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BASAL METABOLISM IN PREGNANCY

—ENERGY METABOLISM OF NEW BORN—

Yoshio OMATSU

It is the wellknown fact that in pregnant state the basal metabolism (BM) shows a higher level, compared with the usual, but it is also true that there have been much arguments with regard to the rate and the time course of this increase, or to the interpretation of this higher level (see e.g. 1—5). In the present paper, the observations made on 3 healthy subjects, from comparatively earlier stage to the time of delivery, are to be described. In one case, the observation was extended into 3 months after the delivery, and at the same time gaseous exchanges of the new born were measured. Beside these, the food intake and the total-N excreted into the urine were determined with two subjects.

1. Method

For the BM measurement, the expired air was collected into Douglas bags. The collection was done at the individual home with due precautions paid—(1) at least 12 hours passed from the last evening meal, (2) waking up and urination, (3) rest in bed for 30 minutes. (4) the mouth-piece worn for 10 more minutes, and finally the collection. In case an intervention of any factor that might disturb the BM state was suspected, the observation was cancelled. The gas collection of the new born was effectively done with the simple arrangement deviced by Kokui (6). The use of mouth-piece or any other similar attachment, is of course out of the question. The infant properly clothed was loosely covered from the head to its full length with a sheet of nylon. At the centre of the sheet a hole was made, to which a corrugated rubber tube was hermetically attached. The hole came over head, somewhat away. The air was drawn through the tube by a blower into Doulas bag via gasometer. This allowed the infant free and fresh air breathing. In this arrangement the expired air is naturally diluted considerably by the air, but if one keeps the dilution within 3 or 4 times the expired volume, one can expect good result with the usual Haldane apparatus.

The daily calorie intake was calculated from the food intake actually measured every meal, using the assay table (7). The total-N in the urine was measured with the Kjeldahl half-micro method.

2. Subjects

For choosing the subject for this sort of observations, it is most essential that they can understand the nature of the measurements, and added to this their

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cordial co-operations are highly required. Even after these conditions being fulfilled, the requirements for the peesent observations are not mitigated none the less ; the early morning visits for the gaseous collections are tedius and trying moments for both the subject and experimenter. The routine work of the measurements of food taken in would, if the period be of a week or so, not be untolerable, but when it comes to over several months, it would easily become a burden that is hard to endure. Fortunately the author was able to find 3 willing subjects, and 2 of them served at the same time as the co-workers for the food measurement. They were all the spouses of doctors—O being that of the author and the most frequently observed.

Certain detail informations with regard to the subjects are given below.

Table 1

Subj:	Age:	Height: (cm.)	Weight: (kg.)	Date of delivery:	Weight of infant: (kg.)	Period of observation:
O	28	153	51	16 May, 1954	3.65	Sept. 1953—Aug. 1954 (7th week)
H	23	151	47	1 Oct., 1951	2.70	Feb. 1951—delivery (8th week)
C	26	162	46	4 Apr., 1951	2.80	Sept. 1950—delivery (12th week)

The mean stature and weight of female for age 21 to 30 are 150.1 cm. and 48.5 kg, so that the subjects O and H were not far from the means, but C was somewhat tall and lean. They were all of the 2nd pregnancy, the deliveries were of full months and easy, and the new borns were all males. The first BM measurements were done rather late, as seen the weeks within brackets in the last column (which were calculated backward from the dates of delivery), for the measurements were not performed until definite signs of pregnancy were observed.

With regard to the physiological disturbances, O felt morning sickness up to the 12th week (though of lesser degree), general weariness, loss of appetite and nausea (but vomited once). H had somewhat severe experience—strong nausea, vomited even at the 11th week, conditions improved in the 15th and at the 18th normal state was restored. The most severe was C, nearly completely lost appetite in the 12th and 13th weeks, strong nausea, remained in bed nearly all the time, only after the 15th week conditions somehow improved, and gradual restoration observed in the 16th and further on.

3. Food Intake

No restriction was imposed on the food intake. The measurements commenced from the 10th week with O and C. The monthly mean values for (the 3rd to 10th months) of the 3 elements and the protein excretion and its gain are presented in table 2, together with the weekly means after the delivery.

Table 2

Mean calorie intake, N-balance, etc.—per day

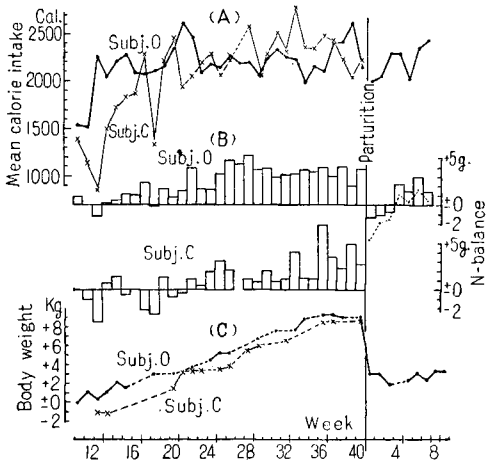
	Total calorie:	Carbohydrate: (g.)	Fat: (g.)	Protein: (g.)	Protein decomposed: (g.)	N-balance: (g.)
Subject: O						
3rd month	1685	314	21	50	51	−0.16
4th	2165	395	25	77	70	1.12
5th	2160	410	22	68	61	1.12
6th	2325	421	26	87	74	2.08
7th	2205	411	21	80	52	4.48
8th	2215	396	26	86	65	3.36
9th	2110	385	22	80	58	3.52
10th	2390	446	26	78	59	3.04
Post partum						
1st week	2005	353	28	72	80	−1.28
2nd	2070	373	23	80	87	−1.12
3rd	2300	440	22	71	75	−0.64
4th	2295	424	26	77	63	2.24
5th	2025	346	32	75	65	1.60
6th	2360	403	33	98	79	3.04
7th	2455	410	42	94	85	1.44
Subject: C						
3rd month	1115	193	17	41	50	−1.44
4th	1730	325	18	57	55	0.32
5th	2190	401	26	75	81	−0.96
6th	2105	401	19	70	65	0.80
7th	2290	417	23	90	77	2.08
8th	2290	421	24	83	75	1.28
9th	2490	450	31	87	68	3.40
10th	2240	405	24	87	66	3.36

The calorie intakes for the 3rd month (the first figures, 2nd column) are rather or extremely small, being 1685 Cal. for O and 1115 Cal. for C. If we take the standard calorie requirement per day of female doing light work as 1800 Cal., using the figure computed by the Kokumin-Eiyo Kenkyu Kyogikai (The National Nutrition Investigation Committee) (8), and assume the digestion loss of 5%, we get 1900 Cal. (in round number) for the food intake. The present intakes then come to 89% for O and 58% for C. Morning sickness of slight (O) and severe (C) degrees, and the inevitable loss of appetite were undoubtedly

the cause of these low intakes. As the sickness subsided, the food intakes showed higher levels ; thus in the 4th month O gained 480 and C 615 Cal. per day. From the 5th month onwards, the intakes seemed to attain higher and fairly constant levels, though with certain fluctuations. More detailed informations will be obtained from fig. 1 (A), in which the weekly means are plotted.

Fig. 1

(A) Weekly calorie intake
(B) Weekly N-balance
(C) Body weight change with respect to the initial



The intake curve of subj. C shows quite an irregularity all through the period, while that of subj. O indicates fluctuations like the former in the earlier half of the period, but settles down to a roughly constant level after the 6th month. The minimal and maximal intakes read from the curves are :

O . . . 1510 Cal. (11th week), 2620 Cal. (21st and 39th do.)

C . . . 850 Cal. (12th do.), 2785 Cal. (33rd do.)

Here we also see that subj. C showed a much wider range.

The parts occupied by protein and fat in the total calories were calculated as :

O . . . . protein 14.3% fat 10.2%
C . . . . do. 14.7% do. 10.3%

which indicate that the composition of the food taken were not far different from the customary diet in this country. Another important factor would be the obviously necessary accumulation of protein inside the body. The monthly means of protein taken in or dissimilated (the latter being calculated from the N-excretion into urine) are seen in the 5th and 6th columns respectively. During the relatively earlier stages, for O the 3rd month and for C the 3rd and 5th months, more protein was dissimilated over the protein intake. This was due mainly to the lesser food intake caused by morning sickness, but the 5th month of C seemed to be exceptional —the food intake was high enough and so the protein intake, and the real cause of the unbalance was the high rate of dissimilation, which was the highest throughout the pregnant state in both series. From the 4th (for O) or 6th (for C) month, protein gain was the usual feature, which showed during the 7th to 10th months a high mean gain of 17 gr. per day for O or of 15 gr. for C.

Detailed protein metabolism will be seen in the histograms of fig. 1, B, in which the weekly means of N-balance are shown. Subject O . . . Corresponding to the low calorie intake (see A) in the 3rd month, there appears a loss of nitrogen

in this month. By the improvement of food intake in the next month, the N-balance regained. More food intake in the 5th month sets the balance to the positive side, though there is a small loss in the 2nd week. From the 7th month onwards a steady and large accumulation of nitrogen is maintained, tailing off a little in the last month, as seen in table 2. Subject C . . . . In the 3rd month the progressive loss of appetite and the inevitable lowering of calorie intake set the N-balance more and more negative, and in the last week the loss becomes 3.5 g. per day. A partial return of food intake in the 4th month seems to favour the balance—a positive accumulation, followed by a nearly balanced state. But the 5th month starts with a definite loss, which continued to the 2nd week. A temporary gain appears next, followed by a small loss. Only from the 6th month, the balance becomes always positive ; neverthless the rather unstable state just seen, does not cease at all after the positivity gained, and we see large fluctuations taking place until the end of pregnancy—a remarkable contrast to the case of O. For this peculiarity we have no definite explanation to offer, and we only add that O was a housewife with serene daily life, while with C the job she held as an active staff member of a news paper gave her much stresses bodily and mentally which might disturb her body conditions, probably resulting in the fluctuations in N-balance.

The nutrition after delivery was studied with subject O, and the weekly mean values are shown in table 2. In the 2nd column we see that after the 1st week's relatively low intake (probably due to a slightly lowered appetite felt, caused very probably by the shock of delivery and later bodily readjustments), the intake increases rapidly to cover the lactation. The protein balances in the last column are calculated just the same way as during pregnancy, and are shown in the extension of the upper histogram of fig. 1, B. During the 1st and 2nd weeks, possibly the 3rd, more protein seems to be decomposed. But these figures indicate only the difference of protein taken-in and that decomposed and finally found its way into urine ; so that in order to see the total metabolism of protein of the mother, we ought to add that part of protein spared by lactation. The protein secreted as milk was estimated by calculation, using the existing data (9). The dotted line overlapped the part of the extended histogram is intended to show the corrected N-balance of the maternal body. Thus in the 1st week the protein loss might be the order of 22 g. per day ; moreover in this period there must be more protein lost in the uterine bleeding, though of very variable amount. At any rate the main daily loss would be more than 22 g.—a figure certainly showing the highest protein loss in the whole period observed. The loss quickly becomes small and we see such figures as 11 g. for the 2nd week and 10 g. for the 3rd. In the 4th the balance turned, and a gain of 6 g. is registered, and after that there are small accumulations for following weeks, seemingly to make up the earlier loss.

4. Basal Metabolism

BM was measured with 3 subjects from relatively earlier stage of pregnancy (O . . . 7th week, C . . . 12th do. and H . . . 8th do.) to the day before the delivery, and with the first subject the measurement was continued up to the 11th week after the delivery. The weekly means of oxygen used per minute, R.Q. and the volume of expired air of the first subject are tabulated below, with short remarks concerning with the bodily conditions.

Table 3

Week:	O_2 consumption: (c.c./min.)	R.Q.	Ventilation: (l/min.)	Remarks:	Week:	O_2 consumption: (c.c./min.)	R.Q.	Ventilation: (l/min.)	Remarks:
7	*170	0.89	4.94	MS first	30	213	0.84	5.89	
8	*166	0.89	4.41	N & AB	31	213	0.90	6.12	
9	*171	1.00	5.55	MS strong	32	207	0.92	5.83	
10	168	1.00	5.47	MS weakened	33	214	0.85	5.77	
11	*177	0.90	5.54		34	224	0.84	5.94	U
12	171	0.94	4.91	AG	35	220	0.84	5.87	F1
13	182	0.93	5.47		36	223	0.87	5.89	U & F2
14	182	0.92	5.36		37	223	0.85	5.80	
15	184	0.90	5.26		38	211	0.90	5.85	F2 & F3
16	—	—	—	cold	39	210	0.94	6.04	
17	—	—	—	cold	40	210	0.90	5.77	F2 & F3
18	190	0.94	5.67		Post partum				
19	193	0.97	5.77		1	203	0.81	5.03	
20	200	0.94	5.85		2	185	0.92	4.82	
21	199	0.96	6.07		3	178	0.96	4.48	
22	203	0.90	5.89		4	178	0.95	4.40	
23	200	0.92	5.86		5	184	0.92	4.71	
24	203	0.93	5.87		6	173	0.87	4.36	
25	199	0.94	5.71		7	176	0.93	4.57	
26	210	0.93	5.83		8	173	0.95	4.53	
27	214	0.91	5.84		9	183	0.94	4.65	
28	214	0.92	6.24		10	183	1.03	4.85	
29	213	0.90	6.11		11	184	1.01	4.87	

Note: Abbreviations are MS . . . morning sickness, N . . . nausea, AB and AG . . . appetite bad or good, U . . . frequent urinations, F1 . . . upper abdominal pressure relieved, F2 . . . pressure in lower abdomen, and F3 . . . pains in lower abdomen.

Oxygen consumption. The figures asterisked denote a single or sometimes the mean of two observations, and accordingly are less reliable than the others. The oxygen consumption at the relatively earlier satges, before the 12th week, is certainly low, even due respect being paid to the unreliable nature of those figures. This corresponds to the period, when the subject felt slight MS and partial loss of appetite—consequently resulting in the low total calorie intake

seen in table 2 (subj. O 1st row) reflects in this low oxgen consumption. With the progress of week, the oxygen consumption increases steadily, reaching 200 c.c. level at the 20th week, which is 18% higher with regard to the initial level (the 7th to 11th weeks). The increase of BM-oxygen goes on further until the maximum at the 34th week reached, with an oxygen intake of 224 cc. per min., roughly 32% higher of the initial level. The oxygen intake maintains the highest level for some weeks (the 34th to the middle of 37th), and from there it fall rather abruptly to a definite low level (roughly 210 c.c. per min.) for the next 3 weeks, ending up to the delivery. It would be of interest to observe an increase of BM-oxygen just prior to the delivery, which is certainly expected from the muscular activity caused by the onset of uterine pains—the actual figure obtained was 228 c.c. per min. (or 134% of the initial level) at 3 hours before the event. In fig. 2 A, the dot with circle on the top of the line showing the delivery marks this last BM measurement.

Respiratory quotient and ventilation. The R.Q. often differed appreciably in successive days; because any irregularity in breathing in such measurement resulting in changed lung ventilation, thus causing sometimes washing out of CO_2 or in other times retention of it. And it is true that in pregnant state breathings are more liable to be subjected to irregularities due to the abnormal physiological condition as well as to mental unstability often experienced. So that even in the weekly means the variations are rather large, yet there is a tendency of R.Q. to fall to a definitely low level after the 33rd week. The monthly means seen below show again this inclination of R.Q., in that after the 8th month R.Q. are undoubtedly lower than the previous months.

Month :	3	4	5	6	7	8	9	10
R.Q.	0.97	0.92	0.95	0.93	0.92	0.89	0.85	0.90
Ventilation : (1/min.)	5.19	5.36	5.76	5.92	5.90	5.98	5.86	5.86

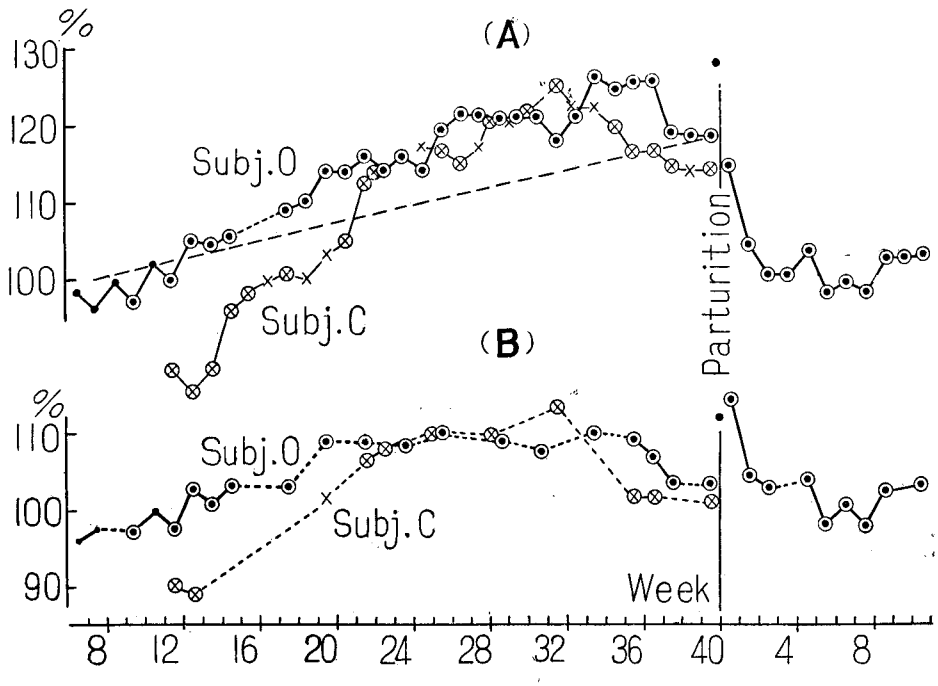
Like R.Q. the volume of expired air per minute, the ventilation, differs from day to day; or rather precisely, any alteration in the latter can be regarded as a cause of the change in R.Q. This daily variability makes it difficult to get any idea about the behaviour of the ventilation with the progress of pregnancy, save that in the later stage, say from the 6th month further on, it is somewhat highar than those of the earlier months. The mean weekly values may be used for this purpose, but there are still certain irregularities. More suitable would be the monthly means, which are shown in the above table. The ventilation increases gradually from the 3rd month up to the 8th, and in this it increased by 0.79 1. per minute or 15%, compared with the 3rd month's. In the 9th and 10th months, a slight fall seems to be the case. This probable slight fall,

especially of the 10th month, which was also seen with subject H, may be associated with the lowered position of the fetus, making the breathing movement easier. On the whole, we say that the ventilation increases somewhat in the earlier half of pregnancy and in the later half it remains practically constant at the increased level—this was verified with the other two subjects.

Percentage increase of BM. The alterations in BM can be seen more clearly in the percentages to usual state. BM of the usual state was calculated for each week using the body weight observed at the period. The part of weight increase due to the intra-uterine development was simply taken as the weight increase of the mother, and any special position of the fetus was ignored—a quite different viewpoint will be seen in discussion. The results are shown in fig. 2, A. (To avoid complication, the curve of H had been omitted. The points with circles denote more than 2 observations.)

Fig. 2

(A) Weekly total BM expressed in percentage of calculated normal
(B) Weekly per kilo-BM do.



In the main features the 2 curves show very similar appearances; thus all of them start with negative signs of several to more than 10%, corresponding to the low food intakes referred before, and cross no change line at the 10th week (O), and the 17th (C and H)—each comes roughly to the period at which the subject felt no more MS. After crossing the line, the BM curves ascend

gradually with the weeks passed, though there are sometimes lingerings, set backs and rapid progresses. The ascent terminates at a summit—for O . . . between the 34th and 36th weeks, C . . . 32nd, and H . . . 33rd. The maxima are : O . . . 126.5%., C . . . 125.4% and H . . . 126.7%. Passing the summits the curves descend more or less sharply down to the last week, and thereby make descents of 8% . . . O, 11% . . . C, and 12% . . . H.

The behaviour of BM after the childbirth was traced with subject O. The details of weekly means are presented in the last quarter of table 3. The oxygen consumption (2nd column) of the post partum 1st week does not fall to the level of usual state, but remains high, quite near to the last week of ante partum (210 c.c. per min.) and far from the initially assumed value of 173 c.c. under normal condition. In fact, such figures (c.c. per min.) were obtained in this week, 1st day . . . 205, 2nd . . . 202, 4th . . . 203 and 7th . . . 202. It should be remembered that the maternal body weight has gained roughly by 3 kg. (mean body weight up to the 18th week being 53.9 kg.—the initial being 51 kg., table 1), so that the calculated BM becomes now 177 c.c. per min. instead of 173 c.c. of the initial. But this does not reduce much the high value of the 1st week. The mean of 185 c.c. for the 2nd week looks to be a little higher for the new standard, but it included two days near the standard. The 3rd and 4th weeks come very near to the calculated value. After this period, there appear certain ups and downs but generally the BM seems to keep a few per cent higher level than the standard. The post partum portion of the curve for O in fig. 2, A was drawn with the figures calculated with the new standard.

The chart B of fig. 2 shows BM changes of two subjects O and C, with regard to unit body weight—the body weights used were respective weekly means. Corresponding to the earlier low percentages of BM seen in A, we have similar counterparts in the present instances. Such inferior state however retreats sooner or later, and after around the 20th week, both curves attain plateaux at roughly + 10% level, which are maintained until near the last month. In the last period, there appear rapid falls to near the standard level.

With subject O the post partum period starts with an amuzingly high value of about +15% in the first week, corresponding to the high 1st week percentage in chart A, but soon falls to the range of normal level in the 2nd week.

The other items in the table require little comment, but the mean low R.Q. of the 1st week may be mentioned. The observed values were, 1st day . . . 0.82, 2nd . . . 0.83, 4th . . . 0.79 and 7th . . . 0.80—quite concordant and definitely low. This is interesting, because the mean ventilation of this week is the highest, being 5.03 ls. to the total mean of 4.65 ls., so that we may expect at the least a R.Q. well over 0.90, like all the others. The decidedly low value of 0.81 can hardly be taken as accidentally occurred, as remarked just above. It must be linked up with special metabolic changes taking place inside the maternal body at this period—possible re-organization of the body into usual state. The high

rate of energy consumption shown above of the 1st week and the high protein loss referred before, especially the latter's being the highest throughout the whole period of ante et post partum, give a good reason for the assumed metabolic changes.

5. Gaseous Exchange of New-Born

The child of subject O was used for this measurement. The first measurement was done while it was in sleep (8 hours from birth). From the 2nd day further on, the time of the collection of the expired air was chosen at least 2 hours from lactation and of course in the state of sleeping. This is not quite in accordance with the definition of BM, but is certainly showing the minimal rate of metabolism, which Gordon (referred in 10) termed as ' standard metabolism'. For the collection of the gas, it is certain that a long duration is preferable, and the time was ranged from some 10 to 50 minutes, usually around 20 to 30 minutes. The gas was collected into different bags for every 10 minutes or so ; from those collections, by the usual routine, the O_2 consumed and CO_2 expired were determined and the means of them were taken as the day's gaseous exchanges. The surface area in the following tables were calculated from Meeh's formula. The daily results of the 1st week are shown in table 4 ; this is done because in this early stage of post natal life there took place a great deal of changes in body weight and in gaseous exchange. The lactation of the newborn was given as follows : 16th and 17th . . . no suckling, 18th . . . occasional, and 19th . . . regular suckling started.

Table 4

Gaseous metabolism of new-born

Day :	O_2 comsumption : (c.c./min.)	R.Q.	Body weight : (kg.)	O_2 used per kg : (c.c./min.)	O_2 used per sq. m : (c.c./min.)
1	14.1	0.78	3.65	3.86	57.7
2	20.9	0.82	3.41	6.12	89.6
4	20.8	0.80	3.41	6.09	89.2
do	21.3	0.82	3.48	6.12	90.2
5	24.3	0.94	3.52	6.90	102.1
6	25.9	1.00	3.60	7.19	10.7
7	27.3	0.84	3.75	7.28	110.0

The oxygen consumption per min. (2nd column) shows a great change in this week. The 1st day (as remarked above 8 hours after birth) registered a very low level of 14.1 c.c.—corresponds to 57.7 c.c. per sq. m. per min., or to only 49% of the maternal oxygen consumption at the same unit. On the 2nd day it jumped up by roughly 50% to 20.9 c.c., on the 4th it remained nearly at this level, and from there increased steadily up to 27.3 c.c. Thus we see the oxygen consumption increased almost twice at the end of the 1st week.

The R.Q. starts from the very low value of 0.78 of the 1st day, maintains fairly low level around 0.82 for seemingly successive 3 days, and then rises roughly to the normal level. It would not be far from the truth, if we attribute those low values to an entire use of its reserve food materials—presumably protein and fat, because the regular lactations only started on the 4th day, and the quick rise in the 5th may be taken as an effect of the preceding whole day lactation.

The body weight (4th column) indicates no feeding by a fall of 240 g. on the 2nd day, and the occasional lactations (3rd day) seemed to check the fall and we see it remains on the 4th day at the same level as on the 2nd. Body weight picks up slowly from there an increasing pace.

Things settle down more or less squarely in the 2nd week: thus we see the mean oxygen consumption of 26.6 c.c. with the range of 26.4 to 27.0 c.c., or the mean body weight of 3.84 kg. with progressive increases from 3.79 to 3.90 kg. Further developments are given in table 5 in the form of weekly means, together those of the 1st and 2nd weeks.

Table 5

Weekly mean gaseous metabolism of new-born

Week:	O_2 consumption: (c.c./min.)	R.Q.	Body weight: (kg.)	O_2 used per kg: (c.c./min.)	O_2 used per sq. m: (c.c./min.)
1	23.4	0.87	3.56	6.61	98.0
2	26.6	0.92	3.84	6.92	105.5
3	27.7	0.95	3.98	6.96	107.4
4	35.7	0.93	4.27	8.36	131.9
5	38.5	0.97	4.79	8.03	131.7
*6	39.4	0.89	5.00	7.88	130.8
7	40.0	1.06	5.29	7.56	128.1
8	42.9	0.98	5.34	8.03	136.4
9	45.4	0.85	5.54	8.18	140.7
10	48.0	0.97	5.68	8.43	146.3
11	50.7	0.82	5.85	8.66	151.6
12	52.5	0.88	5.93	8.84	155.5
13	52.5	0.90	5.98	8.77	154.9
14	53.5	0.85	6.08	8.79	156.1

With the setting down of the rate of development, the number of days observed were reduced from the 4th week further on to 2 or 3, the 6th with a single observation being excepted. In the 1st row the means for the 1st week are given, but those are included in order to show just the magnitudes of the oxygen consumption, etc., for the rapid development seen in table 4 prohibits surely the use of the means. Following the relatively quiet 2nd week, things became somewhat livelier in the 3rd week, and we get a steady increase of oxygen consumption, starting from 26.2 c.c. to 29.0 c.c. with the mean of

27.7 c.c., while the body weight gained up to 4.12 kg. at the end. In the 4th week, however, there appeared an outburst of energy consumption, and the oxygen used per min. goes up all at once to a high mean of 35.7 c.c. or 28% rise against the precedent week. The rise seemed to have taken place rather suddenly, for 4th June (of the 3rd week) registered 29.0 c.c., and while 5th and 8th showed 35.8 and 35.7 c.c. respectively.

The succeeding weeks reveal steady rises of oxygen consumption, and at the same time similarly gains the body weight. To observe more closely the physical development and the rate of metabolism, it would be advisable to reckon the oxygen used in terms of per kg. of body weight or per sq. m. of body surface. The latter item, see the last column, discloses very particular features. It starts with a steady level at the 2nd and 3rd weeks, which is somewhat low compared with the normal maternal (117 c.c.)—the 1st week being put aside by the reason often stated before. Like the abrupt increase of oxygen consumption per min. seen in the 4th week, we have here a very high figure of 131.0 c.c. or an overshooting of 12% of the maternal level. Exactly the same high level is seen in the next week, but the level seems somewhat lowered in the 6th and 7th weeks. Another, though less specutaclar jump takes place on the 8th week, which continues to do so in the 4 succeeding weeks, and finally reaches at a level of roughly 155 c.c. in the 12th week, i.e. 32% higher than the maternal.

Turning to the 6th column, the oxygen consumption per unit weight, does not show such regularity we have just seen above. It shows a steady level within the 2nd and 3rd weeks, then abruptly rises to a very high level at the 4th week, like the counterpart of the last column—though the rise finds only a likness in much later period, the 10th week, and from that height it descends rather sharply in the following weeks, and somewhat recovers in the 8th week. From there it takes up an increasing tendency to the 12th week, and settles down to a little lower level in the following weeks.

For just mere comparison with the minimal rate of oxygen utilization certain bodily activities were studied with the following results.

Table 6

Gaseous exchanges in various activities

Days from birth:	Activity:	O_2 consumption: (c.c./min.)	R.Q.	Ratio to MM:
5	Turning head repeatedly, sulky	35.2	0.94	1.4
do.	Yawning several times, started crying	46.7	1.01	1.9
21	Flatus, faeces evacuated	42.0	0.97	1.2
do.	Stretching the whole body, crying loudly	87.8	0.94	2.5
23	Straightened the back 3 times, moving arms and head	41.2	0.97	1.2
do.	Bearing down for faeces evacuation	42.9	0.98	1.2

The oxygen consumption actually observed are seen in the 3rd column, but it would be more easy to see the increased consumption in those activities, if the oxygen figures be reckoned in terms of the metabolism of the respective date, which are shown in the last column. (MM stands for the minimal metabolism). The ratio ranges from 1.2 to 2.5 of the 21st day, showing that the infant was capable, probably very easily, to perform motions requiring energy consumption 2.5 times the resting minimal rate. Incidentally the table would serve as a precaution for the measurement of MM, in that absolute stillness of the infant is the necessary requirement.

Discussion

Calorie intake. We have seen in the 3rd month intake deficiencies of 11 and 42% below the assumed normal level. With the latter there would have been a deficiency of 785 Cal. per day, and this should have prevailed during at least the fortnight, making up a total deficiency of 10990 Cal. This must have been supplied within the body. Assuming then the calorie source be protein (50 g. per day . . . see protein used in the month) and fat of the body, the total weight of the material used alone would be 1.59 kg. There is a sign of definite loss of weight in the case of C in fig. 1 (C), at any rate at the end of the 3rd month and the whole 4th.

The increased metabolism, according to the report quoted before (8), comes to 15% in the fore-half period 30% in the later-half, making the assumed calorie intake of 2185 and 2470 Cal. respectively. With O, the months of 4th and 5th fall exactly within the former estimate but the later-half period shows certain irregularities, from quite near (the 10th) to definitely low (the 9th) to the assumed 2470 Cal. Subj. C indicates still a very low level in the 4th month, and only reaches the former estimate in the next. The level is carried over to the 6th month. The 7th, 8th and 10th register intakes just the mid-value of the two estimates, while the 9th comes exactly to the latter estimate. On the whole, we may say that the calorie intakes were somewhat low, but not particularly so, except the 3rd or 4th month.

BM in pregnancy. Decades ago Root and Root (4) made continuous observations on one pregnant subject and recorded a fall of BM to an extent of 5.4% in the 4th month, and subsequent increase to a maximum of 10%, several days before the delivery, Sandiford and Wheeler (1) found, also on one subject, a steady rise of BM from the 12th week to a maximum (25% increase) just before the delivery. Fujimoto (5) described a rapid rise to about 18th to 20th weeks, a temporary fall between 21st and 26th weeks, which was followed by another rapid rise, and at the end of the period reached to a height 20% increase. Shimomura (11) reported that the augmentation of BM took place in 3 stages, the last being the highest (11% increase), followed by the middle and early stages. Thus one observation differs from another in some details (which

might be due very likely to the individualities of the cases studied), but all of them agree in those respects, viz. a rise with the progress of months and a definite enhancement in the last.

Like Root and Root's observation (4), all the present 3 subjects showed lowered BM of some extent in the earlier period. The maximal lowerings (in p.c. of the respective calculated value) and the time those happened are: O . . . 4.0% (8th week), C . . . 14.6% (13th do.) and H . . . 8.5% (9th do.). The period of lowered BM corresponds to each period of morning sickness. It is no doubt that both the decreased food intake and general immobility have contributed much in the lowering of BM. That subj. C. the most affected by MS, showed a remarkably large fall of BM and the least affected O underwent only a slight reduction, can easily be explained by the above supposition. After the minimal level, the BM increases more or less steadily, each normal level at O . . . the 12th week, C and H . . . 17th do. It is worthwhile to note that those ends of the lowered BM coincide with the termination of MS in every instance. In short, it would not be absurd if we attribute mainly the diminished food intake due to MS to the decreased BM.

Recently it has been suggested that another, but quite different factor, seems to take part in the lowering of BM in question—progesterone.

One of my colleagues, Takano (12, 13) has shown electro-myographically that the abdominal muscles become tonically much less active or often absolutely inactive at the very early stage of pyagnancy, the 2nd or 3rd week. The state of inactivity continues further throughout the whole length of pregnancy, until some hours before the delivery. Later it was made clear that this disappearance of activity is due to progesterone by Kawakami (14), another collegue. More recent investigations (unpublished) seem to point out the possibility of a general depression of tonic activity of the whole skeletal musculature. Such lowered muscular tone would lead us naturally to assume a lowering of BM, from the present cause, and Saito's observation (15) suggests of this possibility. Some preliminary observations made by the present author, in which relatively large dose of progesterone was administered to adult females in mid menophase, revealed symptomes resembling MS—depressed feeling, general weariness, loss of appetite, nausea, etc., and a fall of BM. It would be very probable that further investigations along this line may bring more detailed elucidation of BM in pregnant state, especially in the earlier stage.

From the 4th (for O) or 5th (for C and H) month, the 3 subjects show generally increasing BM, to much later stages, and so far the present findings are quite agree with what nearly all the previous authors had reported. The increasing BM, however, finally reaches to a maximum at some weeks before the delivery—for O . . . 4 to 6, C . . . 8 and H . . . 7 weeks. From the maxima, all of them fall to definitely lower levels, in which percentage drops of 8 to 12 are recorded. Such lowering has seldom been noticed before, except Fujimoto's

observation (5), in which a fall from 3 weeks before the delivery was graphically shown with little comment. Surely there may be instances which do not show such falls at all, but at the same time the possibility may not be overlooked that it requires frequent observations, at least of the order used in the present investigation, in order to bring forth the fall—a measure seldom being observed before.

With regard to the cause of increased oxygen consumption, there have been several opinions formulated : one attributes the in crease solely to the increased body weight (or proportional increased active protoplasm), so that oxygen consumed per unit body weight remains throughout the whole period of pregnancy. That this proposition does not hold to the present cases is easily seen by fig. 2 A, but is more clearly demonstrated in B, where the changes of oxygen consumption per kg. of body weight are shown in relation to the calculated initial consumption. The ratios are not constant, but increase steadily up to a 10% higher level roughly in the 6th month, and from there remain more or less constant to somewhere the 9th month. In the last month definite falls to near the initially assumed level being observed (for O . . . +3.5% and C . . . +0.8%). Thus we see the oxygen consumption does not follow a simple rule, like the proportionality to body weight.

The second proposition is naturally related to the development of the fetus which requires very likely much more energy per unit weight than the maternal body. Take for example, subj. O at the 21st week, we get the body weight 54 kg., and the BM increase of 15% (fig. 2A subj. O). Assuming the 1st proposition be valid, the would-be BM comes out to be $54\text{kg} \div 51\text{kg} \times 173$ c.c. $= 183$ c.c. per min., whereas the 15% increase gives 199 c.c. The difference, 16 c.c., should be given to the 'excess' use of the fetus—because the weight of fetus being already reckoned in the 1st calculation. If we assume the weight of fetus as 0.5 kg., we get 32 c.c. per kg. per min. for it, which is as much as 9.4 times of the maternal utilization (3.4 c.c. per kg. per min.). This is the excess part and the fetus must consume oxygen at a rate of 10.4 times of the maternal body—a rather colossal rate?, even for a very active organization, the fetus. Similar calculation can be done at say the 35th week, when the BM maintains the highest level (fig. 2A, subj. O), and the excess use turned out to be roughly 1.9 times, instead of 9.4 of the 21st week ; i.e. the rate of would-be oxygen utilization has been reduced to 1/5 during the interval—a hardly conceivable sequence, though there might have been a reduction.

Before going into the 3rd proposition, a simple arithmetic performed on the 40th week will be described. The results of calculation are seen below.

The maternal surface area in the lower side of the table was computed from the maternal weight (the body weight at the 40th week minus the weight of new-born) and the stature given in table 1 ; similarly the fetal were calculated

Table 7

Numerical estimation of 40th week BM

	Subj. O			Subj. C		
	Surface area : (sq. m.)	BM : (c.c. per min.)	BM : (c.c. per m^2 per min.)	Surface area : (sq. m.)	BM : (c.c. per min.)	BM : (c.c. per m^2 per min.)
Before pregnancy (calc.)	1.478	173	117.0	1.468	172	117.1
40th week	maternal 1.540 fetal 0.224 'combined' 1.784	calculated 209+ observed 210	117.7	maternal 1.542 fetal 0.199 'combined' 1.741	calculated 204+ observed 204	117.1

from the weight of new-born, using the Meeh's formula. The respective weights are :

	Subj. O	Subj. C
Weight at 40th week : (kg.)	59.8	54.4
Weight of new born : (kg.)	3.65	2.70
Maternal weight : (kg.)	56.15	51.70

The sum of the respective areas gives the *combined area* shown in the last row of the 2nd or 5th column. From the combined area, BM of the 3rd or 6th column was calculated by the usual way, reckoning then the *combined area belonging to female*. The outcomes are 209 and 204 c.c. per min., which are very good accordance with the observed values of 210 and 204 c.c. BM per unit area of the combined are found to be 117.7 and 117.1 c.c. per sq. m. per min. and these are exactly the same or very near to the calculated normal values seen in the 1st row. Such state of affairs strongly suggests that the Rubner's law seems to hold good *in the last stage of pregnancy*, in the above definition of the combined area.

On the other hand, if we take another area which is calculated in the usual way from the body weight at the 40th week and the height, neglecting totally the fetus, we arrive at 195 (for O) and 196 c.c. per min. (for C), which are definitely lower (-7.2 and -4.0%) to the observed values. (There is a possibility of overestimate, because the usual formula may not be applied here, and the actual figures might have been somewhat smaller, whereby reducing the estimates in some extent, and thus increasing the percentage reductions a little more.) For the unit area of sq. m., the BM turned out to be 123.2 and 123.7 c.c. per min.— quite inproportional to the previous 117 c.c. Thus the use of the usual area is proved to be far from any satisfaction.

The body weight basis which has sometimes been employed, gives the following figures :

	Weight : (kg.)	BM : (c.c. per min.)	Weight (kg.)	BM : (c.c. per min.)
Before pregnancy : (calc.)	51	3.39	46	3.74
40th week :	59.8	3.51	54 4	3.75

Subj. C showing certainly a good agreement between the normal and the 40th week, seems to give a support to the findings quoted in the 1st proposition, but the other fails to do the same ; beside those figures do not come close to between the two subjects.

Thus for one who prefers simplicity, the *combined area* seems to be the most competent, *in the last stage of pregnancy.*

The present argument can only be valid, however, to the last stage, probably the last 3 weaks. If we take, for example, the 37th week of subj. O, (observed BM . . . 223 c.c. per min.) there appears a residue which cannot be accounted for by the rule of combined area, as easily be seen from fig. 2A. We get for the calculated combined area-BM 209 c.c. (observed body weight . . . 60.3 kg., and fetal weight assumed . . . 3.3 kg.), which leaves 14 c.c. per min. or 6.2% of BM unexplained. That similar states have happened in still less advanced stages, likely as far back as the 5th month, can be attested if we draw a straight line between the points 40th week and the 8th on the 100% line (see the broken line in fig. 2A)—indicating very roughly a course of the combined area-BM. (Actual curve would not be straight, but be concave upward, because the weight of fetus is said to vary in cube with the time after the 7th month.) So that the parts of the curve O which overshoot the straight line corresponds at the least to the unexplained portion of BM. Similar state appears with the other 2 subjects, after the 21st week for H and 27th for C. That the overshooting occured invariably in the 3 instances, may very probably preclude the possibility of mere coincidence. In literature, there has been a case which shows apparently an overshooting. Among the diagrams shown by Sandiford and Wheeler (1), reproduced in Du Bois's famous book on BM, there is a combined area-BM (fig. 1, B), and in the latter reference we have the following entry, " the sum of these two surface areas divided into the calories produced per hour gave almost a level line throughout pregnancy ". This statement, however seems to me to be due to too much stress being paid to those BM values before the conception and of the earlier months, of which number of observation could hardly claim sufficiency. If we take, instead of those values observed 5 or more months ago, the post partum BM level following immediately the delivery and continued further over 6 months, we see distinctly an overshooting all the way in the last 2 months of pregnancy—before this period there was a break of observation lasting 2 months.

With regard to the cause of this unexplained portion, we present some tentative alternatives. 1. BM of the mother has been enhanced, presumably by some new hormonal environment of pregnant state. Increase in volume of the pituitary body, the thyroid gland or the adrenals has been reported (16): a hyper-function of the thyroid gland has also been described (17). Those finding are certainly in agreement with the assumption of increased BM of the mother. 2. High energy metabolism of the content of the womb may be postulated. It would not be difficult to conceive that the rate of energy expenditure of the fetus is higher than the mother, or the placental materials may consume more energy than the maternal tissues as a whole. A part of this supposition has been included in the combined area-BM, in the sense that a small creature, the fetus, uses more energy to the extent that the law of the surface area demands, and this part has been excluded from the present discussion. There remains then a possibility of allotting excessive metabolism to all the content of the womb, where materials transformations should be very intense for the purpose of development of new organism. The degree of assumed excessive metabolism per unit weight at the 36 or 37th week turned out to be of the order of $0.7\times$ the maternal BM in normal—not a particularly inconceivable figure.

The prolonged overshooting of BM and its final drop invite us to an interesting speculation. The lowered BM in the 10th month, which come very near to the values estimated by the law of combined surface area, indicates strongly that the fetus at this stage uses energy as much the same sort of way as the adult and not partuclarly more; in other words, this implies that it has completed its development into an entirety, ready to maintain the body by itself, independent of the mother. The fact generally known that 9th month fetus can survive in case of premature delivery, may support this supposition.

It would not be out of place to add here Kawakami's observation on the skin temperature of new-borns (18). His findings point to the coclusion that the ability to regulate the temperature of the skin is less developed new-borns of premature deliveres, and it requires many days to catch up the normal development, while of delayed ones it is in well advanced stage over the normal, within the womb. Apparently, essential in the post natal life but the least wanted functions for the fetus (surely the skin temperature regulation is one of them) seem to be prepared in the last stage of intra-uterine existence.

Summary

The continuous measuremeuts of basal metabolims were performed on 3 subjects from the 3rd month of pregnancy to the deliveries, and in one instance this was continued further into the post partum period. The gaseous metabolism of one of the new-born infants was also studied.

(1) Coincides with the appearance of morning sickness, a fall of BM below the calculated normal level was observed. After this earlier slump, the BM

rose up gradually to a maximum, high above the calculated values at the moment, and from there fell somewhat sharply during the last 3 or more weeks.

(2) It was shown that the law of 'combined' surface area is valid *only* in those last weeks, and there remains a long period, stretching roughly from the 5th or 6th month to the 9th, of distinctly high BM-level.

(3) The post partum 1st week showed a decidedly high level, as the whole comparable to the last stage of ante partum, and on the weight basis far superseding all the previous figures recorded duriug pregnancy.

(4) With the new-born, a very low metabolic rate was recorded at 8 hours from the delivery. A very rapid metabolic progress was observed during the 1st week, which was maintained further up to the 12th week.

(5) A suggestion on the bodily state of the fetus in the 10th month has been presented.

In conclusion, the author reflect with great pleasure to thank the subjects, for without their unfailing co-operations the present results could hardly be realized, and to Prof. K. Furusawa his gratitudes are due, for the advices and encouragements given to him during the long period of observations.

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