Onderstepoort Journal of Veterinary Science and Animal Industry, Volume 11, *Number* 1, *July*, 1938.

Printed in the Union of South Africa by the Government Printer, Pretoria.

The Basal Metabolism of 3 to 4 weeks old White Leghorn Chickens.

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ARMSBY (1917), who introduced the conception of nett energy values, clearly discriminated between the energy values of feeds and the energy required by the animal. The latter requirement, he analyzed into definite and distinct physiological functions, such as basal metabolism, elaboration of new tissues, fat deposition, egg production, lactation, gestation, and work. The basal metabolism of an animal, which is its minimum energy expenditure compatible with the mere existence of life, is a necessary and essential step in the determination of the different components of an animal's total energy requirement. It is that fraction of the energy needs, on which the energy required for all the other fractions, such as growth, egg production, etc., are superimposed. A growing chicken would therefore first utilize its feed energy to cover its basal heat requirements, and thereafter convert the remaining energy for anabolic purposes such as tissue synthesis, fat production, etc. It is therefore self-evident, that in a study of the energy requirements of animals, the basal heat production should constitute the initial determination. Such a determination is generally conducted when the animal is in a post-absorptive condition and free from the stimulus of food, with an environmental temperature corresponding to the critical temperature of the animal. The experimental animal should be inactive and as nearly as possible at complete rest.

Under these conditions the basal metabolism of an animal or individual is readily reproducible, and appears to be one of the most constant of biological measurements. For this reason, it is also extensively used as a diagnostic measure for certain types of diseases. However, it has been amply demonstrated that the constancy of the basal heat production holds better when expressed per unit of surface. Consequently the surface area is used in preference to weight, for expressing the basal metabolism, since in the latter case differences in size of the animal are reflected in the more variable set of data obtained. As a result, formulae have been evolved by time consuming devices, to estimate the surface area of different species of animals for expressing the basal heat production.

While the basal heat production, generally speaking, may be regarded as a biological constant for mature animals, it is nevertheless definitely influenced by such factors as age and sex. Du Bois (1916) in his curve on the basal metabolism of humans, per unit of body surface, shows a striking change from birth to old age. The first weeks of life were marked by an extremely low level of metabolism approximating 27 to 30 calories per square meter per hour. From then onwards it rose rapidly until at one year of age, the metabolism is 50 per cent. above adult level. It appears that the maximum rate of metabolism occurring from 2-6 years of age is about 60 calories per square meter per hour. After this stage, the metabolism drops comparatively rapidly to 20 years of age and then very gradually afterwards. Mitchell and Carmann (1922) working on rats, showed, that the basal heat production at 30-40 days of age was distinctly higher than at 90-190 days of age. The same effect of age on the basal metabolism was noted by Deighton (1923) and Wood (1926) in growing pigs. Mitchell, Card and Haines (1927) found a remarkable similarity between the basal metabolism of chickens and humans, in that the metabolism per unit of surface is distinctly below the adult level at hatching, rising rapidly to a maximum and then decreasing to the adult level, which is maintained for a considerable fraction of the life span.

That the environmental temperature at which the basal metabolism determinations are conducted, influences the heat production values considerably, has been significantly demonstrated in studies on the respiratory exchange of animals. Within the range of thermal neutrality the heat production is unaffected. If, however, the environmental temperature becomes lower than the critical temperature of the animal, heat production is increased to cope with this extra demand for heat. It is therefore essential that the environmental or experimental temperature should coincide with the critical temperature of the animal under experimentation. Mitchell (1927) found the critical temperature for mature birds to be in the neighbourhood of 63° F. Kleiber (1933), in a study on the influence of environmental temperature on the utilization of food energy by baby chicks found the lowest CO_2 production at 40° C. From these data it would appear that the critical temperature of one-month-old chickens would lie approximately between 30° C. and 35° C. In this study the temperature has been maintained as far as possible about 31° C.

Experimental Results.

1. *Surface area determination.*

Owing to the fact that no formula exists for chickens by which the surface area could be estimated, it was decided to utilize the existing material to formulate a prediction formula for the estimation of the surface area. After the basal heat production had been measured, the chickens were subjected to a period of fasting equivalent to that employed in the actual determinations, namely 18 hours. They were weighed, killed, de-feathered and the clean carcass washed with alcohol and ether. The Mold method originally used by Lee (1929) and successfully utilized by Smuts (1935) on mice and guinea-pigs, was then applied to the completely dry carcasses of the treated chickens. Each chicken was kept in a definite position while the gauze cemented with collodium ether was wrapped around it. The chickens were then left for some time in front of an electric fan for the mold to get thoroughly dry. The mold was then cut loose from the carcass and further sub-divided into as many small pieces as were necessary for tracing the areas on paper. These areas were subsequently determined by means of a planimeter and recorded as the measured surface area.

The feet were not included in the mold but cut off and traced separately. The area of each foot was multiplied by 2. This area was then added to the mold area and constituted the radiating area of the chicken.

The complete data of the measured surface areas and the corresponding equations with the percentage deviations are recorded in Table I.

TABLE I.

Data and Calculation of the Surface Area of White Leghorn Chickens.

Animal No.	Weight. Grms.	Measured Surface Area. Sq. cm.	$K = \frac{S}{W^{\frac{2}{3}}}$	Area according to $S = 11 \cdot 2W^{\frac{2}{3}}$ Sq. cm.	Percentage Deviation from measured Area.	$S = 36 \cdot 31 \ W^{\cdot 457}$ Sq. cm.	Percentage Deviation from measured Area.
624	254	471·9	11·8	449·2	− 4·81	445·5	− 5·6
285	235	434·3	11·4	426·5	− 1·80	440	+ 1·38
323	340	427·1	11·1	432·5	+ 1·26	444·3	+ 4·03
385	247	433·3	11·0	440·9	+ 1·75	450·2	+ 3·9
630	280	482·3	11·3	479·4	− 0·6	476·7	− 1·16
242	255	476·5	11·9	450·3	− 5·50	456·7	− 4·16
618	274	465·8	11·0	472·5	+ 1·44	472·1	+ 1·35
641	325	454·5	11·9	426·5	− 6·16	440·1	− 3·17
417	327	512·9	10·8	531·5	+ 3·65	510·6	− 0·45
628	292	495·0	11·3	492·9	− 0·42	486·1	− 1·8
602	239	452·4	11·7	431·3	− 4·66	443·5	− 1·97
293	339	493·3	10·2	544·5	+ 10·38	520·4	+ 5·49
604	252	469·8	11·8	446·8	− 4·9	454·3	− 3·3
650	319	497·2	10·7	522·9	+ 5·17	506	+ 1·77
425	277	479·6	11·5	475·8	− 0·8	474·4	− 1·08
636	320	486·2	10·4	524·0	+ 7·56	506·6	+ 3·9
637	374	588·5	11·3	581·5	− 0·2	556·9	− 5·37
226	279	451·3	10·6	478·2	+ 5·96	476	+ 5·47
Average	—	—	11·2	—	3·77	—	3·06

By substituting the measured surface area and the weight of each bird in the Meeh formula $S = KW^{\frac{2}{3}}$, K the constant was determined for 17 individual chickens, and gave an average of 11·2. Using this value for K, and applying it to the above equation, the surface area was calculated from the individual weights and compared with the measured areas. As will be seen from Table I, column 2, a remarkably close fit was obtained. In only one case was the percentage deviation more than 10 per cent. Disregarding the signs the average deviation is 3·77 per cent. This value compares extremely well with deviations obtained with other small animals under similar conditions.

If, however, the exponent of W (weight in grams) in the Meeh formula as well as its constant (K) are evaluated from the above data by the method of least squares by using the following equations:—

$$(1)\ \Sigma \log S = N \log K + \quad \Sigma \log W$$

$$(2)\ \Sigma \log S.\ \log W = \log K. \quad \Sigma \log W + \quad S(\log W)^2$$

then even a better fit is obtained. The surface area predicted from the determined equation $S = 36{\cdot}31\ W^{\cdot 457}$ is given in Table I together with the percentage deviation from the measured areas. In no case was the percentage deviation greater than 6 per cent. The average percentage deviation disregarding signs is only 3·06. From these results it would appear that the latter formula can be applied with success in predicting the surface area of approximately one month old chickens.

2. *Basal metabolism.*

In studying the effect of length of fasting on the respiratory exchange of chickens the Haldane Gravimetric method as modified by Mitchell (1926) and previously employed by one of the authors was used in this study. The outgoing chain consisted of two rows of bottles which were connected to the animal chamber by a two-way stopcock. In case of abnormal activity the current of outgoing air could be diverted to the one train, the other train absorbing only when the animal was quiet. The latter train consisted of small bottles which could be accurately weighed. The animal chamber consisted of a fruit jar into which the chicken fitted snugly but with apparent comfort during the period of observation.

Chickens were fasted for 12 and 18 hours respectively after which period they were subjected to a basal heat determination. The results of the 12-hour basal metabolism determinations are given in Table II. The heat production was computed from the CO_2 production by using Lusk's figures, on the assumption that the total respiratory quotient was non-protein. The usual errors resulting from this simplification as shown by Mitchell, are less than 2 per cent. The environmental temperatures varied from 29° C. to 35° C., with the majority of cases falling between 30° C. and 32° C. In some cases chickens were first subjected to an 18-hours fast and later to a 12-hours fast. This procedure was found necessary in order to avoid the beginning of a fast in the early morning before the animals had fed.

In studying the effect of fasting on the respiratory quotient and metabolic rate, it was originally intended to include a 24 hours fasting period, but due to the fact that the respiratory quotients attained after 18 hours were so strongly representative of a fasting R.Q. this idea was abandoned. As will be seen from Table II the R.Q.'s after 12 hours fasting are still well above the customary R.Q. of ·70 for an animal in the post-absorptive state. The individual R.Q.'s vary somewhat, but with the exception of a few low values, they all lie in the neighbourhood of ·80, giving an average of ·78. This would indicate that at this stage of fasting the animal has not reached a post-absorptive state but was still oxidizing a mixture of fat and protein. Consequently the average heat production of 1,060 calories per square meter could not be interpreted as the basal heat production, since portion of the heat produced may be due to the stimulus of food present in the alimentary canal.

TABLE II.

Heat Production of 3-4 *Weeks Old White Leghorn Chicks after* 12 *hours fasting.*

Chicken No.	Weight.	Surface area.	R.Q.	O_2 per day.	Heat Production.			Average Temper-ature.
					Per 24 hours.	Per Kg. body weight.	Per Sq. m. of Surface.	
	Grms.	Sq. cm.		Liters.	Cal.	Cal.	Cal.	
240	259	460·2	·79	9·74	46·64	180·1	1,013·5	32°C
242	234	439·2	·78	9·74	46·52	198·8	1,058·8	30°C
266	234	439·2	·74	9·74	46·04	196·8	1,048·3	32°C
285	118	321·2	·80	8·23	39·51	334·8	1,230·1	30°C
293	193	402·3	·78	8·57	40·93	212·1	1,017·4	30°C
323	109	309·8	·80	5·54	26·60	244·0	858·6	29°C
385	175	384·6	·71	9·07	42·54	243·1	1,106·1	32°C
417	285	480·6	·73	12·26	57·79	202·8	1,202·5	33°C
425	155	363·9	·73	9·74	45·91	296·2	1,261·6	32°C
602	203	411·6	·76	9·74	46·27	227·9	1,124·4	31°C
604	184	393·6	·82	7·56	36·48	198·4	926·8	32°C
624	140	347·3	·79	6·22	29·78	212·7	857·5	31°C
628	300	492·0	·84	11·42	55·39	184·6	1,125·8	32°C
618	198	407·0	·76	9·07	43·09	217·6	1,058·7	31°C
630	209	417·2	·81	8·23	39·61	189·5	949·4	32°C
641	217	425·3	·76	9·58	45·51	209·7	1,070·7	31°C
650	234	439·2	·83	10·08	48·77	208·4	1,110·9	32°C
Average	—	—	·78	—	—	221·0	1,060·1	—

In Table III the respiratory quotients and heat production per square meter after an 18 hours fast are given. The respiratory quotients approximate an average value of ·72. The heat production per square meter averages 891 calories, a value much lower than that obtained after 12 hours fasting. From these R.Q.'s it is evident that the animal is in a post absorptive state and oxidizing its own fat. In work of this nature an occasional R.Q. of less than ·70 is encountered to which no special significance is attached other than the oxidation of fat. Henry, Magee and Reid (1934), however, fasted a cock for 48 hours and obtained an R.Q. of ·69. This R.Q. was maintained over long periods of fasting. They maintain that such an R.Q. was not due to fat oxidation direct or indirect through conversion to sugar. They suggested that an R.Q. lower than ·70 may be associated with protein metabolism, on account of the fact that a large proportion of the nitrogenous end-products in the fowl are excreted as uric acid and not as urea. Their argument is partly based on the following equations:—

$$2CH_3 \cdot CH\ NH_2COOH + 6O_2 = (NH_2)_2CO + 5CO_2 + 5H_2O$$

$$RQ = \frac{5\ CO_2}{6O_2} = \cdot 838$$

$$8CH_3 \cdot CHNH_2 \cdot COOH + 21O_2 = 2C_5H_4N_4O_3 + 14CO_2 + 24H_2O.$$

$$RQ = \frac{14\ CO_2}{21O_2} = 0 \cdot 667$$

When urea is therefore the end-product of protein metabolism, an R.Q. of ·838 is expected, while in the case of the fowl where uric acid is the end-product, the R.Q. of protein metabolized will be ·667.

It is difficult to understand why an animal such as the fowl will metabolize protein in preference to fat in a fasting condition, if it has the latter nutrient available.

TABLE III.

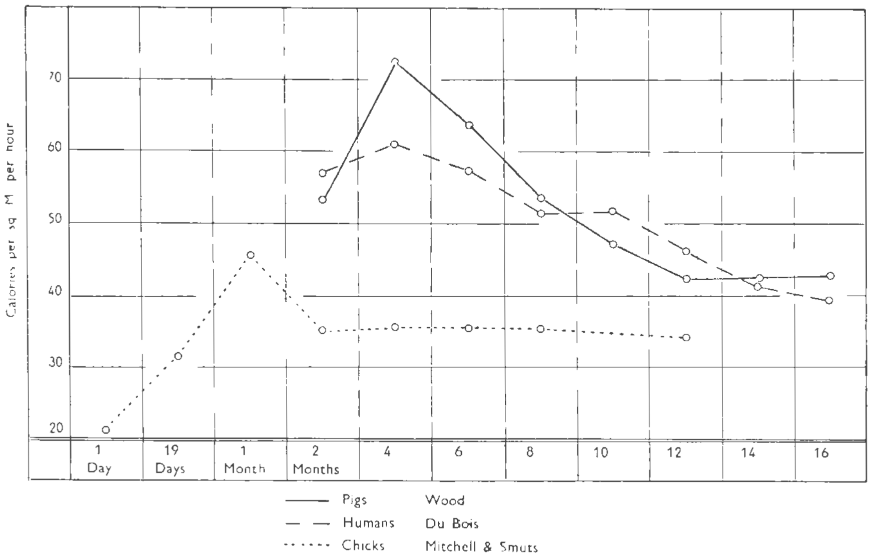
Heat Production of 3-4 Weeks Old White Leghorn Chickens after 18 hours fasting.

Chicken No.	Weight.	Surface Area.	R.Q.	O_2 per day.	Heat Production. per 24 hours.	Heat Production. Per Kg. body weight.	Heat Production. Per Sq. m. of surface.	Average Temperature.	Heat Product per 24 hours per Sq. m. calculated from $S = 81 \cdot 9\ W^{\cdot 705}$
	Grms.	Sq. cm.		Liters.	Cal.	Cal.	Cal.	°C	
240	217	425·3	·76	8·58	40·76	187·8	958·4	30	1,120
242	143	350·8	·74	6·22	29·40	205·6	838·1	32	1,085
266	234	439·2	·70	9·41	44·10	188·5	1,004·1	30	1,148
285	149	357·7	·77	6·05	28·82	193·4	806·1	31	1,033
293	198	407·0	·72	6·05	28·45	143·7	699·0	32	834
323	96	292·3	·70	5·71	26·76	278·8	915·5	29	1,305
385	124	328·6	·71	7·39	34·66	279·5	1,023·6	35	1,415
417	262	462·6	·74	10·75	50·82	194·0	1,098·6	30	1,219
425	255	456·8	·71	9·24	43·43	170·0	948·8	33	1,065
602	256	457·6	·72	9·07	42·65	166·6	932·0	32	1,021
604	233	438·4	·74	8·23	38·90	167·0	887·3	31	1,018
624	151	363·9	·70	5·38	25·21	167·0	692·8	31	894
628	217	425·3	·70	8·74	40·10	184·8	942·9	34	1,102
618	156	365·0	·71	7·06	33·11	212·2	907·1	30	1,150
630	269	468·1	·71	8·57	40·16	149·3	857·9	30	956
641	154	362·8	·70	5·88	27·55	178·9	759·4	33	967
650	160	369·3	·73	6·89	32·48	203·0	879·5	32	1,109
Average	....	......	·72	—	—	183·5	891·2	—	1,085

It is nevertheless a strange phenomenon that only occasional cases of R.Q.'s less than ·70, appear in a series of determinations. Mitchell (1927), in 58 determinations of basal metabolism after 48 hours fast only obtained five lower than ·70. Probably the nutritional state of the bird may be an influencing factor.

From our data it appears that chickens of one month of age reach a post absorptive state in 18 hours. Mature birds according to Mitchell, must be fasted at least for 48 hours to attain a fasting level. Henry, Magee and Reid (1934) found that it takes 16 to 26 hours for a fowl to empty its alimentary canal. This would then be more or less the period necessary to fast a fowl for a basal metabolism determination, since the food stimulus will be removed. The observation of the latter workers agrees with ours in that our chickens were reduced to a fasting level after 18 hours.

GRAPH I.



In Graph I the variation of basal metabolism with age for humans, pigs and chickens has been plotted. The curve for humans has been duplicated from Du Bois (1916), while that of the pig is a reproduction of the data of Wood (1926). For comparison, a curve representing the trend of the basal metabolism in poultry has been inserted. These figures were obtained from the data of Mitchell (1927) as well as ours. Naturally the basal metabolism per square meter of one-month-old chickens reported by Mitchell (1927) is higher than ours, since the prediction formula differs. The point on the graph represented at one month has been obtained by employing the formula of Mitchell (1929) $S = 8 \cdot 19\ W^{\cdot 705}$ and utilizing our heat production values, since the values obtained in this study appear to be more representative of the basal metabolism as indicated by the R.Q.'s.

The interesting features of the curves are, that the chicken reaches its highest metabolic rate at approximately one month of age, the pig attains the same level at approximately four months, and the human between four and six years. With the chickens the basal heat production increases from hatching to one month at a rapid rate, being about 22 per cent higher at the latter age, than at hatching. From one month, the basal heat production seems to fall as rapidly as it increased and reaches a level of heat production almost equivalent to that of mature birds in two to three months time. The highest basal metabolism reached by pigs is approximately 70 per cent. more than the adult level, while with chickens it is only approximately 12 per cent. more. This difference may bear some relation to the life span of the animal and the rate at which it attains maturity.

From these results it will appear, that from three weeks to five weeks, the basal needs of chickens are at their highest, and would therefore in practice constitute the period during which they should be fed more liberally to attain good growth.

Summary and Conclusions.

1. By the application of the mold method the individual surface area of 17 chickens of approximately one month of age were determined and formulae evolved for the prediction of the surface area. The value for K in the Meeh formula was found to be 11·2, while by the method of least squares a formula equivalent to $S = 36{\cdot}31\ W^{\cdot 457}$ was obtained.

2. The basal heat production of one-month-old chickens, when expressed per square meter of body surface, was found to be 891 calories per day. If the formula of Mitchell for estimating the surface area is applied, the basal heat production becomes 1,085 calories per day.

3. It appears that the highest basal metabolism in chickens is reached between $3\frac{1}{2}$ to $4\frac{1}{2}$ weeks.

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