THE SEASONAL VARIATION OF BASAL METABOLISM AND ACTIVITY OF THYROID GLAND IN MAN

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Since Gessler (1) reported a seasonal variation of his own standard metabolism in 1924, this problem has been investigated by many authors. Their opinions are, however, not in complete accord with one another. Most of the American authors (e.g. Tilt (2), Benedict and Carpenter (3), Du Bois (4)) support the view that the basal metabolism is almost constant throughout the year, while many Japanese investigators (e.g. Sirai (5), Fukuda (6), Sasaki (7), Inoue (8), Fukuhara (9)) claim the presence of seasonal variation, i.e. increase in winter, and decrease in summer. Sirai (7) studied the interrelation between his own basal metabolism and the heights of environmental temperature. It was found that the basal metabolism increased by about 6% as the room temperature fell from 15° C. to 5° C. Fukuda (6) confirmed Sirai's results and assumed that the findings on Americans differ from those on Japanese because the latter, living in the house with a poor heating plant, have to adapt to the cold of winter by raising their own metabolism, while it is not the case with the former living in a stable temperature even in the winter.

It is known in animals that the activity of the thyroid gland increases when the animal is adapted to cold environment. It may, therefore, be presumed that a seasonal variation in the thyroid activity is one of the essential factors causing the seasonal changes of basal metabolism in man. The purpose of the present experiment was to study the seasonal variation of basal metabolism more in detail and also to test the truth of the above presumption.

METHOD

Experiments were carried out on Japanese male adults (college students and research workers) from 1953 to 1955, and were divided into three groups according to purposes and methods of experiments.

The first group of experiment was planned to verify the seasonal variation of basal metabolism under a constant standard environmental condition for the subject. The subjects rested overnight in a room controlled at a certain constant temperature (D.T. 25° ± 1° C., W.T. 20° ± 1° C.) and the metabolism was measured at basal condition in the bed immediately after awaking the next morning. The supper of the previous night was taken 12 hours before the experiment, stimulating foods being avoided to prevent a specific dynamic

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action. These measurements of basal metabolism were carried out for 2-4 days in the latter part of every month throughout the year, and the mean value of them was taken as the representative value of the experimental month. To exclude any possible effects of seasonal change of diet upon metabolism, the same diet was taken for a week or more before the measurements in January (or February), May, August, and November, while various diets were taken in the other months. The caloric value of the diet was 2,400 Cal. per day, and protein intake was 75 g. per day.

The second group of experiment was planned to compare the seasonal variation of basal metabolism under the standard condition with that of the basal metabolism in natural environment which was usually observed by previous Japanese authors (Sirai et al. (5-9)). In the first part of this experiment, basal metabolisms of 8 adult male subjects were measured in the winter of 1954 at ordinary room temperature immediately after awaking and were compared with those which were measured on a different day in the experimental week with the same subjects under the above mentioned standard condition (25°C) where they stayed from the previous night.

In the second part of the experiment, seasonal variations of the basal metabolism under natural environments were again measured a year after with four of the eight subjects, and were compared with those measured in the previous year under the standard condition. In the second experiment, the protein bound iodine (P.B.I.) of serum drawn from cubital vein in basal condition was measured two or three times in the experimental period of every month to examine seasonal variations of thyroid activity.

The third group of experiment was planned to find out the reason why the basal metabolism presents a seasonal variation. As it was expected from other experiments that the change may be a result of physiological adaptation to heat and cold, the effect of changing the environmental temperature upon the basal metabolism was determined with five adult subjects.

The experiment was carried out in winter, when the temperature of living room was 5°-14°C. (mean 8.8°C). After the basal metabolism and P.B.I. in serum were measured to get the control values in winter, the subjects entered a hot room at D.T. 30°C and W.T. 24°C and stayed there more than about ten days. They spent the most part of day and night in the hot room, except going to school for about 8 hours. The basal metabolism was measured daily and serum P.B.I. was also measured at least once a week after entering the hot room.

The determination of basal metabolism was performed by the Douglas bag method with modified Haldane apparatus of “Roken” type. The metabolism was calculated as a value per unit body surface by Takahira's formula (10) for Japanese. P.B.I. of serum was measured by Baker's (11) method. Special attention was paid to maintaining the temperature of the sample at 39°C throughout the measurements, because the room temperature varies considerably from season to season and the reaction velocity is influenced markedly by the temperature of the solutions.
RESULTS

1. The seasonal variation of the metabolism under standard condition

The metabolisms of the four subjects measured monthly under the standard condition are represented by the solid lines in fig. 1, where the respiratory quotient and the temperature of laboratory room are also shown. It clearly shows that the basal metabolism (B.M. in the figure) increases in winter and decreases in summer.

The mean value of 4 subjects in a year is 34.2 Cal/m²/hr. ± 2.0 Cal/m²/hr. (standard deviation), and its maximum is 37.0 Cal/m²/hr. of January (8.2% higher than the mean), while the minimum is 31.5 Cal/m²/hr. of August (7.9% lower than the mean). The extent of variation from maximum to minimum is 16.3% of the mean value. The respiratory quotient shows no significant seasonal variation, though it has been a debated problem among previous investigators.

2. Comparison of the basal metabolism under standard condition with that measured in bed under natural environmental condition

![Graph showing seasonal variation of B.M. and serum P.B.I.]

FIG. 1. Seasonal variation of B.M. and serum P.B.I.
The metabolisms of 8 subjects measured in bed under natural environmental conditions were compared with those of the standard condition (D.T. 25°C ± 1°C, W.T. 20°C ± 1°C) in winter. The results are shown in Table 1. Both the metabolism and R.Q. in the standard condition do not show any significant difference from those under the natural condition. The seasonal variation of the basal metabolisms of 4 out of the 8 subjects were measured under natural condition and are plotted with dashed lines in Fig. 1 in which the metabolisms under the standard condition of the same subjects are represented by solid lines. The dashed lines overlap the solid lines in the scope of experimental errors. From the above, it is clear that the seasonal variation of basal metabolism measured under natural environment by many previous Japanese authors really equals that measured under the standard condition. In Table 2 the mean value of year, the mean maximum and minimum values are tabulated. In this table, the values of other 5 subjects obtained by Fukuda in this laboratory are also included, the number of subjects being made 9 in total.

As is seen in the table, the mean value of the year is 34.6 Cal/m²/hr., while the mean maximum value is 37.8 Cal/m²/hr. (9.2% higher from the mean) in winter and the mean minimum value 31.7 Cal/m²/hr. (8.4% lower from the mean) in summer. The extent of variation from maximum to minimum is 17.6%. In Kyoto where these investigations were carried out, the annual mean atmospheric temperature was 15.2°C and the minimum monthly mean value was 8.8°C in January, while the maximum monthly mean value was 27.0°C in July. Thus the monthly mean shows about 22.2°C change in a year. Such a large variation of environmental temperature should bear causal relation to the above mentioned seasonal variation of basal metabolism.

The mean value of basal metabolism seems to be somewhat lower than the standard value of the Japanese adult male i.e. 36.7 Cal/m²/hr. (Oiso (12)). This discrepancy may be due to using sedentary workers as subject as their muscular development may be inferior to the Japanese average. The above extent of seasonal variation, however, coincides well with the extents reported previously. For example, the average maximum value of Sasaki (7) who measured

<table>
<thead>
<tr>
<th>Subject</th>
<th>Cool room</th>
<th>Standard room</th>
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<tbody>
<tr>
<td></td>
<td>B.M. (Cal/m²/hr.)</td>
<td>R.Q.</td>
</tr>
<tr>
<td>S. O.</td>
<td>31.4</td>
<td>0.833</td>
</tr>
<tr>
<td>T. Y.</td>
<td>36.6</td>
<td>0.880</td>
</tr>
<tr>
<td>M. I.</td>
<td>34.3</td>
<td>0.858</td>
</tr>
<tr>
<td>J. K.</td>
<td>38.0</td>
<td>0.902</td>
</tr>
<tr>
<td>T. M.</td>
<td>38.5</td>
<td>0.929</td>
</tr>
<tr>
<td>T. Y.</td>
<td>41.7</td>
<td>0.906</td>
</tr>
<tr>
<td>T. I.</td>
<td>35.6</td>
<td>0.802</td>
</tr>
<tr>
<td>K. M.</td>
<td>36.5</td>
<td>0.893</td>
</tr>
<tr>
<td>Mean</td>
<td>36.6</td>
<td>0.875</td>
</tr>
<tr>
<td>Stand. Dev.</td>
<td>±2.8</td>
<td>±0.040</td>
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seasonal changes of basal metabolism on 25 adult subjects was 40.1 Cal/m²/hr. in winter while the average minimum value was 33.3 Cal/m²/hr. in summer, or 10.2% and -7.9% respectively against the general mean 37.1 Cal/m²/hr. The extent of variation is 18.1%.

3. Seasonal variation of thyroid activity as estimated from the concentration of serum P.B.I.

The amount of serum P.B.I. was determined on four subjects throughout a year, and the results are illustrated in fig. 1. A distinct seasonal variation, an increase in the winter and decrease in the summer, could be seen on each of the subjects. The mean value of a year of the four subjects was 6.3 γ% while the maximum value was 7.9 γ% in January and minimum value 4.7 γ% in August. The normal range of P.B.I. was reported by Talbot (13) to be 6.0 γ% to 8.4 γ%, and by Baker (11) to be 3.5 γ% to 7.0 γ%. Thus the author's values coincide well with the previous reports. As P.B.I. in serum is believed to be a mirror image of the thyroxin content in the blood, it may be assumed from the above results that the thyroid activity increases in winter and decreases in summer.

4. The adaptative change of basal metabolism by changing the environmental temperature

Changes of basal metabolism and R.Q. of two subjects measured after entering the hot room are presented in fig. 3, where the concentrations of P.B.I. in serum are shown at its bottom. As is seen in the figure, the basal metabolism
in cold room is reasonably higher than the value in winter. On the other hand, it begins to fall gradually in a few days after entering the hot room, attaining the minimum value after 7 to 10 days with no further variation. The average value of 5 subjects were calculated at the end of each week in the hot room.
and are shown in table 3, together with the control value. It is shown that the maximum decrease of basal metabolism amounts to 7 to 12% (10.5% on the average) of the control value. It was verified with one of them that the basal metabolism thus reduced in a hot room can return to the original high value in a week or so after coming back to a cold climate.

The R.Q. did not show any significant changes in the course of experiment (cf. table 3), while the concentration of serum P.B.I. decreased by about 22% on the average from the control value (mean value 7.8%).

From the above results it is presumed that some adaptative mechanism is provoked by exposing the subject to heat for a long period, and the thyroid activity is consequently reduced. This reduction of thyroid function reflects on the decrease of basal metabolism.

**TABLE 3.** Changes of Basal Metabolism after Entering a Hot Room

<table>
<thead>
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<tbody>
<tr>
<td>M. F. (21)</td>
<td>B.M. 39.3 R.Q. 0.920</td>
<td>37.5(-4.6%) 0.880</td>
<td>35.0(-10.9%) 0.935</td>
<td></td>
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<tr>
<td>S. K. (21)</td>
<td>B.M. 39.4 R.Q. 0.901</td>
<td>35.1(-10.9%) 0.901</td>
<td>35.0(-11.2%) 0.930</td>
<td></td>
<td></td>
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<tr>
<td>T. Y. (19)</td>
<td>B.M. 41.5 R.Q. 0.935</td>
<td>37.5(-9.6%) 0.921</td>
<td>36.4(-8.7%) 0.850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. Y. (20)</td>
<td>B.M. 38.4 R.Q. 0.885</td>
<td>36.2(-5.7%) 0.910</td>
<td>35.6(-7.3%) 0.902</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. I. (27)</td>
<td>B.M. 36.5 R.Q. 0.800</td>
<td>33.1(-9.3%) 0.901</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>B.M. 39.0 R.Q. 0.888</td>
<td>25.9**(-8.6%) 0.903</td>
<td>35.5**(-9.6%) 0.904</td>
<td></td>
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</tr>
</tbody>
</table>

** Indicates that the difference of B.M. after entering the hot room from that in the cold room is statistically significant at the 1% level.

( ) Figure in the parenthesis is the percentage change of the value in the hot room from the control.

**DISCUSSIONS**

From the above results it is deduced that the seasonal variation of basal metabolism described above is a consequence of the metabolic adaptation of the subject to heat and cold. In order to calculate the temperature quotient of basal metabolism by 10°C change of environmental temperature, the percentage deviation of monthly basal metabolism from the mean of the year were measured and are plotted in fig. 2, where the mean atmospheric temperature of ten days around each experimental day is taken as the abscissa. The values obtained in two years studies as well as Fukuda's values in the author's laboratory are all included in the figure. The correlation coefficient of basal metabolism with environmental temperature is calculated to be
The equation of regression line is

\[ y = -0.659x + 10.3, \]

where \( y \) represents the percentage decrease or increase of basal metabolism in each month from the annual mean value and \( x \) is the mean atmospheric temperature of each month.

This means that the basal metabolism changes 6.6% by 10°C change of environmental temperature (or 2.4 Cal per 10°C). This temperature quotient coincides well with Sasaki's (7) as well as Sirai's (5) values which are about 6% per 10°C.

In the above experiment of long exposure to heat, it was verified that basal metabolism decreased about 10.5% from the control value. It corresponds to a change of 2.0 Cal per 10°C, and almost coincides with the seasonal variation mentioned above. Recently, Kawada (14) reported that the change of basal metabolism per 10°C was only 3%. His value was, however, calculated from basal metabolisms of soldiers living in various places, i.e. Tokyo, Obihiro and Sapporo, and from mean atmospheric temperatures of these places. Therefore, his temperature quotient thus calculated is not comparable with the author's.

Though it was assumed in this calculation that the correlation of basal metabolism with environmental temperature was linear, this assumption was not entirely correct since the curve tended to bend upward in low temperature range. Moreover there was a marked tendency that the changes in basal metabolism lagged behind the changes in environmental temperature. The measurements made in sequence from the winter to the summer gave always more or less higher value for each midway month; on the contrary, when similar measurements were made beginning from the summer, the values were distinctly lower compared with the former, until the same maximum was attained at last in the winter. These circumstances can be seen from fig. 2, in which the sequences of measurements are indicated by arrows over the lines. The regression line in the former sequence can be expressed by the equation,

\[ y = -0.722x + 12.6, \]

while that of the latter, by

\[ y = -0.653x + 8.8. \]

The difference of regression coefficients of these two equations is statistically significant below a level of 1%. The basal metabolism in the spring is therefore higher than that in autumn even when the environmental temperature is the same. This strongly suggests that it takes time for establishing an adaptive change of basal metabolism to seasons.

Present knowledge of the mechanism of adaptive change of basal metabolism is still incomplete. With rats, Starr (15) verified the increased activity of thyroid gland in cold environment by the examination of the mean cell
height of their glands. Blincoe (16), Leblond (17), Steller (18) et al. found by use of I\textsuperscript{131} tracer that activity of thyroid glands of rats or cows was increased in cold. These reports give a suggestion that a seasonal change of thyroid activity may be a main factor which causes the change of basal metabolism. The existence of seasonal variation of thyroid activity and also its alteration by changing the environmental temperature are already mentioned in the part of experimental results. To examine an interelation between seasonal changes of basal metabolism and of thyroid activity, the correlation coefficient of P.B.I. to change of basal metabolism and the equation of regression of that were calculated (fig. 4). The coefficient of correlation (r) is $0.772 \pm 0.076$ and the regression line is

$$y = 1.040x + 28.1,$$

where $y$ represents the basal metabolism (Cal/m\textsuperscript{2}/hr.) and $x$ % of serum P.B.I. Thus the correlation coefficient is fairly high and is compatible with the value $r = 0.763 \pm 0.029$ calculated from Salter's (19) data of P.B.I. and basal metabolism.

![Fig. 4. Correlation between B.M. and serum P.B.I.](image-url)
in thyroid diseases. The regression line calculated by the author from the same data is

\[ y = 1.953 x + 23.6. \]

The difference of the regression coefficient of this equation from that of the seasonal variation is not statistically significant. Moreover, the ratio of change of basal metabolism to that of serum P.B.I. calculated from the data of the experiment of heat exposure lies from 1.66 to 2.66 and is comparable with the regression coefficient of Salter’s data. Thus it may be concluded that a seasonal change of thyroid activity plays the main rôle in causing a seasonal change of basal metabolism.

**SUMMARY**

1) Basal metabolism was measured on 9 male adults every month throughout one year or two in a room at uniform temperature. The metabolism undergoes seasonal changes, increasing progressively with getting cold and decreasing with getting warm. The average maximum range of this variation is 17.6% of the mean for the year in Kyoto, where the monthly mean atmospheric temperature shows a variation about 22.2°C. in a year.

2) The changes in basal metabolism lag behind those in environmental temperature. Consequently the metabolism is higher in the spring than in the fall, even when the environmental temperature is the same.

3) Monthly determinations of P.B.I. in serum were made on 4 subjects throughout one year, and similar seasonal variation to that in basal metabolism was found. The maximum content 7.9 r% was found in January and the minimum of 4.7 r% in August. There is a clear positive correlation between metabolism and P.B.I.

4) It was verified experimentally that both the basal metabolism and the concentration of serum P.B.I. can be reduced in parallel by changing the environmental temperature to a summer level (about 30°C.) from the winter cold (about 9°C.) and staying there over a week or so.

5) From these, it is concluded that the thyroid activity present adaptive changes to seasonal changes of environmental temperature, and thus the seasonal alteration of basal metabolism is provoked.

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**REFERENCES**

1. GESSLER, H. *Pfluger's Arch.* 207: 370, 1925.
5. Sirai, I. *J. Research in Physical Education* 7: 129, 1940.