AVERAGE VALUES FOR BASAL RESPIRATORY FUNCTIONS IN ADOLESCENTS AND ADULTS [1]

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INTRODUCTION

In preparing a review of the literature concerning physiological changes in adolescence (Shock, '39), the scarcity of adequate data on basal respiratory functions became apparent.[2] Although numerous reports of oxygen consumption have been published, little information on respiratory volume, tidal volume or carbon dioxide and oxygen content of expired air is available either for adolescents or for adults under basal conditions. In such studies the maintenance of basal conditions is important since they can be most easily reproduced and thus allow comparisons between individuals. Repeated respiratory measurements have been made on a limited number of adults (Griffith et al., '29; Hafkesbring and Borgstrom, '27; Hafkesbring and Collett, '24), but such observations do not give us the probable range of values expected in normal subjects. Furthermore, it was found that with the exception of Griffith et al. ('29) in none of these studies were all the respiratory functions measured in the

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[2] Bibliographical references to this literature and to that concerned with basal oxygen consumption have been omitted from this report because of limitation of space.

same individuals. This report is presented to show the range in values of basal respiratory functions in normal adolescents and adults and to indicate changes that take place during adolescence.

METHOD

We have recorded the respiratory rate, the respiratory volume per minute, tidal volume, concentration of oxygen and carbon dioxide in the expired air, oxygen consumption and alveolar carbon dioxide tension in two groups of subjects. The first group consisted of fifty normal boys and fifty normal girls representatively sampled from normal school children, on whom the tests were begun at the ages of 11 or 12 years, and were repeated at 6-month intervals over a period of 5 years.[3] The second group consisted of forty-six normal adult males and forty normal adult females, ranging in age from 27 to 43 years. The average age of the adult males was 27.41 years (with standard deviation of 5.9 years) and of the adult females, 28.75 (S.D. = 5.8). The adults were chosen from staff members and from university students who were presumably healthy, although no systematic medical examination was given. In view of the sedentary activities of these subjects, the average values for metabolic tests may be somewhat lower than for the general population. In the adult group, we used only the tests made in triplicate on 2 successive days, although as many as sixty tests were made on each subject.

Three observations on each subject were carried out on each of 2 successive days as follows: The subject was brought by automobile from his home at 7.30 each morning without breakfast. The laboratory used was on the ground floor of the building so that activity was minimized. While the subject lay on a cot for 20-minute rest period, three determinations of blood pressure and pulse-rate were made by a trained woman assistant. At the end of 20 minutes, a Siebe-Gorman half-mask was tied over the nose and mouth of the subject.

[3] The study of these children is still in progress.

The subject was allowed 10 minutes for respiratory adjustment to the mask and then three 8-minute tests of the basal oxygen consumption were made by the Tissot open-circuit gasometer method,[4] in which the total expired air is collected and the carbon dioxide and oxygen concentration is determined by the Boothby-Sandiford modification of the Haldane technique ('20). All gas volumes were reduced to standard conditions of 0°C. and 760 mm. of mercury. Total respiratory volumes were obtained directly from the gasometer reading, and tidal air volumes were computed by dividing the total respiratory volume in liters per minute by the average respiratory rate per minute. The respiratory rate was counted twice each time for a 1-minute period, during each of the three gas-sampling periods. Samples of expiratory alveolar air were obtained by the Haldane-Priestley technic and were analyzed for carbon dioxide in the Haldane apparatus. Surface areas were derived from the height and weight of the subject by the Du Bois formula ('16).

RESULTS

The average of six determinations of each of the respiratory factors (i.e., three on each of 2 successive days) has been calculated for each subject. These values have been used in compiling frequency distributions for 100 children studied when they were 12, 14 and 16 years old, respectively, and for the ninety-six adults. The mean values with their probable errors are shown in table 1. In this table, the values for total ventilation per minute and for oxygen consumption are divided by the weight or surface area of the subject in order to take into consideration the factor of size of the individual. The reduction in variability which results from this procedure is shown in the values of the coefficient of variations which appears in parentheses in table 1.

Table 2 gives the mean differences between the respiratory functions at the age of 12 and of 14, and the age of 14 and

[4] Each subject was tested on 2 days before the actual experimental series was begun, in order to accustom him to the procedure.

TABLE 1

Mean values for respiratory functions under basal conditions at different age levels

	AGES 11.75–12.24		AGES 13.75–14.24		AGES 15.75–16.24		AGES 18.00–26.99		AGES 27.00–43.00	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Ventilation rate/min.	16.3±0.4 (21.5)	16.1±0.3 (14.5)	17.0±0.2 (14.6)	15.6±0.2 (12.5)	15.6±0.3 (14.9)	15.2±0.3 (13.5)	14.0±0.3 (15.9)	14.7±0.5 (20.8)	13.7±0.3 (14.6)	14.4±0.4 (17.9)
Ventilation volume liters/min.	4.79±0.05 (10.2)	4.54±0.07 (14.4)	5.27±0.07 (13.0)	4.86±0.06 (12.7)	5.13±0.08 (13.3)	4.21±0.08 (13.9)	5.04±0.10 (13.2)	4.45±0.11 (16.2)	5.25±0.09 (11.8)	4.63±0.08 (10.8)
Ventilation volume l./sq.m./min.	3.81±0.05 (11.1)	3.41±0.04 (10.3)	3.55±0.03 (9.5)	3.24±0.04 (12.6)	2.98±0.04 (11.1)	2.67±0.04 (12.7)	2.76±0.05 (13.3)	2.91±0.05 (11.6)	2.93±0.04 (9.2)	2.84±0.06 (14.8)
Tidal volume cc./breath	305±6 (19.4)	289±5 (17.2)	316±6 (18.3)	315±4 (13.2)	344±8 (19.7)	282±6 (16.4)	372±9 (16.2)	319±9 (19.6)	390±7 (13.7)	338±7 (13.4)
Tidal volume cc./sq.m./breath	242±4 (16.2)	216±4 (16.1)	212±3 (13.9)	208±3 (13.2)	200±3 (14.8)	177±4 (16.3)	203±5 (17.8)	202±6 (19.9)	218±4 (12.7)	202±4 (11.7)
Expired air % O_2	16.99±0.03 (1.8)	6.90±0.03 (1.5)	16.84±0.03 (1.9)	16.97±0.03 (1.7)	16.35±0.05 (2.4)	16.59±0.07 (3.1)	16.48±0.05 (2.8)	16.98±0.06 (2.4)	16.90±0.05 (1.9)	17.08±0.05 (2.0)
Expired air % CO_2	3.49±0.03 (7.6)	3.57±0.03 (5.4)	3.58±0.02 (6.7)	3.51±0.03 (7.3)	4.01±0.04 (7.6)	3.81±0.04 (8.9)	3.8±0.05 (9.7)	3.41±0.05 (9.8)	3.53±0.04 (8.9)	3.32±0.04 (8.6)
Alveolar air CO_2 tension	41.0±0.3 (6.7)	40.1±0.2 (5.4)	42.2±0.2 (5.8)	39.4±0.3 (8.3)	42.1±0.4 (7.8)	38.8±0.3 (5.8)	43.0±0.5 (5.1)	41.6±0.6 (8.1)	42.7±0.06 (8.8)	40.0±0.5 (7.8)
Oxygen consumption cc./min.	195±2 (11.7)	189±3 (13.7)	223±3 (13.1)	198±2 (11.6)	244±3 (11.5)	187±3 (10.9)	232±3 (8.4)	187±3 (9.2)	218±3 (9.5)	186±2 (8.9)
Oxygen consumption cc./kg./min.	5.15±0.06 (11.0)	4.46±0.06 (12.1)	4.65±0.05 (10.0)	3.90±0.04 (11.4)	4.13±0.04 (9.2)	3.43±0.04 (9.2)	3.43±0.05 (10.9)	3.38±0.05 (10.5)	3.39±0.05 (9.7)	3.13±0.07 (15.1)
Oxygen consumption cc./sq.m./min.	154.5±1.6 (9.6)	140.8±1.1 (7.5)	149.7±1.3 (8.9)	130.1±1.0 (7.9)	141.8±1.4 (8.6)	117.9±1.2 (7.6)	125.9±1.2 (6.8)	118.3±1.5 (8.2)	122.1±1.0 (5.6)	112.5±1.8 (10.5)
Heat production Cal./sq.m./hr.	45.03±0.46 (9.3)	40.99±0.32 (7.2)	43.46±0.35 (8.5)	37.96±0.29 (8.0)	41.13±0.38 (8.0)	34.29±0.34 (7.7)	36.57±0.38 (7.3)	34.28±0.40 (7.7)	35.44±0.28 (5.6)	32.63±0.50 (10.1)

Figures in parentheses are coefficients of variation.

and 16, in boys and girls. The significance of the age differences has been assessed by computing the ratio between the mean difference in the 100 subjects and its probable error (critical ratio). For these observations, the probable error of the mean difference was calculated from the actual distribution of differences, since each subject was measured at all three ages considered. The significant values in table 2, which indicate residual growth, appear in bold-faced type.

We have found that in boys there is an increase in the absolute minute respiratory volume (which is due to an increase in body size) between the ages of 12 and 14 years. In boys the respiratory rate decreases between the ages of 14 and 16, the tidal volume increases, the concentration of oxygen in the expired air decreases and the expired carbon dioxide increases. In girls, there is an increase in the total respiratory volume between the ages of 12 and 14 years. The changes in the composition of the expired air in girls from 14 to 16 years of age are similar to those in boys, but are not so sharply defined. The average oxygen consumption per minute increases from the age of 12 to 16 years in both sexes. However, when the oxygen consumption is measured as cubic centimeters of oxygen consumed per kilogram per minute or as calories of heat produced per square meter per hour, there is a decrease.

The statistical methods suitable for a series in which repeated observations are made on the same individuals cannot be applied to a series in which the observations are made on different individuals. For this reason, the methods used in comparing the adolescents at the ages of 12, 14 and 18 years could not be employed in comparing the 16-year-old group with the adults. This latter comparison was made by computing the probable error of the difference from the formula.

$$\text{P.E.}_{\text{Mn diff.}} = \sqrt{\text{P.E.}^2_{\text{Mn}_1} + \text{P.E.}^2_{\text{Mn}_2}}$$

The results are shown in table 3. Sixteen-year-old girls are similar to adults with respect to most respiratory functions.

Sixteen-year-old boys differ from adult males in that they breathe more rapidly, have a smaller tidal volume, a higher concentration of oxygen and lower concentration of carbon dioxide in the expired air, and a lower oxygen consumption or heat production.

TABLE 2

Significance of age trend in basal respiratory functions. Re-examination of same 100 children

	CHANGES BETWEEN THE AGES OF 12 AND 14 YEARS 14–12				CHANGES BETWEEN THE AGES OF 14 AND 16 YEARS 16–14			
	Girls		Boys		Girls		Boys	
	Mn diff	C.R.	Mn diff	C.R.	Mn diff	C.R.	Mn diff	C.R.
Ventilation rate/min.	−0.40	1.8	+ 0.56	1.3	−0.53	3.0	−1.64	6.8
Ventilation volume liters/min.	+0.34	6.2	+0.51	7.7	−0.52	7.0	−0.09	1.5
Ventilation volume l./sq.m./min.	−0.15	2.7	−0.29	6.5	−0.50	8.9	−0.57	15.9
Tidal volume cc./breath	+26.0	5.3	+15.0	2.5	−23.7	5.0	+30.1	6.8
Tidal volume cc./sq.m./breath	−9.97	2.8	−29.1	6.5	−24.1	7.0	−12.6	4.7
Expired air % O_2	+0.06	1.3	−0.19	5.2	−0.42	7.1	−0.51	11.2
Expired air % CO_2	−0.04	1.2	+0.12	4.7	+0.35	9.7	+0.43	12.8
Alveolar air CO_2 tension	−0.48	1.2	+1.69	5.2	+0.84	2.7	+0.04	0.1
Oxygen consumption cc./min.	+11.0	5.3	+29.1	12.5	−2.3	1.3	+23.8	8.9
Oxygen consumption cc./kg./min.	−0.57	13.5	−0.54	10.4	−0.41	8.7	−0.54	12.3
Oxygen consumption cc./sq.m./min.	−10.3	8.2	−5.6	3.6	−9.0	7.7	−7.2	5.3
Heat production Cal./sq.m./hr.	−2.88	8.3	−1.70	4.0	−2.73	7.9	−2.24	5.5

C.R. = critical ratio, calculated as $\frac{\text{Mn diff}}{\text{PE}_{\text{Mn diff}}}$

Values greater than 4.0 indicate significant differences.

TABLE 3

Significance of age difference in basal respiratory functions

	16–20				20–35			
	Male		Female		Male		Female	
	Difference	C.R.	Difference	C.R.	Difference	C.R.	Difference	C.R.
Ventilation rate/min.	+1.6 ± 0.42	3.8	+0.5 ± 0.53	0.9	+0.3 ± 0.42	0.7	+0.3 ± 0.60	0.5
Ventilation volume liters/min.	+0.09 ± 0.12	0.8	−0.25 ± 0.13	1.9	−0.21 ± 0.13	1.6	−0.17 ± 0.13	1.3
Ventilation volume l./sq.m./min.	+0.23 ± 0.07	3.3	−0.25 ± 0.07	3.6	−0.16 ± 0.06	2.7	+0.07 ± 0.08	0.9
Tidal volume cc./breath	−28.0 ± 11.70	2.4	−36.8 ± 11.14	3.3	−18.60 ± 11.37	1.6	−19.5 ± 11.61	1.7
Tidal volume cc./sq.m./breath	−2.9 ± 6.23	0.5	−24.8 ± 7.13	3.5	−15.2 ± 6.45	2.4	0 ± 7.03	0
Expired air % O_2	−0.13 ± 0.07	1.9	−0.39 ± 0.09	4.3	+0.41 ± 0.07	5.8	−0.10 ± 0.08	1.3
Expired air % CO_2	+0.21 ± 0.06	3.50	+0.41 ± 0.07	5.9	+0.27 ± 0.07	3.9	+0.09 ± 0.07	1.3
Alveolar air CO_2 tension	−0.85 ± 0.60	1.4	−2.74 ± 0.70	3.9	+0.35 ± 0.73	0.5	+1.61 ± 0.82	2.0
Oxygen consumption cc./min.	+11.8 ± 4.30	2.7	+0.7 ± 3.70	0.2	+13.9 ± 4.01	3.5	+0.50 ± 3.57	0.1
Oxygen consumption cc./kg./min.	+0.70 ± 0.07	10.0	+0.05 ± 0.07	0.7	+0.04 ± 0.07	0.6	+0.25 ± 0.09	2.8
Oxygen consumption cc./sq.m./min.	+15.9 ± 1.9	11.8	−0.4 ± 1.9	0.2	+3.8 ± 1.5	2.5	+5.8 ± 2.3	2.5
Heat production Cal./sq.m./hr.	+4.56 ± 0.54	8.4	+0.01 ± 0.52	0.2	+1.13 ± 0.47	2.4	+1.65 ± 0.64	2.6

C.R. critical ratio, calculated as $\frac{\text{Mn diff}}{\text{PE}_{\text{Mn diff}}}$

DISCUSSION

It is interesting that Griffith et al. ('29), Hafkesbring and Borgstrom ('27), and Hafkesbring and Collett ('24), found respiratory volumes which, if reduced to standard conditions of temperature and barometric pressure, fall within the range of our subjects of the same age and sex. The same groups of authors also reported carbon dioxide and oxygen contents of expired air similar to those in our series. A comparison of the respiratory volumes of our subjects with those of Trumper ('29), however, indicates that the individuals whom he studied were hyperventilating. This difference may be accounted for by the fact that our subjects were trained by repeated testings.

The average values for alveolar CO_2 tension which we have obtained are significantly higher than those reported by Griffith et al. ('29), for subjects of a comparable age. Our values are also higher than those reported by Radsma, Streef and Klerks ('33) in a group of ninety-five adults tested in the tropics. We are not prepared to say whether or not this difference can be attributed to climatic factors. Berconsky and Rossignoli ('32) also obtained slightly lower averages on a group of nineteen adult females. Our values are also slightly higher than those usually quoted in the literature from Fitzgerald and Haldane ('04), although it should be pointed out that basal conditions were not observed in tests made by Fitzgerald and Haldane. The higher values reported here are in closer agreement with the average values for CO_2 tension in arterial blood of 45.9 in fourteen males and 43.2 in seven females found by Shock and Hastings ('34).

Our average values for basal oxygen consumption of boys are, like those reported by Bierring ('31), 7 to 10% lower than the extensive series reported by Boothby, Berkson and Dunn ('36). This discrepancy may be due to the training period used in both our experiments and those of Bierring, although the number of cases in our series exceeds that of any previous studies made at this age level. In the case of girls our values are again 5 to 8% lower than most of those reported in the literature, with the exception of the results of Benedict and Hendry ('21). However, their experiments were conducted on sleeping girls under experimental conditions that were quite different from the usual clinical procedure. At the higher age levels Stark ('32), Tilt ('30), McKay ('30) and Coons ('31) have reported values comparable to ours, although the number of subjects tested was smaller.

It is apparent from tables 1 and 2 that although total ventilation volume, total oxygen consumption and tidal volume tend to increase with age, when the factor of increase in physical size is removed these variables decrease as the subject grows older. Examination of the coefficients of variation, given in parentheses in table 1, shows also that reducing these measurements by factors involving the size of the body makes the results more homogenous. This decrease in variability as expressed by the coefficients of variation (shown in table 1) is not large in certain of the measurements, but the consistency of the trend is significant. It is evident that calculated surface area is a better measurement of body size than is body weight alone, probably because, in adults especially, body weight is influenced often by increased water and fat without an increase in metabolizing protoplasm.

In measuring the respiratory functions as described above, we have considered that values lying within $\pm$ two times the probable error of the mean ($P.E._{Mn}$) may be regarded as normal, that values lying within ± 3 $P.E._{Mn}$ are high or low normals, and that values ± 4 $P.E._{Mn}$ are definitely abnormal.

In this way it is possible to use these mean values as standards in order to determine whether or not an individual is hyperventilating. Hyperventilation will result in a) increased respiratory volume per minute or per square meter per minute, b) increased tidal volume per breath or per square meter per breath, c) lowered concentration of carbon dioxide and increased concentration of oxygen in the expired air and d) lowered alveolar carbon dioxide tension.

SUMMARY

We have tested a group of fifty male and fifty female adolescents, and a group of forty-six adult males and forty adult females; and have recorded the respiratory rate, the respiratory volume per minute, the tidal volume, the oxygen and carbon dioxide concentrations in the expired air, the oxygen consumption and the alveolar carbon dioxide tension. We have found evidence for growth changes over the adolescent period in certain respiratory functions, such as CO_2 and O_2 content of expired air, alveolar CO_2 tension and tidal volume, which have not been reported before. These measurements may serve as normal figures in the age groups from 10 to 20 years. We have pointed out some of the criteria of hyperventilation.

CONCLUSIONS

1. In boys, the minute respiratory volume increases between the ages of 12 and 14 years, due to an increase in body size.

2. In boys, the respiratory rate decreases between the ages of 14 and 16, the tidal volume increases, the concentration of oxygen in the expired air decreases, and the expired carbon dioxide increases.

3. In girls, the respiratory volume and tidal volume increase between the ages of 12 and 14 years.

4. The composition of the expired air in girls changes between the ages of 14 and 16 as it does in the boys, but the change is not so clearly defined. In boys there is a significant increase in alveolar CO_2 tension between the ages of 12 and 14 years. No significant change in alveolar CO_2 tension was found in girls.

5. The average oxygen consumption per minute increases from the age of 12 to 16 years in both sexes. In respect to body size there is a decrease in oxygen consumption.

6. Most respiratory functions of 16-year-old girls are similar to those of adult females.

7. Sixteen-year-old boys breathe more rapidly, have a smaller tidal volume, higher concentration of oxygen and lower concentration of carbon dioxide in the expired air and a lower total oxygen consumption than adult males.

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ERRATUM

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100 gm of purified diet (1.5 mg per kilo) for optimum growth