Reference Values for Respiratory Rate in the First 3 Years of Life

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ABSTRACT. Background. Raised respiratory rate is a useful sign to diagnose lower respiratory infections in childhood. However, the normal range for respiratory rate has not been defined in a proper, large sample.

Objective. To assess the respiratory rate in a large number of infants and young children in order to construct percentile curves by age; to determine the repeatability of the assessment using a stethoscope and compare it with observation.

Methods. Respiratory rate was recorded for 1 minute with a stethoscope in 618 infants and children, aged 15 days to 3 years old, without respiratory infections or any other acute disease when awake and calm and when asleep. In 50 subjects we compared respiratory rate taken 30 to 60 minutes apart to assess repeatability, and in 50 others we compared simultaneous counts obtained by stethoscope versus observation.

Results. Repeatability was good as the standard deviation of differences was 2.5 breaths/minute in awake and 1.7 breaths/minute in asleep children. Respiratory rate obtained with a stethoscope was systematically higher than that obtained by observation (mean difference 2.6 breaths/minute in awake and 1.8 breaths/minute in asleep children; P = .015 and P < .001, respectively). A decrease in respiratory rate with age was seen for both states, and it was faster in the first few months of life when also a greater dispersion of values was observed. A second degree polynomial curve accurately fitted the data. Reference percentile values were developed from these data.

Conclusions. The repeatability of respiratory rate measured with a stethoscope was good. Percentile curves would be particularly helpful in the first months of life when the decline in respiratory rate is very rapid and prevents to use cut off values for defining "normality." Pediatrics 1994;94:350–355; respiratory rate, age-related centiles, reference values, repeatability.

ABBREVIATION. RR, respiratory rate.

In many studies tachypnea has been found to be the most reliable clinical sign that a child has pneumonia rather than an upper respiratory tract infection.1–4 Although most of these studies were carried out in developing countries to help primary health workers to manage respiratory infections correctly, also in developed countries many infants and young children with respiratory infections are seen in outpatient settings where roentgenographic facilities are not immediately available. In these situations a more precise definition of tachypnea and percentile curves for reference values would be particularly useful. The only centile curves available do not cover the first years of life in detail, and were obtained 40 years ago by repeated measurements in few subjects regardless whether they were awake or asleep.5 Furthermore, these infants and children lived at high altitude (Denver, CO), and the lower oxygen partial pressure could therefore have influenced the results.5 Surprisingly only a few other studies have dealt with the problem of defining the "normal" respiratory rate. In a community-based study,6 the respiratory rate was counted for 60 seconds in a very large number (>6000 examinations) of infants younger than 12 months in different states (sleeping, awake and calm, awake and not calm). Also this study was done at high altitude (Lima, Peru), and, moreover, the infants had a history of cough and therefore could have had a respiratory tract disease. The other two studies available on a large number of infants refer only to subjects under 6 months.7,8 Richards et al9 reported the distribution of mean respiratory rate values recorded during sequential 22-hour electronic monitoring: this method of counting is impractical to be used in clinical settings and the data cannot therefore be used as reference values by clinicians. In Morley et al’s study10 the mean respiratory rate was assessed by stethoscope or by a hand on the chest during three 15-second intervals in asleep and awake infants; this short time of counting could have introduced some error in the final evaluation of respiratory rate. The mean values found by the authors are higher than those previously described and do not vary with postnatal age.

These discrepancies in methodologies, populations studied, and results, and the lack of age-related reference values for the first years of life led us to perform this study. The aim was to record the respiratory rate in infants and children aged 15 days to 3 years with neither severe diseases nor clinical signs of respiratory infections in order to: 1) determine the repeatability of recordings 30 to 60 minutes apart by stethoscope, which is a very common method to assess respiratory rate in developed countries; 2)
compare respiratory rate counts obtained by stethoscope and by observation; and 3) construct reference centile curves by age in a large number of subjects.

SUBJECTS AND METHODS

Six hundred eighteen infants and children, 336 males and 282 females, aged 15 days to 3 years, were assessed during 1 year. Distribution in this age range is shown in Table 1. The subjects were seen evenly across the seasons by four investigators. Each investigator assessed a minimum of 100 subjects. Of the 618 subjects assessed, 309 were in good health and were seen in day care centers and 309 were seen in hospital as inpatients or outpatients. The main diagnoses for these patients were gastrointestinal and urologic disorders, skin diseases, and orthopedic problems.

Exclusion criteria were the presence of any chronic or severe illness, dehydration, or a history of fever or respiratory findings suggesting a respiratory infection in the previous 2 weeks.

In each child the respiratory rate was recorded by the same assessor both when the child was awake and calm and when he was in quiet sleep according to behavioral criteria (sleep not associated with any spontaneous movement, including no eye movements or vocalizations). Infants and children who were unsettled or crying did not have their respiratory rate measured. In awake children older than 1 year of age respiratory rate was assessed when they were playing quietly. For each state respiratory rate was assessed by listening to breast sounds for 60 seconds with a stethoscope put gently on the baby’s naked chest.

In 305 subjects evenly distributed across the ages (10 for each of the following classes of age: >2 months, 2 to <6, 6 to <12, 12 to <24, and 24 to 36 months) the respiratory rate was recorded twice, by the same assessor, 30 to 60 minutes apart, listening to breast sounds for 60 seconds with a stethoscope, when the child was awake and calm and when he was sleeping.

In 305 subjects evenly distributed across the ages (same as above) the respiratory rate in the two different states (awake and calm and sleeping) was recorded simultaneously by two assessors, one listening to breast sounds and the other counting the respiratory rate by observation of the abdominal and chest wall movements. To avoid as far as possible an operator effect, the two assessors exchanged roles (observer-listener) randomly.

STATISTICS

Repeatability Analysis and Comparison Between Observed and Stethoscope Counts

The repeatability of respiratory rate measurement by stethoscope was evaluated by calculating for each pair of recordings the difference between the first and the second measurement (first minus second measurement). The standard deviation of these differences is an index of the precision of the method. The SD of the differences was used to calculate the 95% confidence of repeatability ("the value below which the differences between two single test results may be expected to lie with a specified probability").

The agreement between respiratory rate counts obtained by stethoscope and those obtained by observation was assessed using the same technique, ie, by calculating the difference in respiratory rate counts (stethoscope minus observation). The mean of the difference between the two counts is an estimate of the systematic difference (bias) between the methods.

State of the Child and Influence of Potential Confounding Factors

The influence of the state of the child (awake and calm or asleep) and of potential confounding factors (gender, season of the year, and examination in hospital or in day care centers) on respiratory rate counts was assessed with an analysis of variance after grouping the subjects in the following classes of ages: <2, 2 to <6, 6 to <12, 12 to <24, 24 to <30, and 30 to 36 months. All these calculations were done with the statistical package SPSS/PC+.

Construction of Centile Curves

Two problems were encountered in the construction of centile curves from these data: first, the skewness of the distribution of respiratory rate at different ages was highly variable; and second, the dispersion (SD) of the values at various ages was also different.

No single data transformation could resolve these problems and render the data identically and normally distributed across all age values, so as to permit the use of standard techniques. Log transformation however led to equal variances, and consequently was used before the subsequent analysis, which was carried out with the nonparametric technique described by Healy et al. Briefly, an ideal box around the first k (in our case k = 50) observations sorted according to age values is selected, and the least squares regression of respiratory rate on age is then calculated. The centiles of the observed residuals from the fitted line are then calculated and assigned to the median of the age values of the box. The box is then moved 1 point ahead (removing the first point, and including the 51st one), and the procedure is repeated until all data are covered and raw centiles are obtained.

With this method the first half of the first box and the second half of the last box do not contribute points to raw centiles. To avoid losing this information we oversampled subjects at younger ages, and, at the other extreme, we studied also 44 children older than 36 months of age. The raw centiles obtained in the first step of the procedure are very irregular, and need to be smoothed. This is done by

<table>
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<th>Age (Months)</th>
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<th>Asleep Subjects</th>
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<td></td>
<td>Mean</td>
<td>Median</td>
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TABLE. Mean, median, and SD of respiratory rate according to waking or sleeping in 618 infants and children grouped in classes of age
RESULTS

Repeatability of Respiratory Rate Counts

In Fig 1 the differences between respiratory rate counts determined by stethoscope at 30–60 minutes interval are plotted against their mean count. The SD of the differences between the two counts was 2.5 and 1.7 breaths/minute, respectively, when the infants and children were awake and calm and when they were asleep (yielding 95% repeatability coefficients of 4.9 and 3.3 breaths, respectively). The size of the differences and the mean respiratory rate value were not correlated (r = .013 and .035 in awake and in asleep subjects, respectively), ie, the respiratory rate value did not seem to influence the repeatability of the observation.

Comparison Between Respiratory Rate Obtained by Stethoscope and by Observation

Both in awake and in asleep states respiratory rate counts obtained by stethoscope were systematically higher than those obtained by observation (Fig 2). The mean difference (mean bias) was 2.6 and 1.8 breaths/minute, respectively, in awake and asleep states (P = .015 and P < .001). The dispersion was wider in infants and children when awake than when asleep (SD of the differences 7.4 vs. 2.3 breaths, respectively). A tendency toward a greater dispersion at higher respiratory rate was noted.

State of the Child and Influence of Potential Confounding Factors

At all ages mean respiratory rate counts were significantly higher (P < .001, paired Student's t test with Bonferroni correction for multiple comparisons) in infants and children when awake and calm than when asleep (Table 1).

The effect of potentially confounding factors (gender, season of the year, or being seen in a day care center or in a hospital) was then assessed separately in awake and in asleep states with an analysis of variance. None of the factors examined significantly influenced the respiratory rate count in either state so that the data were considered together in the construction of centile curves.

Postnatal Age and Construction of Centile Curves

A decrease in respiratory rate with increasing age was seen both in awake and in asleep infants and...
children (Table 1, Figs 3 and 4). The pattern of respiratory rate decline with age was similar in both states and was much faster in the first few months of life.

To be able to describe with greater accuracy and precision the steeper part of the curves, where the observed fall in respiratory rate was faster, we sampled more babies in the first year of life and, in particular, in the first few months. The dispersion of observed data was wider at young ages: the SDs of the observed respiratory rate counts fell from 9.1 breaths/minute in subjects <2 months to 4.1 breaths/minute in subjects 30 to 36 months old in the awake state, and from 8.7 to 3.7 breaths/minute in the asleep state (Table 1).

To construct centile curves the data were first log-transformed and then a second degree (quadratic) polynomial curve was used. This allowed an excellent fitting to observed data with very simple equations. In Figs 5 and 6 the centile curves for awake and asleep infants and children are shown. The equations describing the 95th centile are:

\[ y = 10^{(1.82144 - 0.012596x + 0.00013401x^2)} \]

in the awake state, and

\[ y = 10^{(1.72858 - 0.0139928x + 0.00017640x^2)} \]

in the asleep state, where \( y \) = respiratory rate, and \( x \) = age in months.

The Appendix gives the general equations describing the centile curves for both states.

**DISCUSSION**

The difficulty in defining the "normal" respiratory rate in infants and young children prompted us to perform this study. Differences between the reported respiratory rates in healthy infants and children may be due to various factors as extensively discussed in a recent review by Berman et al,\(^7\) including the number of infants studied, the period of time counting, the method of counting, and the state of the infant.

Because of the natural variability of the respiratory rate and the presence of periodic breathing in infants <6 months of age,\(^8,15\) a 60-second count has been recommended by the World Health Organization. One minute's counting either at a stretch or in two blocks of 30-second intervals has recently been confirmed to be the best time period of counting by Simoes et al,\(^6\) in an ad hoc study.

Many techniques have been used to count the respiratory rate in infants and children including continuous electronic monitoring from an abdominal or thoracic wall movement detector, observation of the abdominal and chest wall movements, listening to the breath sounds with a stethoscope, and putting a hand on the baby's chest. Recording respiratory rate by electronic monitoring is obviously impractical in clinical practice. Moreover, with this method, particularly if the infant is asleep, movements could distort respiratory tracings or superficial breaths could be missed.\(^8,17\) These problems could also affect the observation counting method.\(^7,18\)
As there is no counting method that can be considered a gold standard we chose to use the stethoscope because, like Morley, we found it very difficult to count respiratory rate by observation in very active, lively infants.

Use of the stethoscope yielded good repeatability and low variability of the respiratory rate over a short period of time (30 to 60 minutes) both in awake and in sleeping infants and children. This counting method probably allows detection of even small breaths that are missed at observation because of chest/abdominal movements. In fact, in subjects in whom simultaneous (stethoscope and observation) counts were performed we found that the respiratory rate recorded by stethoscope was systematically higher than that recorded by observation.

In our study, as in previous ones, respiratory rate counts were higher in awake than in sleeping subjects and decreased with increasing age. Our mean respiratory rate values in the first 6 months of life were comparable to those reported in studies in which continuous electronic monitoring was used for prolonged time periods to record respiratory rate but lower than those reported by Morley et al.9

The variability of respiratory rate among subjects was larger in the first few months of life in our series. Analysis of the causes is beyond the scope of the study, but there are many possible biological explanations. In the first months of life several events occur including maturation of the neurologic control of breathing (eg, the weakening and disappearance of reflexes such as the Hering-Breuer reflex9), the change of the hemoglobin dissociation curve due to the shift from fetal to adult hemoglobin, with differences in oxygen delivery to tissues, changes of the mechanical properties of the respiratory system (eg, changes in lung and chest wall compliance and lung volumes9,10), all of which probably affect respiratory degree and speed of these phenomena probably very greatly from one baby to another, and result in greater overall variability.

Pediatricians are accustomed to use age-related centiles when evaluating findings that change with age. However, in the evaluation of respiratory rate age-related cutoff values are used more frequently than centile curves. The graphic detail of the only centile curves available is poor, particularly for the first years of age. This constitutes an obstacle to their clinical use, in addition to the problems already discussed in the collection of the raw data used to construct these curves. Moreover, since the smoothing of the data was carried out graphically, no equations are provided and it is impossible to redraw the figures. On the other hand, cutoff values and tabulations of descriptive statistics such as means and SDs in classes of age are very inefficient ways of presenting data when age-related changes are rapid, and are potentially misleading unless very narrow classes of age are considered.

The curves presented here allow the decline in the respiratory rate to be followed with greater detail and accuracy, especially in the first months of life. The use of the distribution-free technique developed by Healy et al permitted us to construct accurate centile curves without assumptions on the shape of the distribution at each age and considering only the general trend of respiratory rate. A second degree polynomial curve was sufficient to describe the data accurately both in awake and in asleep infants and children. Only five parameters were required to fully construct the centiles. Thus, the danger of overfitting the data was avoided.

In conclusion, we hope that the curves presented in this study will be helpful, particularly in evaluating babies in the first months of life when the rapid decline in respiratory rate prevents the use of cutoff values to define normality.

**APPENDIX: CENTILE SMOOTHING AND ESTIMATED EQUATIONS**

To construct usable centile curves, the observed raw centiles must be smoothed, fitting interrelated polynomials to them. Polynomials are flexible enough to fit each centile adequately. In our case, a second-degree function was sufficient after log transformation of the data.

Thus, for the i-th centile, these polynomials have the following formula:

\[ Y_i = A_0 + A_1 x + A_2 x^2 \]  

\[ \text{where } x \text{ is the age in months, and } Y = \log_{40}(RR). \]

This ensures that each centile varies smoothly with age. In order to use all the available information the method constrains the centiles to be interpolated in a smooth way. This is accomplished by modeling the coefficients \( A_0 \) as polynomial functions of \( Z_0 \), the normal equivalent deviate corresponding to the i-th centile (for instance, for the 90% centile, \( Z_{90} = 1.645 \), etc) according to the following formula:

\[ A_0 = B_0 + B_1 Z_0 + B_2 Z_0^2 + \ldots + B_4 Z_0^4. \]

Combining Equations 1 and 2 gives the final model.

In our case, for both \( A_0 \) and \( A_1 \), a first-degree function, and for \( A_2 \), an intercept-only function were selected. Thus, for the i-th centile, omitting for clarity the i-th subscript, the equation is:

\[ \log_{40}(RR) = (B_0 + B_2 Z_0) + (B_1 + B_4 Z_0)x + B_3 x^2. \]

For the actual coefficient estimated,

\[ \log_{40}(RR) = (1.6801 + 0.0839 Z_0) - (0.0119 + 0.0043012)x \]

\[ + 0.0001340x^2 \]

for awake data, and

\[ \log_{40}(RR) = (1.5773 + 0.0919 Z_0) - (0.01314 + 0.0005155 Z_0)x \]

\[ + 0.0001765x^2 \]

for asleep data.

**ACKNOWLEDGMENTS**

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**REFERENCES**

DOCTORS CUSTOMERS!

Dr. Stephen Jones of Rockville, MD, calls me his patient. I like that word; it makes me feel secure. Dr. Richard Selzer, the surgeon and writer, once told a Mayo Medical School graduating class that the word patient comes from the Latin pati, "to suffer," adding: "Doctors have patients. This is, above all, what distinguishes us from lawyers, who have clients... We have patients, and they suffer."

Clients suffer, too, at the hands of some lawyers, but the distinction is valid. In recent years, however, a dehumanizing note has crept into the medical language: patients have become health care consumers. Victor Cohen, the former Washington Post health columnist, was among the first to deride the trend toward calling doctors caregivers and health care [one word] producers; the new terms lump the MDs among less well-trained professionals.

The big word now is provider, which has taken care of caregiver.

Thanks to the info explosion, it's spreading. I used to be a writer. Now I'm a content provider. Don't laugh; it could happen to you.


Noted by J.F.L., MD