Studies on the Respiratory Arrhythmia of Man Its Relation to Respiratory Depth, Cardiac Rate and to the Ages of Individuals

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Phasic variation of the instantaneous cardiac rate, synchronous with respiratory movement was first described by Ludwig as early as the middle of the last century, and is now generally known as "Respiratory arrhythmia." This type of arrhythmia is one of the sinus arrhythmias and can be observed more or less in every normal individual, so far as the cardiac rhythm is carefully examined. The cardiac action usually quickens in the inspiratory phase and slows down in the expiratory phase of respiration.

Many studies have been performed pertaining this type of arrhythmia, especially as to its physiological mechanism. E. Hering⁶⁾ and others attributed it to the reflexes originating in the lungs. On the contrary, other authors such as Fredericq,⁴⁾ Foa⁵⁾ and C. Heymans,⁶⁾ insisted on the theory of central origin based upon the apparently undeniable fact that the arrhythmia appeared independently of the inflation movement of lungs. Recently also Vanremootre¹⁶⁾ regarded such central mechanism as the chief causative factor of the human respiratory arrhythmia.

Anrep, Pascual and Rössler,¹⁾ however, confirmed by elaborate experiments in dogs that both the peripheral and central mechanisms were at work.

While many such studies thus far reported have dealt with the physiological mechanism of the respiratory arrhythmia, chiefly in animals under various experimental conditions, the systematic surveys on the influences, such as the depth of respiration, cardiac rate etc. upon the human respiratory arrhythmia have been performed but rarely or insufficiently. Such a circumstance is probably due to the fact that the instantaneous cardiac rhythm in the intact organism is so easily modified by diverse

and yet uncontrollable factors, intrinsic as well as extrinsic, that the data for quantitative evaluation of the respiratory arrhythmia by means of, for example, electrocardiographic or sphygmographic record often become of doubtful value. To obviate such inconvenience it is necessary to take a long series of record of instantaneous cardiac rhythm.

Fleisch's "Pulszeitschreiber"²⁾ which Vanremootre recently utilized, is an adequate instrument, but not perfect as the subject to be examined should keep his arm immobile throughout the test. Such a procedure may often cause some strain in the subject physically as well as mentally, especially in case of observation extending to fairly long periods of time, say ten to twenty minutes.

"Cardiotachograph",¹⁰⁾ which was devised by one of the present authors, is free from such limitation and permits to record automatically all the instantaneous cardiac rates of man or animal, not only in rest but also in activities without forcing any stress, and moreover for any length of time.

In this communication are reported the results of the observations of the respiratory arrhythmia of man by means of Matsuda's *Cardiotachograph*, especially of the influences upon the arrhythmia of the depth of respiration and the cardiac rate, with some remarks on the influences of the age of individual.

EXPERIMENTAL

Methods

The subjects examined were all healthy Japanese, twenty five in number (comprising of twenty males and five females), covering the ages from seven to fifty-six.

The explanation of the instrument, "*Cardiotachograph*," is found elsewhere.¹⁰⁾ Fig. 1 shows one of its records. Each pulse interval (time interval between two consecutive ventricular systoles) is represented by the length of each vertical line. The numerical values of the pulse intervals in unit of second can be read by the scale at the left.

Respiratory movement was always recorded simultaneously by means of a stethograph.⁸⁾ In cases where the accurate volume of tidal air was necessary, it was registered by recording the movement of a calibrated spirometer. Fig. 2 shows such a record.

All subjects were examined in recumbent, sitting and standing postures, all under the condition of complete rest and ease. In the recumbent and sitting postures, the records were taken continuously for over ten minutes after the preliminary ten to twenty minutes' rest. The examination in the standing posture was carried out for at least five minutes

Fig. 1. Record of instantaneous cardiac rate (Cardiotachogram) of a healthy man in recumbent posture.

Upper: time in two seconds. Middle: respiratory record, the upward movement is inspiration. Lower: cardiotachogram. Numerical value for each pulse interval can be read by the scale at the left. E: expiratory pulse interval (average of two *es.*). I: inspiratory pulse interval. The difference between E and I is the measure of respiratory arrhythmia.

Fig. 2. Simultaneous recording of respiratory tidal volume and cardiotachogram. Upper: time signal, every two seconds. Middle: quantitative record of respiratory depth. Its scale is shown at the right. Lower: cardiotachogram, the scale for which is at the left.

beginning exactly three minutes after the subject stood up from the sitting position. The changes in cardiac rhythm in the transitional phase of posture change are not considered in this report.

Each record obtained was first inspected as a whole, and the parts thereof indicating apparently irregular and gross changes of respiration or of cardiac rhythm were excluded from study.

The extent of the respiratory arrhythmia was expressed quantitatively by the maximum difference between the expiratory and the inspiratory pulse intervals. Here the expiratory pulse interval means the average of two values for the expiratory phases preceding and following the inspiration (See Fig. 1).

Results

1. *Normal values of respiratory arrhythmia.* The extent of the respiratory arrhythmia of man in three postures respectively is represented in Fig. 3 as a diagram of frequency distribution. The value for each individual

Fig. 3. Respiratory arrhythmia of man in rest and in three postures. Abscissa: respiratory arrhythmia measured by the difference of pulse intervals in expiratory and inspiratory phases. Ordinate: frequency of occurrence among 25 individuals.

is the average of data for more than twenty consecutive respiratory cycles. There was no case where the respiratory arrhythmia was not observed at all, though the arrhythmia in a few subjects was so slight as to amount only to 0.02 seconds.

The arrhythmia generally varies in extent according to the postures. It decreases in the order from the recumbent to the sitting, then to the standing postures. The maximum respiratory arrhythmia observed was 0.258 sec. in a lying person.

No essential difference was found between males and females. The influence of the age will be considered later.

2. *Influence of respiratory depth.* While it seems to be a natural consequence that the respiratory arrhythmia becomes exaggerated by an increase of tidal air volume, no quantitative study was reported so far concerning the relations between these two quantities. In ten adult men the volumes of tidal air and cardiogram were simultaneously recorded when they carried out voluntary deep breathings of various depth (Fig. 3).

Fig. 4. Effect of respiratory depth (abscissa) on the respiratory arrhythmia (ordinate). Here are shown examples from four subjects as distinguished by four different symbols.

The representative results thereof are shown in Fig. 4. While the respiratory arrhythmia gets marked with hyperpnea, the interrelationship is not linear. The correlation curves run usually paraboloid courses which are different according to the individuals. Generally speaking, the more marked the respiratory arrhythmia for the same respiratory tidal volume, the more marked is the slope of the curve.

3. *Influence of the cardiac rate.* It has long been stated that the respiratory arrhythmia gets conspicuous in case of bradycardia (Lewis⁹⁾ and Friedberg⁵⁾ and others). Shima¹⁸⁾, however, by studying the pulse

rates in great numbers of young men, obtained a different result that there was no definite correlation between the pulse rate and the respiratory arrhythmia.

The present authors reexamined this point by measuring the changes in respiratory arrhythmia accompanying the changes in cardiac rate in one and the same individual. To modify the cardiac rate, the posture of the individual was changed from recumbent to sitting, then to standing, as the cardiac rate usually increased in the order mentioned.

Fig. 5. Change in respiratory arrhythmia (ordinate) due to the change in pulse interval (abscissa). The latter change is brought about by the change in posture. This figure shows an example from one individual.

posture only (e.g. recumbent posture) is considered, no such clear-cut relation appears (see the scattering of dots for each posture in Fig. 5.), probably because the possible effect of the spontaneously occurring small change in cardiac rate is largely obscured by other trifling factors which are concomitant, such as mild fluctuations in respiratory depth. It is, therefore, not incomprehensible that simple comparison of values of various individuals obtained by measuring the arrhythmia during a few respiratory cycles in one posture only, as Shima performed, does not yield any definite information.

Let the correlation curve between the cardiac rate (or pulse interval) and the respiratory arrhythmia as shown in Fig. 5 be called *Respiratory Arrhythmia Characteristic* (RAC). The RAC is linear, approximately but not strictly. In some subjects whose cardiac rates are extremely slow (e.g. 40 or less per minute) especially in the recumbent posture, the respiratory arrhythmia does not proportionately increase with bradycardia so that the RAC curve becomes gradually flat, showing that there is a certain limit in extent of the respiratory arrhythmia. A similar fact was observed by Anrep and others in their experiments on dogs.¹⁾

The slope of the RAC in its range of approximate linearity is different

Fig. 5 is a typical example. As seen clearly in this figure, there exists a definite and almost linear relation between the expiratory pulse interval and the respiratory arrhythmia. Slower the heart rate, larger is the respiratory arrhythmia. Such changes in the respiratory arrhythmia are not due to changes in respiratory depth, for the latter undergoes no gross change as judged by actual measurement of the tidal air volume or of the respiratory rate. When the respiratory arrhythmia in one

from one individual to another, especially according to their ages. This point will be considered in the next section.

4. *Influence of age of individual upon the respiratory arrhythmia.* Fig. 6 shows RAC of five different groups of persons classified according to their ages; group A: 7 to 14 yrs, group B: 15 to 30 yrs, group C: 31 to 40 yrs, group D: 41 to 50 yrs and group E: above 51 yrs. These RAC curves were obtained by measuring the respiratory arrhythmia in three postures as above mentioned, and the values from several persons in each group were plotted together. As seen in this figure, there exists a certain influences of the age upon the RAC. With the advance in age of the group the slope of RAC gets decreased. However, such is only a general tendency and not the absolute rule, for there were at times encountered cases exceptional to this rule.

Fig. 6. Respiratory Arrhythmia Characteristic (RAC) for different age groups (see text). Abscissa: expiratory pulse interval. Ordinate: respiratory arrhythmia.

DISCUSSION

As reported above, the authors' observations of human cardiac rhythm by means of the "*Cardiotachograph*" lead to confirmation of the opinion that the respiratory arrhythmia of man is quantitatively related not only to the depth of respiration but also to the cardiac rate. Without doubt the slowing of heart action brings about a tendency to increase, and the tachycardia a tendency to decrease the respiratory arrhythmia. This is in accord with the animal experiments by Anrep and others¹³ and by Sato¹⁴. The latter author in this laboratory examined the respiratory arrhythmia of dogs in experimental hyper- and hypo-thyroidism which were induced by feeding thyroid glands and by thyroidectomy respectively. Taguchi, who studied the patterns of cardiac rhythm of patients of hyperthyroidism in courses of therapy (iodide or thiouracil administration as well as subtotal thyroidectomy), also confirmed a distinct relationship between the respiratory arrhythmia and cardiac rate.¹⁴ According to the concept prevailing at present, the respiratory arrhythmia is brought about chiefly, if not entirely, by the inhibition of the cardiac vagus center

in the medulla by the reflex from the lungs and/or by direct effect of the respiratory center. Whatever the primary mechanism of the vagus inhibition may be, the above mentioned relation between the respiratory arrhythmia and the pulse rate will not be difficult to expect.

In connection to this, Schweitzer's observation¹²⁾ is worthy to note. He noticed in dogs that the rising in pressure inside the carotid sinus preparation caused a marked exaggeration of the respiratory arrhythmia, doubtless by increasing the vagal tone. Tanemura¹⁵⁾ carried out follow-up studies on cardiac rhythm of patients whose carotid sinus nerves were operatively removed, and confirmed definite decrease or complete disappearance of the respiratory arrhythmia with concomitant tachycardia during a few days immediately following the operation. Such change in cardiac rhythm, however, subsided gradually and spontaneously in the following periods. Throughout the entire course comprising the pre- and post-operative, there were noticed a distinct relation between the respiratory arrhythmia and the cardiac rate.

Fig. 7. Respiratory arrhythmia for different age groups (upper figure) compared with change in heart rate (expressed by pulse interval) brought about by change in posture, from recumbent to sitting (lower figure).

Shima's opinion against such correlation is clearly erroneous, perhaps due to inadequacy in the method and in the treatment of materials for

observation.

The respiratory arrhythmia has been known to be particularly marked in younger individuals as it was called by Sir MacKenzie "Youthful type of arrhythmia." In fact, as shown in Fig. 7, the respiratory arrhythmia is most marked in the group B (adolescent age). Though the slope of RAC for children is as marked as for adolescent subjects, the respiratory arrhythmia in children is less, for the cardiac rate itself is higher (See Fig. 6).

Concerning the influence of age on the respiratory arrhythmia an interesting fact was observed. In the lower half of Fig. 7 are represented the changes in heart rate (expressed by its reciprocal, pulse interval) due to change of posture from recumbent to sitting, as compared to the upper half of the figure which shows the respiratory arrhythmia for different age groups. The patterns of both diagrams are very similar. As the initial change in cardiac rate on the change in posture is thought to be mainly evoked by reflexes originating in various pressoreceptors which modify the cardiac vagal tone, the similarity of both figures suggests that the vagal tone plays the dominant, if not the sole, rôle in the causation of the respiratory arrhythmia in man. Superiority of the vagus to the sympathetic nerve in the genesis of the respiratory arrhythmia was stressed by Anrep and others¹⁾ based on their experiments on dogs.

SUMMARY

1. By means of "*Cardiotachograph*" the quantitative study on the respiratory arrhythmia of healthy men (covering ages from seven to fifty-six) was performed. The observations were carried out in rest and in three postures, viz., recumbent, sitting and standing.

2. The respiratory arrhythmia increases with the respiratory depth. The relations between these two can be represented generally as paraboloid curves, slopes of which however, being different according to the individuals.

3. The respiratory arrhythmia is definitely influenced also by the cardiac rate: the bradycardia usually enforces the arrhythmia. The relationship between the respiratory arrhythmia and the pulse interval is nearly linear, except in state of extreme slowing of the heart. The slope of the correlation line is more marked for younger than for older persons.

4. Among all age groups of subjects, the respiratory arrhythmia is most marked as well as most variable in adolescence. The same patterns for various age groups can be observed in the changes in cardiac rate due to the change in posture.

All these results were discussed briefly in connection to the physiological mechanism of the respiratory arrhythmia.

References

- 1) Anrep, G.V., Pascual, W. and Rössler, R., Proc. Roy. Soc., B, 1936, **119**, 191 and 218.
 - 2) Fleisch, A., Zeitsch. f. exper. Med., 1932, **80**, 487.
 - 3) Foa, C. Pflügers Arch., 1913, **153**, 513.
 - 4) Fredericq, L., Arch. biol., 1882, **3**, 55.
 - 5) Friedberg, C.K., Diseases of Heart, Saunders, Phil., 1950, P. 241.
 - 6) Hering, E., Sitz.-Ber. Akad. Wissenschaft, Wien, 1871, **64** (2), 333.
 - 7) Heymans, C., Ergebn. Physiol., 1929, **28**, 344.
 - 8) Kato, M. and H. Sato, Tohoku Journ. Exper. Med., 1950, **52**, 444.
 - 9) Lewis, T., The Mechanism and Graphic Registration of the Heart Beat. Shaw, London, 1925, p. 429.
 - 10) Matsuda, K. Tohoku Journ. Exper. Med. 1948, **49**, 246.
 - 11) Sato, H., ibd., 1951, **53**, 317.
 - 12) Schweitzer, A: Verhdl. deutsch. Gesell. Kreislauf., 1935, **Tag. 8**, 148.
 - 13) Shima, S., Juzenkai Zassi (Japanese), 1930, **35**, 661.
 - 14) Taguchi, S., in press.
 - 15) Tanemura, T., Tohoku Igaku Zassi, 1949, **42**, 16.
 - 16) Vanremootre, E., Arch. internat. physiol., 1949, **57**, 23., Acta cardiol., 1950, **5**, 163.
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