



# Performance of the Silverman Andersen Respiratory Severity Score in predicting PCO<sub>2</sub> and respiratory support in newborns: a prospective cohort study

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## Abstract

**Objective:** To determine if the Silverman Andersen respiratory severity score, which is assessed by physical exam, within 1 h of birth is associated with elevated carbon dioxide level and/or the need for increased respiratory support.  
**Study design:** Prospective cohort study including 140 neonates scored within 1 h of birth. We report respiratory scores and their association with carbon dioxide and respiratory support within 24 h.  
**Results:** Carbon dioxide level correlated with respiratory score ( $n = 33$ ,  $r = 0.35$ ,  $p = 0.045$ ). However, mean carbon dioxide for patients with score  $<5$  vs.  $\geq 5$  did not differ significantly (56 vs. 67,  $p = 0.095$ ). Patients with respiratory scores  $\geq 5$  had respiratory support increased within 24 h more often than those with scores  $<5$  (79% vs. 28%,  $p < 0.001$ ).  
**Conclusion:** The Silverman Andersen respiratory severity score may be valuable for predicting need for escalation of respiratory support and facilitate decision making for transfer in low-resource settings.

## Introduction

In 2013, over two million neonates died from the leading causes of death in children under 5 years of age: prematurity, sepsis, birth asphyxia and pneumonia [1]. The Millennium Development Goals of 2000 successfully targeted and reduced childhood mortality, but neonatal deaths have declined slower than under 5 deaths overall, and hence now almost half of all deaths under 5 years of age occur in the neonatal period [1–3]. The 2014 Every Newborn Action Plan highlighted key interventions required to further reduce global neonatal mortality, and among them both immediate newborn care (within the first minutes extending to one week of age) and care for small or sick babies are expected to have the greatest impact on mortality [4]. Respiratory complications are common in the newborn period. Small babies (a marker for prematurity) often

develop respiratory distress syndrome (RDS) due to surfactant deficiency, while full-term newborns can suffer from infection, meconium aspiration, birth asphyxia or retained lung fluid. There is a critical need for tools to correctly diagnose and therefore appropriately triage and treat respiratory distress in this population.

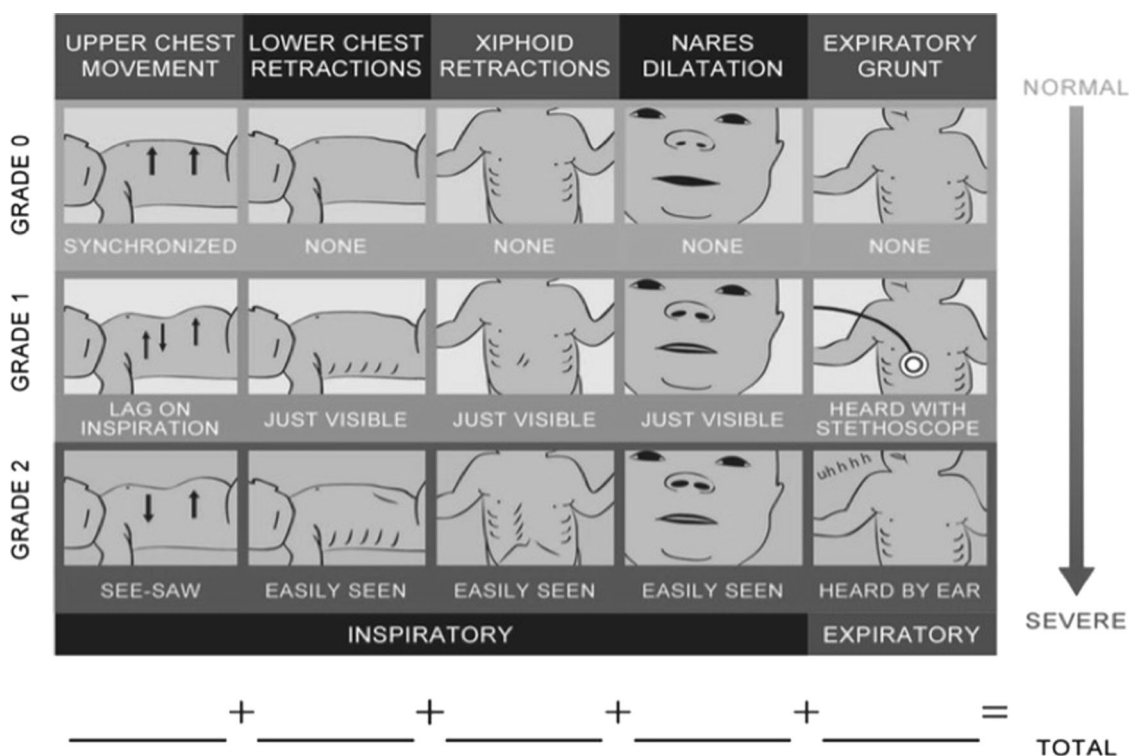
Providers in settings where advanced support for respiratory failure such as CPAP (continuous positive airway pressure) or mechanical ventilation are not available are often faced with the difficult decision regarding when to transfer ill newborns to a facility with higher levels of respiratory support. Especially in low-income countries, these transfers can be dangerous and draining of family resources. Meanwhile, at some facilities, there may be limited number of respiratory support devices, and decisions must be made about who is most appropriate to treat with such therapy. The judicious use of respiratory support and neonatal transfer, therefore, require an objective measure for predicting which patients are most likely to require or benefit from advanced respiratory therapies [5].

Recently, facilities in low-resource settings have used the respiratory severity score (RSS) designed by Silverman and Andersen in 1956 to quantify respiratory distress among neonates (Fig. 1) [6–10]. The RSS is objective, easy to learn, quick to perform and requires no expensive equipment. It can be taught to personnel with limited medical

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**Fig. 1** The Silverman Andersen Respiratory Severity Score (RSS) evaluates five parameters of work of breathing and assigns an overall score with a patient breathing comfortably a “0” and a patient in severe

respiratory distress a “10”. Reprinted with permission from ref. [10] as modified from ref. [6]

training and can be assessed without physically disturbing the patient. Studies of its validity, however, are lacking [8, 11, 12]. An ideal clinical scoring system would be correlated to other laboratory parameters by which respiratory distress is evaluated in high-resource settings to prognosticate a patient’s respiratory trajectory [13].

This goal of this study was to evaluate the ability of the Silverman Andersen RSS to identify newborns in current or impending respiratory distress. Our study objectives were to determine if the RSS measured within 1 h of birth is associated with:

- (1) elevated  $PCO_2$  level and/or
- (2) the impending need for increased respiratory support.

We hypothesized that newborns with high RSS ( $\geq 5$ ) have higher  $PCO_2$  (partial pressure of carbon dioxide) values and are more likely to require increased respiratory support within 24 h compared to those with low RSS ( $< 5$ ). If so, this simple visual assessment tool would show great promise to guide respiratory treatment decisions.

## Materials and methods

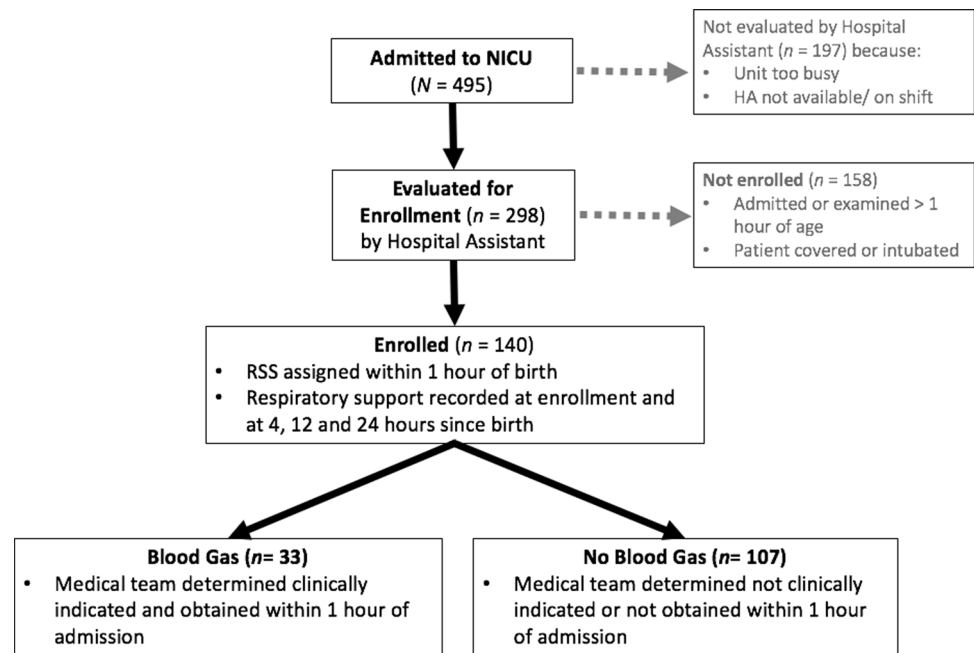
This was a prospective cohort study in a single-center level IV neonatal intensive care unit (NICU; University of Washington, Seattle, WA, USA). Data collection occurred

for 12 sequential months (November 2015 to October 2016).

All neonates admitted to the NICU within 1 h of birth were eligible. Exclusion criteria included intubation prior to 1 h of life, death within 24 h of birth or diagnosis of hypoxic ischemic encephalopathy or a primary neuromuscular condition.

Hospital assistants (HAs), who were not involved in clinical decision making for the patients, were trained to assign a respiratory severity score, measure respiratory rate and record respiratory settings. Via convenience sampling, patients were enrolled only when an HA was able to assign a RSS at the time of admission. An RSS was not assigned if an HA was not on duty, too busy or if a patient was swaddled or under sterile drapes. Decisions to obtain blood gases and change respiratory support were at the discretion of the medical team with guidance from unit guidelines. The medical team was blinded to the RSS. In and out surfactant (for patients failing CPAP) was not the standard of care in the unit during the study. Demographic information and respiratory support at 4, 12 and 24 h were abstracted from the medical record. Patients had incomplete data when they were transferred to another hospital in the first 24 h. Patients who were transferred to mother’s room were determined to have had “no increase in respiratory support” after transfer.

**Fig. 2** Flowchart of patient enrollment via convenience sampling. HA hospital assistant, RSS Silverman Andersen Respiratory Severity Score



IRB approval with waiver of consent was obtained from the University of Washington Human Subjects Division (Application number 49762). Study data were collected and managed using REDCap electronic data capture tools hosted at the University of Washington [14].

## Statistics

We used RSS  $\geq 5$  for exposure of interest given our experience with CPAP initiation at this threshold in rural Uganda [10]. Other settings use cutoffs ranging from 3 to 6 for escalation of neonatal respiratory support [7, 8, 15]. For comparison of RSS with  $\text{PCO}_2$  and with need for increased support, patients were assigned to cohorts of high RSS ( $\geq 5$ ) and low RSS ( $< 5$ ). Respiratory support was “increased from admission” if there was any increase in settings (i.e., flow, pressure) or change in modality (i.e., room air to high-flow nasal cannula or CPAP to mechanical ventilation). For the comparisons with RSS and whether or not the patient had a blood gas taken, the actual value of RSS was used as that would increase the power for detecting a difference in the case where one existed to determine if there were differences in the patients who had blood gases taken. The differences in gestation, birth weight and actual RSS scores were compared between patients who received blood gas to those who did not, as the standard care was used in determining which patients to draw blood from to evaluate the blood gas.

A post-hoc analysis assessed the association between RSS and proportion of patients who were increased to a higher mode of respiratory support (as opposed to just an increase in

settings of the same mode). Respiratory mode was considered “higher” in the following order: no support < nasal cannula < high-flow nasal cannula < CPAP < mechanical ventilation. Another post-hoc analysis examined clinical characteristics of patients below 32 weeks of gestation who did or did not undergo endotracheal intubation between enrollment and 24 h of age.

Descriptive statistics were used to summarize demographics. Fisher's exact test was used for the analysis of associations between the dichotomous variables (RSS group (high/low), any increase in support (Y/N), blood gas taken (Y/N) and increase in support mode (Y/N)). The associations of the dichotomous variables with the numerical variables (gestation, birth weight, RSS score and  $\text{PCO}_2$ ) were analyzed with a two-sided *t*-test. For the *t*-test, the normality was assessed graphically and using the Anderson–Darling test. The normal distribution assumption was violated for the blood gas obtained vs. RSS score, the respiratory rate vs. the intubation in the first 24 h and the RSS score vs. the intubation in the first 24 h; thus, the exact Wilcoxon's test was used for these comparisons. The Levene test was used to determine if the variance was constant across both of the categories in the *t*-test. The variances was not constant for the gestation age of the patients with a blood gas compared to the patients without a blood gas; thus, Welch's two-sample *t*-test for unequal variance was used. A receiver operating characteristic (ROC) curve was used to evaluate the impact of using different RSS cutoffs on the detection of increased respiratory support. For correlation, we will use the guidelines suggested by Evans for the absolute value of *r*

**Table 1** Characteristics of enrolled patients with and without blood gas within 1 h of birth

	Blood gas obtained ( <i>n</i> = 33)		No blood gas ( <i>n</i> = 107)		<i>P</i> -value
	Mean	(Range)	Mean	(Range)	
Gestation (weeks)	32.5	(24–41)	35.7	(26–42)	<0.001**
Birth weight (g)	1924	(574–4286)	2525	(742–4966)	<0.001*
RSS	3.9	(0–8)	1.6	(0–10)	<0.001 <sup>†</sup>
	Proportion	( <i>n</i> )	Proportion	( <i>n</i> )	<i>P</i> -value <sup>^</sup>
Any antenatal steroids	73%	(24/33)	36%	(37/102)	<0.001 <sup>^</sup>
Respiratory support increased in first 24 h	77%	(23/30)	26%	(21/82)	<0.001 <sup>^</sup>

Each analysis is based on available data for that measure, as such denominators differ

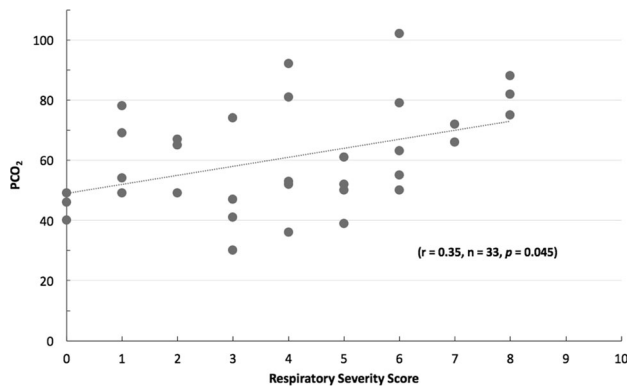
RSS Silverman Andersen respiratory severity score

\*Two-sided *t*-test

\*\*Two-sided *t*-test with unequal variance

<sup>^</sup>Fisher's exact test

<sup>†</sup>Exact Wilcoxon's rank sum test

**Fig. 3** Correlation between arterial PCO<sub>2</sub> and respiratory severity score

(correlation) as follows, where 0.00–0.19 is very weak, 0.20–0.39 is weak, 0.40–0.59 is moderate, 0.60–0.79 is strong and 0.80–1.0 is very strong [16].

A priori power calculations indicated that we would need 9 patients with blood gases in each study group (high and low RSS) to detect a 10 mm Hg PCO<sub>2</sub> difference between groups and to demonstrate a 0.36 proportion difference in increased respiratory support, with 80% power at the 0.05 significance level. The estimates for the means and standard deviations of PCO<sub>2</sub> were based on data previously reported by Nguyen et al. [17].

## Results

Of the 495 patients admitted to the NICU during the period of study, 140 were enrolled and had an RSS within 1 h of birth (Fig. 2). No patients were excluded due to a primary neuromuscular problem, diagnosis of hypoxic ischemic encephalopathy or death within 24 h. Of the 298 evaluated for enrollment, there was no statistically significant

**Table 2** Mean PCO<sub>2</sub> by high vs. low RSS category 0–4

	RSS 0–4 ( <i>n</i> = 19)	RSS 5–10 ( <i>n</i> = 14)	<i>P</i> -value
	Mean (SD)	Mean (SD)	
Arterial PCO <sub>2</sub>	56.4 (16.7)	66.7 (17.3)	0.095

Two-sided *t*-test

difference between those enrolled and not enrolled with respect to mean gestational age (35.0 vs. 34.1 weeks, *p* = 0.07), birth weight (2383 vs. 2257 g, *p* = 0.27) and gender (49 vs. 48% female, *p* = 0.87).

Among the 140 patients enrolled, 49% were female, mean gestational age was 35 weeks (SD 3.7), mean birth weight was 2383 g (SD 896) and 44% had been exposed to antenatal steroids. At the time of RSS assessment, 59% (*n* = 83) were on no respiratory support, 3.6% (*n* = 5) on nasal cannula, 3.6% (*n* = 5) on high-flow nasal cannula and 33.6% (*n* = 47) were on CPAP.

The 33 enrolled patients had a blood gas within 1 h of birth and all were from an arterial source. Patients with a blood gas were smaller, more premature, had higher RSS, were more likely to be exposed to antenatal corticosteroids and were more likely to have their respiratory support increased in the first 24 h than those who did not have a blood gas (Table 1). Mean PCO<sub>2</sub> correlated to RSS (Fig. 3). There was a trend towards difference in PCO<sub>2</sub> between patients with low and high RSS but this did not reach statistical significance (Table 2).

Median RSS among those who had their support increased in the first 24 h was 4 (range 0–10) vs. 0 (range 0–8) among those whose support was not increased. Among all patients, those with high RSS had their respiratory support increased at each time point assessed more often than those with low RSS (Table 3). In the post-hoc analysis, the patients with high RSS were also significantly more

likely to have been increased to a higher mode of respiratory support (instead of just increased settings of the same mode) than those with low RSS (56% (14/25) vs. 16% (16/98),  $p < 0.001$ ).

In an a priori analysis restricted to the patients of 28–36 weeks of gestation ( $n = 72$ ), patients with high RSS were also more likely to have their respiratory support increased in the first 24 h when compared with those with low RSS (71% vs. 29%,  $p < 0.01$ ).

The ROC curve (Fig. 4) shows RSS thresholds of  $\geq 3$ –5 had similar specificities (83–94%) for predicting an increase in respiratory support. Sensitivity, however, was greater with thresholds of  $\geq 3$  (78%) and  $\geq 4$  (62%) compared with a threshold of  $\geq 5$  (44%).

A post-hoc analysis examined clinical characteristics of patients below 32 weeks of gestation who did or did not undergo endotracheal intubation between enrollment and 24 h of age (Table 4). These groups did not differ

significantly in regards to gestational age, birth weight, arterial PCO<sub>2</sub> or respiratory rate during their admission exam. The FiO<sub>2</sub> and RSS, however, were significantly higher in those subsequently intubated.

### Discussion

Elevated RSS within 1 h of birth was strongly associated with an increase in respiratory support in the subsequent 24 h in our study. This relationship was significant at all time points assessed (4, 12 and 24 h since birth), suggesting that

**Table 3** Frequency of need for increased respiratory support from baseline among newborns with high vs. low RSS category

Time since birth	RSS 0–4		RSS 5–10		P-value
	% (n)	% (n)	% (n)	% (n)	
4 h	17% (16/96)	64% (16/25)	<0.001		
12 h	24% (21/88)	56% (14/25)	0.003		
24 h	22% (19/88)	54% (13/24)	0.004		
Anytime in first 24 h	28% (25/88)	79% (19/24)	<0.001		

Fisher’s exact test

Each analysis is based on available data for that measure, as such sample size differs

**Table 4** Subgroup analysis of patients of <32 weeks of gestation: characteristics of those who were and were not intubated in first 24 h

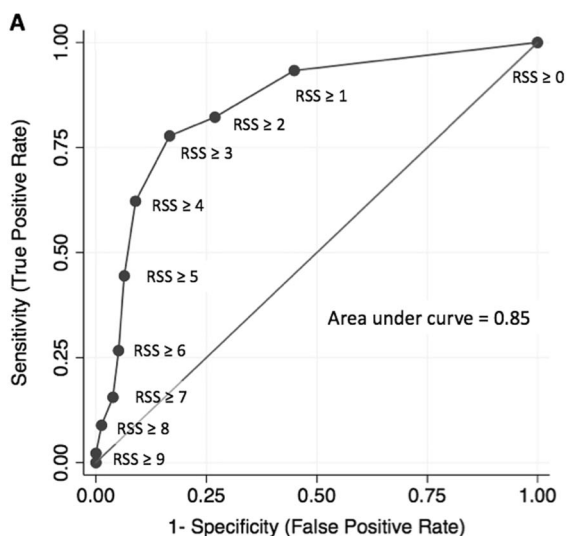
	Intubated in first 24 h (n = 9)		Not intubated (n = 18)		P-value
	Mean	(SD)	Mean	(SD)	
Gestational age (weeks)	28.4	(1.8)	29.7	(1.8)	0.09 <sup>†</sup>
Birth weight (g)	1063	(407)	1225	(291)	0.25 <sup>†</sup>
Arterial PCO <sub>2</sub> (n = 15)	61.9	(17.7)	52.3	(11.5)	0.24 <sup>†</sup>
FiO <sub>2</sub> during RSS (n = 19)	0.35	(0.19)	0.26	(0.9)	0.048*
Respiratory rate during RSS (bpm)	38.4	(8.8)	42.1	(7.7)	0.12*
Respiratory severity score	6.1	(2.1)	2.8	(2.3)	0.003*

Each analysis is based on available data for that measure, as such sample size differs

RSS Silverman Andersen respiratory severity score

<sup>†</sup>Two-sided t-test

\*Wilcoxon’s rank sum



Score Cutoff	Sensitivity	Specificity	Positive LR	Negative LR
( $\geq 0$ )	100%	N/A	1.0	N/A
( $\geq 1$ )	93%	55%	2.1	0.12
( $\geq 2$ )	82%	73%	3.1	0.24
( $\geq 3$ )	78%	83%	4.7	0.27
( $\geq 4$ )	62%	91%	6.9	0.42
( $\geq 5$ )	44%	94%	6.9	0.59
( $\geq 6$ )	27%	95%	5.2	0.77
( $\geq 7$ )	16%	96%	4.0	0.88
( $\geq 8$ )	9%	99%	6.9	0.92
( $\geq 9$ )	dns	dns	N/A	0.98

**Fig. 4** Respiratory severity score cutoff to predict increased respiratory support in the first 24 h. **a** Receiver operating characteristic curve. **b** Sensitivity, specificity and likelihood ratios (LR) of each cutoff. RSS

Silverman Andersen respiratory severity score, N/A not applicable given divisor is 0, dns data not sufficient

a newborn with an elevated RSS ( $\geq 5$ ) could require increased respiratory support anytime in the first 24 h. These results corroborate the few studies of the clinical correlations of elevated RSS. Very early studies of newborns below 2 kg demonstrated that a RSS of  $\geq 2$  was highly associated with mortality and subsequent autopsy findings consistent with RDS [11, 12]. More recent case series of preterm patients with respiratory distress showed improvement in RSS after treatment with CPAP [7, 10]. In a case series from India, a RSS score of 6 at 6 h of age was associated with patients who failed CPAP therapy [8].

Although many facilities in low-resource areas use threshold scores of 3–6 to guide decisions to initiate and increase respiratory support, these thresholds have not been validated for their predictive abilities [7–10]. The ROC curve (Fig. 4) shows that cutoffs of RSS  $\geq 3$  or  $\geq 4$  would best differentiate patients who subsequently did and did not need increased respiratory support. However, the pros and cons of false positive vs. a failed detection must be determined for different clinical scenarios. For example, a low-resource setting may wish to keep only patients unlikely to have impending need for increased support, and might therefore transfer patients with scores of  $\geq 2$ . Of equal importance for this setting, patients with RSS below the cutoff are likely to remain stable from a respiratory perspective and can avoid the risk, stress and financial burden associated with a transfer.

Among the small subset of patients with a blood gas near birth, we found that RSS and  $\text{PCO}_2$  had a statistically significant linear correlation. However, when patients were segregated into clinically relevant groups (low and high RSS), the relationship was not significant. Our study design was susceptible to selection bias given that not all patients had a blood gas assessment; rather only those deemed “ill-enough” by the care team. As is the standard of care in the neonatal unit, the clinical team obtained gases on patients who were smaller, more premature and appeared to have more work of breathing on admission (as indicated by their elevated RSS) compared with those without blood gases. Few patients with minimal work of breathing (RSS of 0 or 1) had blood gases collected. This selection bias is confirmed by the mean arterial  $\text{PCO}_2$  of 60 mm Hg in our sample, which is markedly elevated from published means of 41 mm Hg among all newborns on CPAP [17]. We believe the effect of this bias on our findings was conservative, and that we may have failed to demonstrate a possible association given the paucity of patients with low RSS scores and normal-range  $\text{PCO}_2$ .

Of interest to settings able to perform endotracheal intubation, the post-hoc analysis of very preterm infants shows those intubated in first 24 h had significantly higher RSS than those not subsequently intubated (Table 4). The RSS differentiates these groups while some of the other

traditional “predictive” factors for impending intubation, such as gestational age, birth weight, arterial  $\text{PCO}_2$  or respiratory rate, did not. The RSS, therefore, may be helpful in determining which patients are at high risk of need for subsequent intubation and could be considered for “in and out” surfactant.

This study had several strengths. The assets of a high-resource neonatal unit (such as capacity for blood gases and retaining patients who needed increased respiratory support) allowed close following of each patient’s clinical course. Although work of breathing is one of the many factors that the medical team uses to decide the amount of respiratory support a patient receives, in this study the blinding of the team to the RSS was helpful to assess its performance. Meanwhile, the use of carefully trained but medically inexperienced hospital assistants suggests this score is feasible for staff that may be present in lower-resource settings.

A principal limitation of this study was sampling done via convenience—most admitted patients (355/495) were not enrolled. Although we did not find demographic differences between those enrolled and not enrolled, this potential for selection bias limits generalizability. Also, while the choice to obtain the RSS in the first hour is a reasonable assessment point clinically, the respiratory exam after birth is dynamic and examination at one time point may not be representative of the patient’s clinical trajectory. Future study, therefore, will require considering all patients for enrollment and performing the RSS at additional times to better define its predictive abilities.

In this study, we were unable to verify accuracy of the scores assigned and this can be an area of difficulty even among experienced providers. A recent study showed very poor inter-rater reliability (IRR) in aspects of the respiratory exam of term-corrected infants between attending neonatologists and pulmonologists [18]. As the author points out, these clinicians, however experienced, had no standardized training for the assessment they were performing. In the only study to date of reliability of the RSS, the IRR of the RSS between the doctor and nurses in a low-resource neonatal unit who had undergone standardized instruction ( $\rho = 0.73$ ) was similar to their agreement on the patient’s respiratory rate ( $r = 0.86$ ) [10]. Therefore, the implementation of the RSS in any setting should be accompanied by reliable, standardized instruction.

The Silverman Andersen Respiratory Severity Score is an easy, quick, non-invasive method to assess newborn respiratory distress with a long history of use in many low-resource settings to guide therapy. It is particularly well suited for settings where laboratory, monitoring or diagnostic abilities and capacity to provide increased respiratory support are limited. Based on our results, we conclude the RSS may be a valuable tool to predict impending need for escalation of respiratory support among newborns. This

should be of particular relevance to clinical decision making regarding judicious timing of transfer for patients who need increased respiratory support.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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