Normal ranges of heart rate and respiratory rate in children from birth to 18 years of age: a systematic review of observational studies

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Summary

Background **Although heart rate and respiratory rate in children are measured routinely in acute settings, current reference ranges are not based on evidence. We aimed to derive new centile charts for these vital signs and to compare these centiles with existing international ranges.**

Methods **We searched Medline, Embase, CINAHL, and reference lists for studies that reported heart rate or respiratory rate of healthy children between birth and 18 years of age. We used non-parametric kernel regression to create centile charts for heart rate and respiratory rate in relation to age. We compared existing reference ranges with those derived from our centile charts.**

Findings **We identified 69 studies with heart rate data for 143 346 children and respiratory rate data for 3881 children. Our centile charts show decline in respiratory rate from birth to early adolescence, with the steepest fall apparent in infants under 2 years of age; decreasing from a median of 44 breaths per min at birth to 26 breaths per min at 2 years. Heart rate shows a small peak at age 1 month. Median heart rate increases from 127 beats per min at birth to a maximum of 145 beats per min at about 1 month, before decreasing to 113 beats per min by 2 years of age. Comparison of our centile charts with existing published reference ranges for heart rate and respiratory rate show striking disagreement, with limits from published ranges frequently exceeding the 99th and 1st centiles, or crossing the median.**

Interpretation **Our evidence-based centile charts for children from birth to 18 years should help clinicians to update clinical and resuscitation guidelines.**

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Introduction

Heart rate and respiratory rate are key vital signs used to assess the physiological status of children in many clinical settings. They are used as initial measurements in acutely ill children, and in those undergoing intensive monitoring in high-dependency or intensive-care settings. During cardiopulmonary resuscitation, these indices are critical values used to determine responses to life-saving interventions. Heart rate and respiratory rate remain an integral part of standard clinical assessment of children with acute illnesses,[1] and are used in paediatric early warning scores[2,3] and triage screening.[4,5] Early warning scores are used widely in routine clinical care, and there is good evidence that they can provide early warning of clinical deterioration of children in hospital and in emergency situations.[6–9]

Reference ranges for heart rate and respiratory rate in children are published by various international organisations (webappendix p 1). Of these publications, only two guidelines cite sources for their reference ranges: the pediatric advanced life support guidelines[10] cite two textbooks,[11,12] neither of which cite sources for their ranges, and WHO limits for respiratory rate, which are based on measurements made in developing countries.[13] Evidence underpinning guidelines is therefore scarce, and many ranges are probably based on clinical consensus.

Scoring systems underpinning triage and resuscitation protocols for children invariably require measurement of heart rate and respiratory rate. Rates are converted to a numerical score by applying age-specific thresholds. Accurate reference ranges are key to assessing whether vital signs are abnormal. Thresholds that are incorrectly set too low risk overdiagnosing tachycardia or tachypnoea, whereas those set too high risk missing children with these signs. Additionally, a reference range that is applied to an age range that is too broad is likely to lead to incorrect assessment of children in some parts of these age groups.

We aimed to develop new age-specific centiles for heart rate and respiratory rate in children, derived from a systematic review of all studies of these vital signs in healthy children. We use these centiles to define new evidence-based reference ranges for healthy children, which we compare with existing reference ranges.

Methods

Search strategy and selection criteria

We searched Medline, Embase, CINAHL and reference lists to identify studies that measured heart rate or respiratory rate in healthy children between birth and

See Online for webappendix

Panel 1: **Inclusion and exclusion criteria**

Inclusion criteria

- Cross-sectional, case-control, or longitudinal study
- Minimum of 20 children
- Age range between birth and 18 years
- Objective measurement of heart rate or respiratory rate
- Raw data or average measure of heart rate or respiratory rate reported for each age group

Exclusion criteria

- Preterm infants
- Children with illnesses likely to affect the cardiac or respiratory system
- Children with pacemakers or needing ventilatory support
- Anaesthetised children
- Children known to be taking drugs that would affect the cardiac or respiratory system
- Data gathered from exercising children, without baseline (before intervention) measurements
- Measurements taken at heights greater than 1000 m above sea level
- Age groups including adults (without subgroups)
- Age groups spanning more than 10 years (without subgroups)

18 years of age, from 1950, to April 14, 2009, with MeSH terms and free text. Webappendix p 2 shows the search strategy that was used to identify relevant studies. There were no language restrictions. Panel 1 shows the inclusion and exclusion criteria. SF and MT assessed eligibility of studies for inclusion, and disagreements were resolved by AP.

MT and IM identified sources of existing reference ranges by reviewing paediatric textbooks, resuscitation manuals, and resuscitation guidelines from Europe and North America. To mirror the probable exposure of clinicians to reference ranges, we concentrated on ranges published in resuscitation guidelines, manuals for standardised clinical training courses, and WHO international guidelines (webappendix p 1). These sources are not intended to be exhaustive, because various reference ranges are published in textbooks and as part of triage scores or early warning scores; these reference ranges were not used in this article because of their heterogeneity.

Data extraction

Data for year of study, participants (age range, number, reason for measurements), study setting, method of measurement, and whether children were awake or asleep were extracted by SF and checked by AP. For each age group, the sample size and the minimum and maximum ages were extracted, with reported summary statistics (ie, mean, median, centiles, standard deviation, confidence intervals, or standard error) for heart rate and respiratory rate. We classed data reported separately (ie, for girls and boys, or for ethnic groups) in the same age group as independent groups.

For studies that reported many results for one group of children at a specific age (eg, in different phases of sleep, or using different measurement methods), we selected a single data point to avoid introducing bias on the basis of the following guidelines agreed on before data extraction: (1) if different measurement methods were used, data from the least invasive or stressful method were selected; (2) for data shown as combined age groups, we selected data from separate age groups unless the age ranges of individual groups were very small (eg, infants between one and two days of age); (3) we used awake measures when both awake and asleep measurements were available; (4) we averaged readings across all sleep states when many states of sleep were reported; and (5) we used the first baseline result when more than one baseline measurement was reported in intervention studies. These guidelines were chosen to ensure that data used were relevant to clinical setting, in which children are typically awake and at rest, to improve the accuracy of calculated centile charts, and to avoid potential confounding factors such as definition of sleep states or distress due to invasive measurements or interventions. Combined age groups were separated to ensure that the most accurate age range was associated with each data point, but very small age ranges were left combined, because we believed that the benefit of accurate ages would be small compared with the loss of accuracy for raw centiles calculated from small sample sizes.

Data analysis

We calculated the median and representative centiles (1st, 10th, 25th, 75th, 90th, 99th) for data from each included study. For studies that did not report relevant summary statistics, we estimated them from the mean and standard deviation. We tested for skewness with Pearson's second skewness coefficient and the quartile skewness coefficient (Bowley skewness).[14] We reported no skewness in either heart rate or respiratory rate data, and therefore assumed a normal distribution at each age. We excluded two outlier values of data spread (one standard error, and one set of confidence intervals) as they resulted in negative respiratory rates for several centiles, which is not physiologically plausible.[15,16] We did not identify any outliers in the heart rate data.

We created centile charts using kernel regression, a form of non-parametric curve fitting,[17] which avoids imposing an excessive degree of constraint on resulting curves. We adjusted classic kernel regression to account for the age range and the sample size associated with each data point (webappendix pp 3–4). For heart rate and respiratory rate, we used kernel regression to fit seven curves showing variation related to age, with values calculated for the median and six representative centiles from the included studies. These centiles were compared visually with reference ranges in webappendix p 1.

We did subgroup analyses to assess whether setting, economic development of the country, method of measurement, or awake or asleep state of children had an effect on

vital signs after correction for age using centile charts. Ideally, separate centile charts could be created to compare subgroups, but many subgroups did not contain sufficient data across the full age range to allow such comparison. Therefore, mean and standard deviation of measured vital signs from each study were normalised with centile charts, so that variations due to age were removed. Normalised data were analysed with one-way analysis of variance, taking into account the size and variation in each study. Additionally, regression analysis of normalised means, weighted by the sample size of each study, was done to identify trends related to date of publication.

We defined cutoff values for heart rate and respiratory rate using data from centile charts by calculating the mean value and rounding it to a whole number, for each of the 13 age groups covering the full range of ages (0–18 years). Age groups were selected to correspond with changes of about five beats per min for heart rate and two breaths per min for respiratory rate.

Role of the funding source

The sponsors of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. SF had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Figure 1 depicts the study selection process. We identified 69 studies from 2028 publications. 59 of 69 reported data for heart rate from 150 080 measurements of 143 346 children, and 20 reported data for respiratory rate from 7565 measurements on 3881 children, with ten studies reporting data for both vital signs (for scatter plots of data see webappendix p 5). 46 studies were cross-sectional, 12 longitudinal, and 11 case-control. They were undertaken in 20 different countries on four continents (webappendix pp 6–11): 55 in developed countries (as defined by the UN statistics division[18]), seven in developing countries, and seven in countries that were judged to be neither developing nor developed.

The number of children per study ranged from 20 to 101 259. Studies were done in community settings (eg, home, school or kindergarten; 27 studies, 26 024 measurements), clinical settings (eg, hospitals, clinics, or medical centres; 19 studies, 105 982 measurements), unspecified or many settings (17 studies, 15 957 measurements), and research laboratories (six studies, 3976 measurements). Most measurements (32 studies, 132 891 measurements) were of awake children, and eight studies (505 measurements) were of asleep children; 29 studies (18 545 measurements) did not report the state of wakefulness, or did not distinguish between data from awake or asleep children (webappendix pp 6–11).

Heart rate was measured by electrocardiography in most studies (31 studies, 114 802 measurements), whereas others used automated blood-pressure monitors (12 studies, 21 362 measurements), manual measurement (six studies, 10 228 measurements), echocardiography (four studies, 890 measurements), and pulse oximeters or proprietary heart-rate monitors (six studies, 2798 measurements; webappendix pp 6–11). Most respiratory rate measurements were made manually (seven studies, 6531 measurements); automated measurements were made with strain gauges, thermistors, thoracic impedance, and helium dilution (13 studies; 1034 measurements).

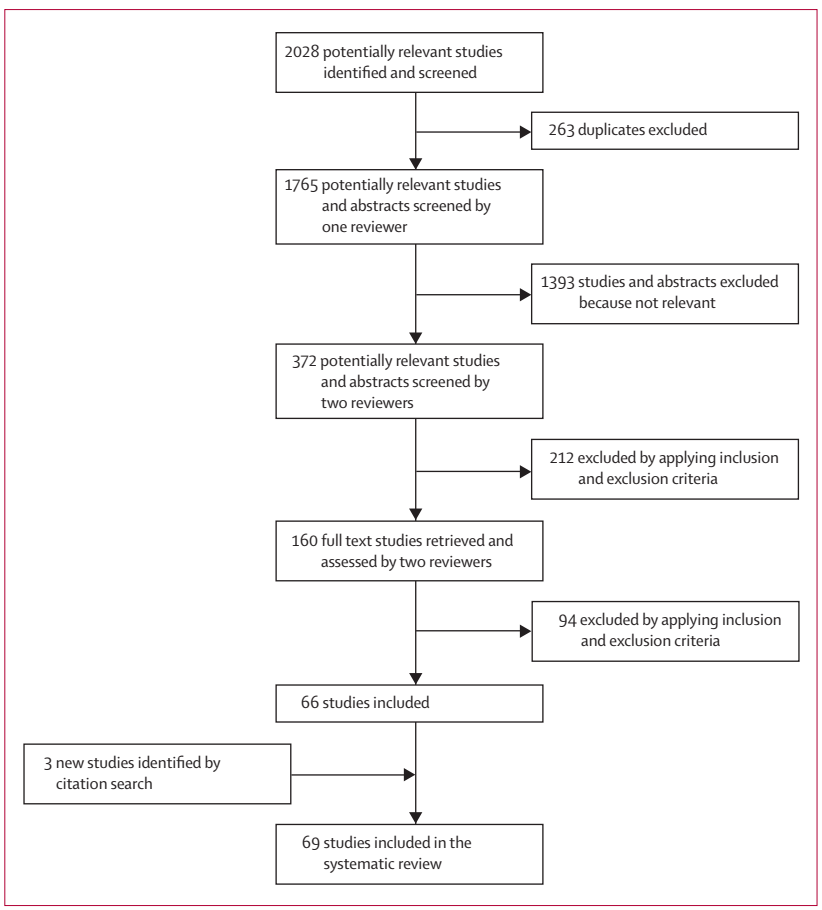


Figure 1: **Flowchart of systematic search**

Figure 2 shows the 1st to 99th centiles of respiratory rate in healthy children from birth to 18 years of age. These centiles show decline in respiratory rate from birth to early adolescence, with the steepest decline apparent in infants during the first 2 years of life. Median respiratory rate decreased by 40% in these 2 years (44 breaths per min at birth to 26 breaths per min at 2 years). Proposed cutoffs for respiratory rate at each of 13 age groups, from birth to 18 years, are shown in webappendix p 12.

Subgroup analysis of respiratory rate data showed no significant differences on the basis of study setting ($p=0\cdot09$), economic development of the country in which the study was done ($p=0\cdot83$), wakefulness of the child ($p=0\cdot36$), or whether manual or automated methods of

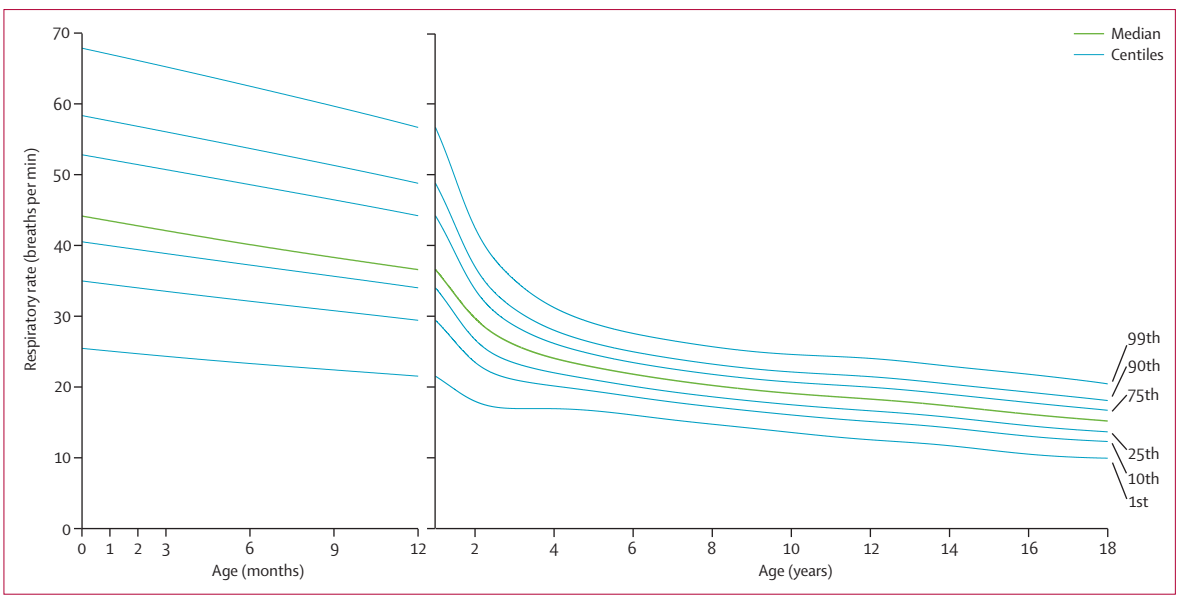
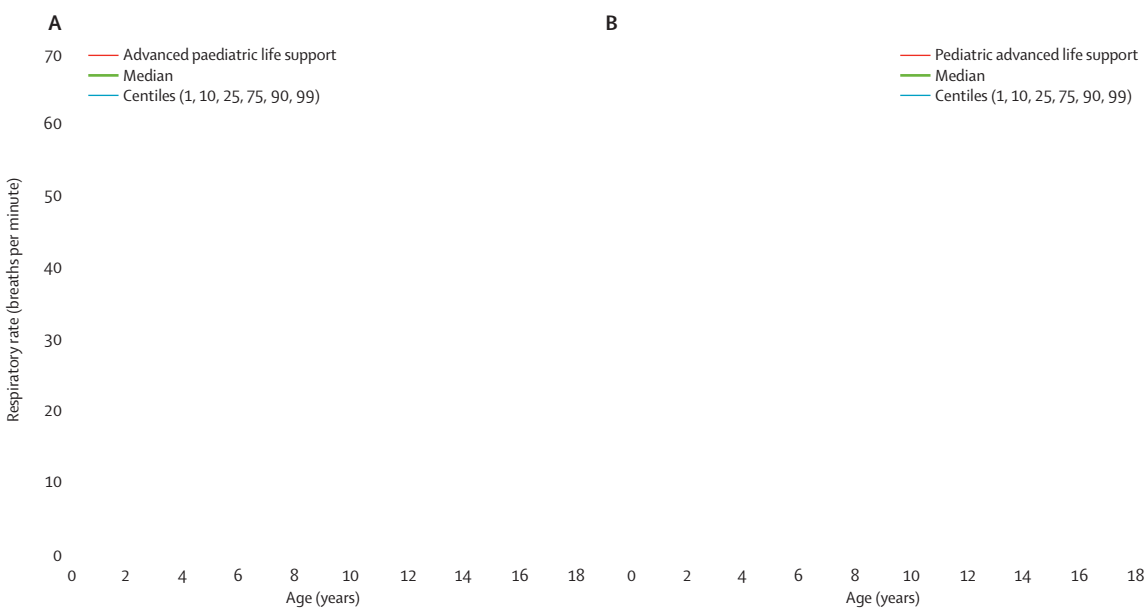


Figure 2: **Centiles of respiratory rate for healthy children from birth to 18 years of age**



measurement were used (p=1·00). Regression analysis of study publication dates did not show any significant difference in measured respiratory rate (p=0·19).

Figure 3 shows how the centiles derived from our systematic review compare with two existing reference ranges—advanced paediatric life support[17] and pediatric advanced life support.[10] None of the existing reference ranges in webappendix p 1 showed good agreement with our centile charts across the full age range, but the best agreement was seen with the ranges cited by advanced paediatric life support and European paediatric life support course.[19,20] Examples of this disparity can be seen in figure 3. For example, for children under 1 year of age, the advanced paediatric life support upper limit for respiratory rate is 40 breaths per min, which is roughly the median value on our centile chart for children in this age range. For children over 12 years of age, the pediatric advanced life support upper limit of 16 breaths per min is below the median value on our centile chart for much of this age range.

We noted that one median value of respiratory rate for children between 0 and 6 months of age[21] was much

rate with age. The first section of figure 4, showing the heart rate centile chart for infants under age 1 year, shows a small peak in heart rate at 1 month. This peak is not an artifact of the modelling method, but can be seen in primary data from various studies that report many heart rate measurements of infants under age 1 year.[22–27] Median heart rate in this age range increases from 127 beats per min at birth, reaching a maximum of 145 beats per min at about 1 month of age, before decreasing to 113 beats per min by age 2 years.

Subgroup analysis showed that heart rates measured in community settings were higher ($p<0\cdot0001$) than those measured in clinical or laboratory settings, and rates measured with automated techniques (eg, electrocardiography) were higher ($p=0\cdot0011$) than those measured manually. Heart rates of children in developing countries were also higher than those measured in developed countries ($p<0\cdot0001$). Although heart rates measured in awake children tended to be higher than those of asleep children, the difference was not significant ($p=0\cdot06$). Regression analysis of study publication dates showed that there was a small but significant trend in heart rate ($p<0\cdot0001$), with older studies reporting lower heart rates than did recent studies.

Figure 5 shows a comparison of reference ranges from advanced paediatric life support and pediatric advanced life support guidelines with our centiles of heart rate. Comparisons were also made between our centile chart and other reference ranges cited in webappendix p 1. As with respiratory rate, none of these ranges showed good agreement with our centile chart across the full age range, from birth to 18 years of age. Best agreement between reference ranges for heart rate and our centile chart was with advanced paediatric life support and advanced trauma life support reference ranges,[19,28] although both these also showed substantial disagreement with our centile charts. For example, in children from 2–5 years of age, the advanced paediatric life support lower limit for heart rate is 95 beats per min, which roughly correlates with the 25th centile of our chart, and reaches the median heart rate at the upper end of the age range. In children 2–10 years of age, the upper limit for pediatric advanced life support is 140 beats per min, which lies above the 99th centile of our chart for most of the age range.

Discussion

Our centile charts of respiratory rate and heart rate in children provide new evidence-based reference ranges for these vital signs. We have shown that there is substantial disagreement between these reference ranges, and those currently cited in international paediatric guidelines, such as those shown in webappendix p 1, which are used widely as the basis for clinical decisions when interpreting these signs in children (panel 2). For example, the paediatric advanced warning score and Brighton paediatric early warning score[2,3] assessment methods refer to advanced paediatric life support reference ranges.

For clinical assessment of children, our findings suggest that current consensus-based reference ranges for heart rate and respiratory rate should be updated with new thresholds on the basis of our proposed centile charts, especially for those age groups where there are large differences between current ranges and our centile charts, indicating that many children are likely to be misclassified. Normal ranges, such as those published in textbooks and clinical handbooks, should also be updated in view of our results. To assist the development of cutoff values for use in clinical settings, we provide values corresponding to the median and six different centiles for both heart rate and respiratory rate for 13 age groups between birth and 18 years of age.

By providing several different centiles for children of all ages, we have provided clinicians and those responsible for developing clinical guidelines and early warning scores with sufficient information to select cutoff values that are most appropriate to the type of clinical setting in which they are likely to be used. Selection of appropriate cutoff values should take into account the consequences associated with misclassification of both healthy and unwell children. For many measurements made over time, centile charts could also be used to assess magnitude of changes in heart rate or respiratory rate.

For accurate measurement of heart rate in children, clinicians should be aware that manual measurement of heart rates, which is common practice in many settings, could underestimate true rates. In these children, measurement of heart rate by automated methods provides accurate results. Professional bodies responsible for publication of guidelines and scoring systems should consider revising current thresholds, by selecting heart rate and respiratory rate values that represent an upper centile for each age group; to assist with this selection, we propose to make the data used to create our centiles of heart rate and respiratory rate (figures 2 and 4) freely available upon request.

A key strength of our approach is that the centile charts were created with kernel regression, a non-parametric modelling technique that avoids imposing any particular form onto the shape of the centile charts; this is important for this type of data, because there is no reason to expect that it will follow an analytical function such as a straight line or exponential curve. However, several methodological limitations are worth noting. Our systematic review included an extensive search of published works from three large databases, with no restriction on language or country of publication. However, our search strategy and inclusion criteria could have missed relevant studies, particularly studies published before 1960. We excluded 13 studies because we were not able to extract necessary data or could not obtain full copies, and we did not attempt to

Panel 2: **Research in context**

Systematic Review

We searched Medline, Embase, CINAHL, and reference lists to identify studies that measured heart rate or respiratory rate in healthy children between birth and 18 years of age, from 1950, to April 14, 2009. Measurements during exercise, at altitude, or of children whose illness was likely to affect their heart rate or respiratory rate were excluded. Non-parametric kernel regression taking into account age range and sample size was used to construct centile charts based on extracted data.

Interpretation

Substantial disagreement exists between consensus-based reference ranges for heart rate and respiratory rate in children. These reference ranges do not correspond with centile charts derived from our systematic review of observational studies, which includes data from children of all ages.

contact original authors to obtain individual patient data, because gathering such data would not have been feasible in view of the number of studies included, some of which were published over 25 years ago. We noted pronounced heterogeneity of settings in which childrens' heart rate and respiratory rate were measured, their state of wakefulness, and methods of measurement, all of which could have an effect on the measured variables. As reported, subgroup analysis showed that setting, method of measurement, and economic development all had a significant effect on heart rate in children (setting $p<0\cdot0001$; method of measurement $p=0\cdot0011$; economic development $p<0\cdot0001$), but not on respiratory rate (webappendix p 13). We excluded children with illnesses that might affect the heart rate or respiratory rate, and measurements known to be made during exertion, but many studies did not report whether children were settled or agitated during measurement, which could have introduced additional heterogeneity that could not be assessed. However, by use of subgroup analysis of wakefulness as a proxy for agitation, such heterogeneity is unlikely to have an important effect on the results. Heterogeneity of data is also a strength, making our centiles relevant to a wide range of clinical settings.

Our centile charts have been developed with data from healthy children. As with all clinical measurements, they should be used as part of an overall assessment of a child's health, and interpretation of measured values should also take into account any factors that might be expected to affect them. For example, measurements of heart rate are known to be increased in children who are anxious or feverish,[29] and, based on our results, in children in developing countries. These factors should therefore inform the selection of appropriate centiles for use as cutoff values in such situations.

The benefit of integrating our centiles into early warning scores needs to be assessed. Improvement in sensitivity and specificity will be dependent on age and accuracy of previous reference ranges. For existing advanced paediatric life support reference ranges, which had the greatest agreement with our centiles, figures 3 and 5 suggest that a large number of children are currently misclassified. For example, at 10 years of age the advanced paediatric life support cutoff for heart rate classifies about 40% of healthy children as abnormal, and the cutoff for respiratory rate misclassifies about 63% of healthy children. Furthermore, on the basis of age distribution of children typically seen in a primary care setting,[27] we estimate that the specificity of advanced paediatric life support could be improved by as much as 20% for heart rate and 51% for respiratory rate if revised centile charts are used. The validity of our centiles and any cutoffs derived from them should be assessed both in healthy children and in those presenting with a range of diseases.

We have shown that existing reference ranges for heart rate and respiratory rate in children are inconsistent, and do not agree with centile charts derived from a systematic review of observational studies. This finding has potentially wide-ranging implications for clinical assessment of children, and for design of resuscitation guidelines, triage scores, and early warning systems.

Contributors

SF and MT identified eligible studies. MT and IM identified sources of existing reference ranges. SF and AP extracted data. SF and RS did the statistical analysis. All authors contributed to the writing of this article.

Conflicts of interest

IM is the UK chair for the European Paediatric Life Support Course, and a member of the European Guidelines writing team.

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