from 17 to 24 hours. This lowering of temperature of mice under the conditions observed may in part explain the comparatively low metabolic values obtained.

The adequacy of the Chicago method has also been tested both by an alcohol check and by analysis of the carbon dioxide content of the chamber before and after an experiment. Such analyses were made for most of the experiments recorded in Table II, and it was found that the carbon dioxide content of the chamber both before and after a determination was in every case approximately 0.04 per cent. An alcohol check was made by using an alcohol burner such as is illustrated in Fig. 1, and the burning of approximately 0.5 cc. of alcohol in this burner required the mercury reservoir to be enlarged to at least 700 cc. The burner was placed in the metabolism chamber which connected with a manometer and the mercury reservoir to which mercury was admitted from a burette to replace the carbon dioxide absorbed by the soda-lime in the chamber. The reservoir of the alcohol burner consisted of a capillary tube surmounted by a cup which contained the alcohol that was burned while the chamber was coming to constant temperature, during which time oxygen was admitted. When the temperature of the chamber became constant, and when the alcohol level in the burner reached the zero point at the upper end of the capillary reservoir, the system was closed, and the amount of oxygen burned was measured by the amount of mercury admitted to restore the manometer level. Mercury was admitted

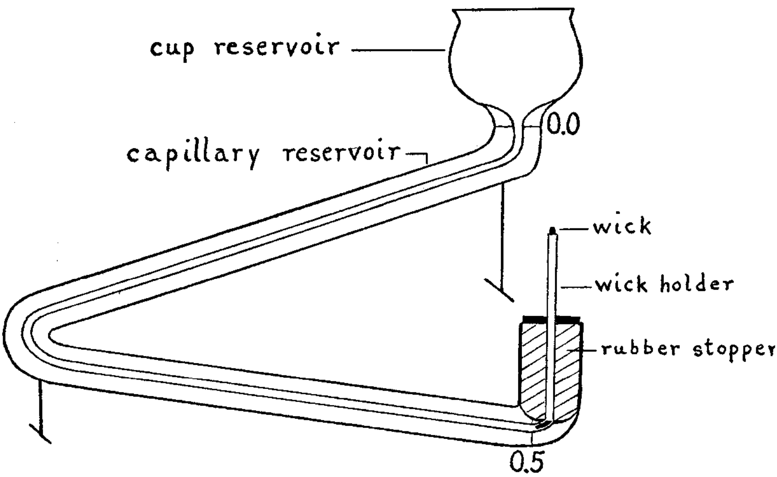

Fig. 1. Vertical section of alcohol burner

to the system about as fast as the oxygen was consumed, so that, when the alcohol was burned down to the 0.5 cc. mark at the lower end of the capillary reservoir, the mercury required to restore the manometer level could be admitted at once. After the lapse of 2 or 3 minutes the displacement of the manometer level would indicate the absorption of a few more cc. of carbon dioxide, but this lag in absorption was disregarded because it was compensated by a similar lag at the zero point. Four alcohol checks carried out in this way resulted in oxygen consumption measurements deviating 0.4 to 1.37 per cent from the theoretical amounts.

It should be pointed out, however, that the Chicago method requires rather elaborate apparatus which must be kept in perfect mechanical condition and be carefully operated. This is especially true when a chamber of 8 liters capacity is used for a mouse rather than a rat, for which that size is better suited. If changes should occur in the temperature or barometric pressure of the 8 liters of air, they would result in a proportionately greater error in the record of the volume of oxygen consumed by a mouse than by a rat in the same length of time. Such errors, however, would be more applicable to individual determinations, for in a number of determinations there would likely be as many errors tending to increase as to decrease the determination, so that the final effect of these errors would be ironed out in the average of a series of determinations.

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