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Original Article

Visual function scale for identification of infants with low respiratory compliance

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Lung compliance;
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Aim: Precise estimation of respiratory function is essential to optimise neonatal respiratory care. However, current clinical scores have not been validated with quantitative measures of respiratory function. The aim of this study was to develop a physiological scoring system to predict low respiratory dynamic compliance of <0.6 ml/cmH_2O/kg.
Methods: Forty-four newborn infants were studied before (dynamic compliance) and shortly after scheduled extubation (physiological signs). A novel scoring system was developed based on the association between physiological signs and dynamic compliance.
Results: The respiratory rate was identified as the primary independent variable for dynamic compliance in the univariate analysis. The prediction score for low dynamic compliance comprised the presence of nasal flaring, see-saw respiration, suprasternal/intercostal retraction, and the respiratory rate ranks (0—3). The area under the receiver—operating characteristics curve of the composite score had discriminatory capability of 0.86 (95% confidence interval: 0.75—0.97) to predict low dynamic compliance with the optimal cut-off value of ≥3 (sensitivity, 0.882; specificity, 0.667).

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Conclusion: Our novel scoring system might help predict newborn infants with low dynamic compliance, who may require escalation of respiratory support, or transfer to higher level units.

1. Introduction

During the early neonatal period, respiratory distress is commonly observed in approximately 7% of infants, with approximately a third of these infants further requiring mechanical ventilation.[1] Respiratory failure is one of the leading causes of neonatal mortality and morbidity.[2] Inaccurate assessment of respiratory failure may lead to both adverse outcomes and wasted medical resources required for intensive care. However, objective assessment of respiratory failure based on physical observation is difficult even for experienced neonatologists.[3] Precise markers of respiratory distress available at the cot-side may significantly improve the decision to escalate respiratory support and to transfer infants to higher-level units.

Several physical scores, such as the Silverman scoring system,[4] Downes score,[5] and Acute Care of at-Risk Newborns (ACoRN) respiratory score,[6,7] have been proposed to allow cot-side assessment of neonatal respiratory distress. Until recently, associations between these physical scores and quantitative measures of respiratory function remained unknown. Hedstrom and colleagues recently reported a modest correlation between the respiratory severity score and carbon dioxide levels of newborn infants, who were admitted to the neonatal intensive care unit ($n = 33$, $r = 0.35$, $p = 0.045$),[8] highlighting the importance of validating clinical assessment tools using modern objective markers. The recent distribution of neonatal ventilators, which provide quantitative measures of respiratory function, may dramatically accelerate the interpretation process of subjective physical findings into an objective diagnosis. Studies have demonstrated that the dynamic respiratory compliance obtained using the function of the ventilator is useful to evaluate respiratory conditions and diseases objectively and predict extubation failure.[9–12] Respiratory failure during the early neonatal period, such in respiratory distress syndrome, transient tachypnoea of the newborn, and pneumonia, is primarily characterized by low respiratory compliance.[13] Therefore, prediction of the respiratory compliance based on physical signs may significantly improve the quality of respiratory evaluation and management especially in low-resource settings.

The aim of this study was to develop a physical scoring system that allows objective evaluation of infants with low respiratory compliance.

2. Methods

This study was conducted in compliance with the Declaration of Helsinki. The study protocol was approved by the local ethics committee. Informed parental consent was obtained for each participating infant.

2.1. Study population

From August 2013 to August 2015, 44 newborn infants who were ventilated at a tertiary neonatal intensive care were recruited and studied before and after scheduled extubation. During the study period, extubation was considered with a postmenstrual age of ≥28 weeks' gestation and dynamic respiratory compliance (C_{dyn}) of ≥0.50 ml/cmH_2O/kg. Infants who had undergone abdominal surgery and those with congenital major anomalies or chromosomal anomalies were excluded.

2.2. Study protocol

The baseline characteristics of each patient were collected from the patient record. Continuous flow, time-cycled, pressure-limited ventilators with an integrated flow sensor based on a heated wire anemometer (Babylog 8000 plus or VN500; Dräger, Lübeck, Germany) were used with a reusable circuit and a counter-flow humidifier (Neonatal Reusable Tubings and Humicare 200; Gründler Medical, Freudenstadt, Germany). The flow sensor is located on the distal end of the respiratory circuit just before the Y-piece. The breath-by-breath pressure, flow, and volume signal are provided using a least-squares fit of the equation of motion of the passive respiratory system to give quantitative measures of the expiratory tidal volume (V_{te}), resistance (R), and tube leakage.[12]

All infants were ventilated using the synchronized intermittent-mandatory ventilation mode at the time of the study. In our unit, the default setting of the positive end-expiratory pressure (PEEP) is 5 cmH_2O. The peak inspiratory pressure (PIP) is determined to achieve V_{te} of 6 ml/kg. The respiratory function was assessed shortly before planned extubation, when the infant was quietly asleep. The pressure support function of the VN500 was turned off, and the airway discharge within the tracheal tube was cleared in advance. The mandatory ventilation rate was then increased by approximately 30% for about 1 minute. Once the infant's spontaneous breathing was well attenuated (as assessed by clinical judgment), the ventilation rate was reversed to the patient's setting, and V_{te} was recorded for 10 consecutive breaths to give the mean V_{te}, excluding the values within the upper and lower quartile ranges. Tube leaks, if any, were attenuated to <10% by gentle application of cricoid pressure.[11] C_{dyn} was calculated using the following equation, where BW is body weight:

$$C_{dyn}\ \mathrm{ml/cmH_2O/kg} = V_{te}\ [\mathrm{ml}]\ /\ \mathrm{BW}\ [\mathrm{kg}] \times (\mathrm{PIP} - \mathrm{PEEP})^{-1}\ [\mathrm{cmH_2O}]$$

Upon completion of the data acquisition, the patient was extubated. Approximately 5 minutes after extubation, when the infant was calm and breathing regularly in the supine position (and before any respiratory support other than oxygen supplementation was started), the respiratory rate was visually assessed as the mean value during 30 seconds, and chest auscultation was performed to check for grunts, wheezing, crackles, and stridor. Chest wall motion on both the anteroposterior and lateral views was recorded for approximately 1 minute each using a digital video camera. Two paediatricians with 17 years (E.H.) and 6 years (M.K.) of experience in neonatology independently assessed the video recordings and assigned scores of 0–2 points for visual items of the Silverman scoring system (i.e., upper chest movement, intercostal and xiphoid retractions, and nasal flaring).[4,14] Suprasternal and subcostal retractions were also assessed and assigned scores of 0–2 (0, none; 1, present but mild; or 2, moderate to severe).

2.3. Statistical analysis

Data are presented as the frequency (percentage) for qualitative variables and median (interquartile range) for continuous variables. To investigate correlations between C_{dyn} and physical findings, an exploratory analysis was first performed using the univariate general linear model (SPSS 23.0; IBM Corp., Armonk, NY, USA). To determine whether the visual inspection of respiratory signs was objectively performed, inter-rater variability was assessed using the intra-class correlation coefficient for both the original three–rank scales and additional dichotomy scales, where scores 1 and 2 were binned.

The respiratory rate was assessed with or without transformation into ranks of 0–3, which were defined according to the quartile ranges. An exploratory analysis was performed using simple linear regression analysis to identify potential independent variables of C_{dyn}. A P-value of <0.004 was assumed to be significant after correcting for multiple comparisons over 13 variables (Bonferroni correction). A novel composite evaluation score to predict low C_{dyn} of <0.6 ml/cmH_2O/kg was developed by employing a mandatory variable (respiratory rate in rank) and up to two additional variables based on the clinical hypothesis, findings from the exploratory analysis, and collinearity between variables. Receiver–operating characteristic (ROC) analysis was performed to assess the diagnostic relevance and cut-off point for low C_{dyn} for the newly developed composite score and the Silverman scoring system.

3. Results

3.1. General findings

The study population comprised 44 newborn infants born at 29.7 [27.5–35.8] weeks' gestation and was evaluated at a post-menstrual age of 31.5 [29.6–37.4] weeks (Table 1).

Suprasternal (n = 3), intercostal (n = 1), xiphoid (n = 1), and subcostal (n = 3) retractions; see-saw respiration (n = 1); and nasal flaring (n = 1) were not assessed because of insufficient information obtained from the video recordings for these regions. In addition, the record of the chest auscultation from one infant was accidently lost. The inter-rater agreement of the dichotomized scale was generally higher than the three-rank visual scales (Supplementary information). Further analysis was performed using the dichotomized scales except for the ROC analysis, which was performed using both our original dichotomized scales and the three-rank Silverman scoring system. Additionally, scores provided by M.K. were not considered further.

Table 1 Clinical characteristics of the study cohort.

Variables	Values
Gestational age (weeks)	29.7 (27.5–35.8)
Postmenstrual age at measurement (weeks)	31.5 (29.6–37.4)
Birth weight (g)	1213.5 (872.3–2254.5)
Weight at the measurement (g)	1250 (964.5–2376.3)
Female sex	13 (30)
dynamic compliance (ml/cmH_2O/kg)	0.63 (0.51–0.70)
Ventilator settings before extubation	
Peak inspiratory pressure (cmH_2O)	13 (12–15)
Positive end-expiratory pressure (cmH_2O)	5 (5–6)
Respiratory rate (cycles/min)	30 (25–30)
Inspiratory time (s)	0.40 (0.35–0.40)
Fraction of inspired oxygen	0.21 (0.21–0.23)

Values are shown as number (percentage) or median (interquartile range).

Forty infants (90%) showed retractions of at least one region, whereas expiratory grunt was not observed in any infant. The interquartile range of the respiratory rate was 37.0–52.3 (median, 46.5). The infants were intubated with endotracheal tubes of either 2.5 mm (n = 17), 3.0 mm (n = 22), or 3.5 mm (n = 5). After extubation, 29 infants (post-menstrual age, 30.1 [27.3–40.1] weeks) required respiratory support using nasal continuous positive airway pressure; however, none required re-intubation at least within the next 7 days.

3.2. Exploratory analysis for potential independent variables of dynamic respiratory compliance

Throughout a range of physical observations, only the respiratory rate showed significant correlation with C_{dyn} in the univariate analysis (Table 2). No variable other than the respiratory rate improved the prediction model in the multivariate analysis.

3.3. Prediction score for low dynamic respiratory compliance

A composite score was proposed using the presence of nasal flaring (0–1), see-saw respiration (0–1), suprasternal or intercostal retraction (0–1), and the respiratory rate ranks (0–3) (Table 3). Low C_{dyn} of <0.6 ml/cmH_2O/kg was

Table 2 Correlations between clinical variables and dynamic respiratory compliance.

Variables		Co-efficient	95% Confidence interval		P value
			Lower	Upper	
Univariate model					
Respiratory rate (breaths/min)	46.5 (37.0–52.3)	−0.521	−0.708	−0.265	<0.001
Respiratory rate in rank	1 (1–2)	−0.558	−0.733	−0.313	<0.001
See-saw respiration	15/43 (35)	−0.157	−0.437	0.150	0.314
Nasal flaring	9/43 (21)	−0.313	−0.561	−0.014	0.041
Retraction					
Suprasternal	19/41 (46)	−0.306	−0.561	−0.002	0.052
Intercostal	24/43 (56)	−0.192	−0.466	0.115	0.216
Xiphoid	32/43 (74)	0.009	−0.292	0.309	0.956
Subcostal	34/41 (83)	−0.044	−0.347	0.267	0.786
Any of the above	37/41 (90)	−0.111	−0.405	0.204	0.489
Suprasternal or intercostal	29/41 (71)	−0.276	−0.538	0.035	0.080
Expiratory grunt	0/44 (0)	–	–	–	–
Auscultation					
Crackle	3/43 (7)	0.029	−0.274	0.327	0.851
Wheeze	3/43 (7)	−0.088	−0.378	0.218	0.574
Crackle and/or wheeze	6/43 (14)	−0.043	−0.378	0.218	0.783
Multivariate model					
Suprasternal or intercostal retraction		−0.080	−0.176	0.015	0.096
Movement of upper chest and abdomen		−0.046	−0.136	0.044	0.305
espiratory rate in rank		−0.080	−0.117	−0.043	<0.001

Values are shown as number (percentage) or median (inter-quartile range).

Table 3 Composite prediction score for low dynamic respiratory compliance.

Variables	Scores			
	0	1	2	3
Respiratory rate in rank	<37	38–47	48–53	>53
Nasal flaring	Absent	Present		
Suprasternal or intercostal retraction	Absent	Present		
See-saw respiration	Absent	Present		

predicted by the composite score with an area under the ROC curve of 0.86 [95% confidence interval, 0.75–0.97; $p < 0.001$] (Fig. 1). The optimal cut-off value of the prediction score was ≥3 points, with a positive predictive value of 0.652 and negative predictive value of 0.889 (Table 4). The predictive value of the original Silverman scoring system was generally poor, with an area under the ROC curve of 0.56 [95% confidence interval, 0.38–0.75; $p = 0.494$].

4. Discussion

Clinical decisions based on unreliable assessment of respiratory function may delay the commencement of proper respiratory support, which may increase the risk of death and severe sequelae especially in low-resource settings. In contrast, when respiratory distress is overestimated, infants are unnecessarily separated from their mothers to undergo intensive care. Antenatal prediction of respiratory failure is generally difficult; a considerable fraction of infants develop respiratory failure following low-risk delivery,[3] thus confirming the importance of early, precise assessment of respiratory function. Our data suggest that newborn infants with low C_{dyn} might be objectively identified by cot-side visual observation. Further improvement and validation of the scoring system might enable clinical decisions regarding when to start relatively more invasive respiratory support and to transport ill infants to higher-level units.

Based on established scoring systems, such as the Silverman scoring system,[4] Downes score,[5] and ACoRN respiratory score,[6,7] we developed a novel composite score to identify infants with low respiratory compliance. Using physical observations available at the cot side, this scoring system provided excellent predictive performance of newborn infants with low C_{dyn}. Subsequently, all scoring items were provided from visual observations, which might be easily adopted for use of remote video diagnosis between primary and higher-level units. Unlike Hedstrom et al., who found modest correlation between the respiratory severity score and carbon dioxide levels of infants

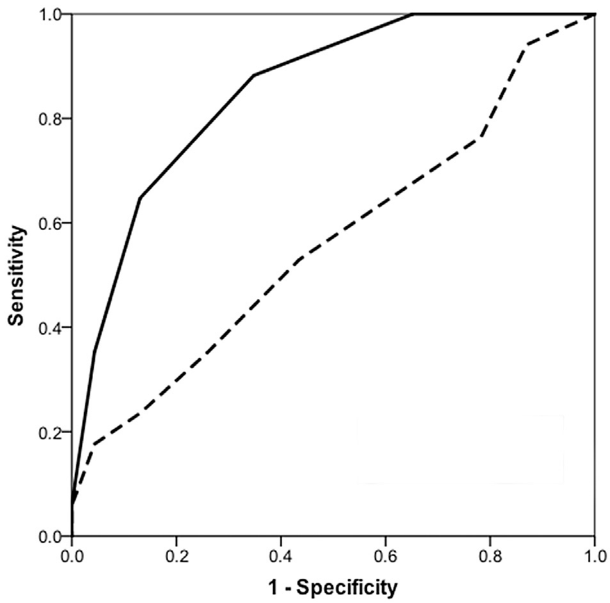

Figure 1 Receiver—operating characteristic curve of the original composite score and Silverman scoring system to predict low dynamic respiratory compliance. The area under the receiver—operating characteristic (ROC) curve for the original composite score (solid line) to predict low dynamic respiratory compliance was 0.86 (95% confidence interval, 0.75—0.97), showing good discriminatory capability for the composite score. The predictive value of the Silverman scoring system (broken line) was generally poor, with an area under the ROC curve of 0.56 (95% confidence interval, 0.38—0.75).

hospitalized at a neonatal intensive care unit,[8] the predictive performance of the Silverman scoring system for low C_{dyn} was relatively poor in our current study. To improve the system, we dichotomized the scores for each item for more objective assessment. In addition, several redundant items were removed or integrated with others according to the collinearity among one another. In the univariate analysis, the respiratory rate ranks showed an exclusive association with C_{dyn}. Under a fixed minute ventilation volume, an increase in the respiratory rate is likely to result in less severe presentations of respiratory failure because of a theoretically reduced tidal volume. However, our data suggest that tachypnoea and other abnormal physical findings coexist in infants with low C_{dyn}. A novel scale for neonatal respiratory distress was subsequently developed using modified physical items from the Silverman scoring system and the respiratory rate ranks, which showed significantly improved predictive performance of infants with low C_{dyn}.

Table 4 Diagnostic performance of the composite prediction score.

Variables	Composite score	Silverman scoring system
Sensitivity	0.882	0.412
Specificity	0.667	0.769
Positive predictive value	0.652	0.538
Negative predictive value	0.889	0.667
Positive likelihood ratio	2.647	1.784
Negative likelihood ratio	0.176	0.765

Several limitations of our study need to be noted. First and foremost, our study cohort was assessed before and shortly after scheduled extubation, rather than before and after intubation of infants with acute respiratory failure. Physical signs after extubation might be affected by laryngeal oedema and spasm. Nonetheless, observed correlations between the composite respiratory score and C_{dyn} suggest that physiological signs of respiratory failure reflect respiratory function to some extent. The static respiratory compliance (C_{st}) is more reproducible and reliable than C_{dyn} because of its independence from the ventilator setting.[11,15] We used C_{dyn} because (i) C_{dyn} has been shown to be well correlated with C_{st} in newborn infants[16,17] and (ii) measurement of C_{dyn} is less burdensome for infants with no requirements for specialized equipment, disconnection from the ventilator, and manual ventilation during the test.[18] We defined low C_{dyn} as <0.6 ml/cmH_2O/kg based on previous observations that C_{dyn} in patients with respiratory distress syndrome is 0.3—0.6 ml/cmH_2O/kg.[14] However, the optimal threshold for performing intubation in newborn infants might be different. The physical signs used in our scoring system may theoretically vary according to changes in the resistance as well as C_{dyn}.[1] We were unable to use the dynamic respiratory resistance because this variable is considerably affected by the size of the tracheal tube.[19] Additionally, the number of infants studied was not large enough to perform multivariate tests. Careful consideration is required when translating the current findings into clinical practice.

5. Conclusions

Newborn infants with low C_{dyn} might be objectively identified using a visual scoring system, which comprises physical respiratory observations available at the cot side. With further validation, this scoring system may help: (i) improve the quality of neonatal respiratory care by providing practical information regarding when to provide more advanced respiratory support in newborn infants; (ii) develop a training system for medical staff, who might have an opportunity to care for ill newborn infants; and (iii) optimize the assessment of respiratory distress in low-resource settings, where infants need to be transported before starting appropriate respiratory support.

Conflict of interest statement

The authors have no conflicts of interest relevant to this article to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pedneo.2019.02.006.