Published in final edited form as:

Crit Care Med. 2017 August ; 45(8): 1317–1324. doi:10.1097/CCM.0000000000002514.

Non-linear imputation of PaO₂/FIO₂ from SpO₂/FIO₂ among mechanically ventilated patients in the intensive care unit: a prospective, observational study

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Conflicts of Interest: The author(s) declare that they have no competing interests.

Copyright form disclosure: Drs. Brown, Hou, Tidswell, Khan, Exline, Park, Schoenfeld, Liu, Grissom, Moss, Rice, Hough, Rivers, Thompson, and Brower received support for article research from the National Institutes of Health (NIH). Dr. Khan's institution received funding from United Therapeutics, GlaxoSmithKline, Actelion Pharmaceuticals, and the NIH/National Heart, Lung, and Blood Institute (NHLBI). Dr. Exline disclosed that OSU is a member of the Prevention and Early Treatment of Acute Lung Injury (PETAL) network (NHLBI), and he received other support as an expert witness for medical malpractice cases. Dr. Park's institution received funding from the NIH, National Institute of Allergy and Infectious Diseases, Bristol Myers Squibb, and National Board of Medical Examiners. Dr. Schoenfeld's institution received funding from the NHLBI; and he received funding from Alexion Pharmaceuticals, Inc., Baker Botts LLP, Boston Biostatistics Research Foundation, Brainstorm Cell Therapeutics Inc., Cardeas, Lavin Consulting LLP, Mitsubishi Pharma, North Shore Hospital, Pfizer, and Purdue Pharma, L.P. Dr. Liu received funding from the NHLBI. Dr. Grissom's institution received funding from the NIH, NHLBI, and the NIH/NHLBI PETAL Network. Dr. Rice received funding from GlaxoSmithKline, Avisa Pharma, and Cumberland Pharmaceuticals. Dr. Hough's institution received funding from the NHLBI. Dr. Rivers' institution received funding from Abbott Laboratories, Alere, Spectral Diagnostics, Lajolla Pharmaceutical, Health Decisions, and the NIH. Dr. Thompson received funding from consultancy for Alexion, Asahi Kasei, Boehringer Ingelheim, Bristol-Myers Squibb, GlaxoSmithKline, Vertex, and Regeneron. Dr. Brower's institution received funding from the NIH/NHLBI, and he received funding from Applied Clinical Intelligence and Global Therapeutics.

Dr. Duggal disclosed that he does not have any potential conflicts of interest.

This work was completed at Intermountain Medical Center, Cleveland Clinic, Brigham and Women's Hospital, Baystate Medical Center, OHSU Hospital, Ohio State University Wexner Medical Center, University of Michigan Hospital, Harborview Medical Center, and Henry Ford Hospital.

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Abstract

Objectives—In the contemporary intensive care unit (ICU), mechanically ventilated patients may not have arterial blood gas (ABG) measurements available at relevant timepoints. Severity criteria often depend on ABG results. Retrospective studies suggest that non-linear imputation of $\text{PaO}_2/\text{FIO}_2$ from $\text{SpO}_2/\text{FIO}_2$ is accurate, but this has not been established prospectively among mechanically ventilated ICU patients. The objective was to validate the superiority of non-linear imputation of $\text{PaO}_2/\text{FIO}_2$ among mechanically ventilated patients and understand what factors influence the accuracy of imputation.

Design—Simultaneous SpO_2 , oximeter characteristics, receipt of vasopressors, and skin pigmentation were recorded at the time of a clinical ABG. ARDS criteria were recorded. For each imputation method, we calculated both imputation error and the area under the curve (AUC) for patients meeting criteria for ARDS ($\text{PaO}_2/\text{FIO}_2 \geq 300$) and moderate-severe ARDS ($\text{PaO}_2/\text{FIO}_2 \leq 150$).

Setting—Nine hospitals within the Prevention and Early Treatment of Acute Lung Injury network.

Patients—We prospectively enrolled 703 mechanically ventilated patients admitted to the emergency departments or ICUs of participating study hospitals.

Interventions—None.

Measurements and Main Results—We studied 1034 ABGs from 703 patients; 650 ABGs were associated with $\text{SpO}_2 \geq 96\%$. Non-linear imputation had consistently lower error than other techniques. Among all patients, non-linear had a lower error ($p < 0.001$) and higher ($p < 0.001$) AUC (0.87; 95% CI 0.85–0.90) for $\text{PaO}_2/\text{FIO}_2 \geq 300$ than linear/log-linear (0.80; 95% CI 0.76–0.83) imputation. All imputation methods better identified moderate-severe ARDS ($\text{PaO}_2/\text{FIO}_2 \leq 150$); non-linear imputation remained superior ($p < 0.001$). For $\text{PaO}_2/\text{FIO}_2 \leq 150$, the sensitivity and specificity for non-linear imputation were 0.87 (95% CI 0.83–0.90) and 0.91 (95% CI 0.88–0.93) respectively. Skin pigmentation and receipt of vasopressors were not associated with imputation accuracy.

Conclusions—In mechanically ventilated patients, non-linear imputation of $\text{PaO}_2/\text{FIO}_2$ from $\text{SpO}_2/\text{FIO}_2$ appears accurate, especially for moderate-severe hypoxemia. Linear and log-linear imputation cannot be recommended.

Keywords

Respiratory failure; pulse oximetry; severity scores; Acute Respiratory Distress Syndrome

INTRODUCTION

The ratio of partial pressure of arterial oxygen (PaO_2) to the fraction of inspired oxygen (FIO_2), the $\text{PaO}_2/\text{FIO}_2$ ratio, is commonly used to measure the severity of hypoxemia in patients with respiratory failure. The $\text{PaO}_2/\text{FIO}_2$ ratio is fundamental to the consensus definition of ARDS(1) as well as general critical illness severity indices such as the Sequential Organ Failure Assessment (SOFA) score.(2) Among mechanically ventilated patients, the $\text{PaO}_2/\text{FIO}_2$ ratio may be necessary to diagnose ARDS. However, the $\text{PaO}_2/\text{FIO}_2$ ratio requires that an arterial blood gas (ABG) be obtained to measure PaO_2 .

Because many clinicians rely on pulse oximetry to evaluate hypoxemia and make adjustments to the mechanical ventilator, patients with ARDS may not have an ABG available in a relevant timeframe for early diagnosis of ARDS or calculation of severity scores. Arterial catheters (which make ABG testing more convenient) are falling out of favor,(3, 4) pulse oximeters have become ubiquitous, and clinicians may use venous blood gases (or exhaled gas sampling) to monitor PCO_2 or pH.(5) A non-invasive surrogate for the $\text{PaO}_2/\text{FIO}_2$ ratio, based on measuring the oxyhemoglobin percent saturation with a pulse oximeter, would allow patients without ABGs to be assessed for disease severity and/or evaluated for the hypoxemia criterion for ARDS. To assure equivalence, a non-invasive surrogate for $\text{PaO}_2/\text{FIO}_2$ would require imputation of PaO_2 from SpO_2 . The $\text{SpO}_2/\text{FIO}_2$ ratio has therefore been proposed as a non-invasive surrogate for the $\text{PaO}_2/\text{FIO}_2$ ratio.(6–11)

The oxyhemoglobin percent saturation can be measured with a pulse oximeter (SpO_2), or directly in the arterial blood (SaO_2). The relationship between PaO_2 and SaO_2 (and therefore SpO_2) is sigmoidal. However, much prior work investigating the association between $\text{SpO}_2/\text{FIO}_2$ and $\text{PaO}_2/\text{FIO}_2$ ratios employed linear (or log-linear) regression modeling in adults(6, 7) and children.(8–11)

In a large, retrospective study of patients with ARDS enrolled in three clinical trials,(12) we demonstrated that a non-linear imputation based on the Ellis inversion(13) of the Severinghaus equation(14) outperformed linear and log-linear imputation methods, observations which complemented prior studies of non-intubated patients with pneumonia. (15–18) To externally validate these retrospective observations, we undertook a prospective study, with attention to patient characteristics that might affect the accuracy of imputation. We hypothesized that non-linear imputation was superior to other imputation methods and that the receipt of vasopressors and darker skin pigmentation would be associated with less accurate imputation.

MATERIALS AND METHODS

We studied mechanically ventilated patients admitted to the emergency departments (EDs) or intensive care units (ICUs) of participating study hospitals, which were part of the NIH

Prevention and Early Treatment of Acute Lung Injury (PETAL) Network. We excluded children, pregnant women, and prisoners. At the time a clinical ABG was obtained for a ventilated patient, the nurse or respiratory therapist obtaining the ABG completed a brief case report form (CRF) that included current SpO_2 , quality of the oximeter waveform, skin pigmentation (graded informally from very light to very dark, on a 5-point ordinal span, with reference skin pigments included on the CRF). Research coordinators then documented age, sex, body mass index (BMI), body temperature (as measured clinically, without preference for core vs. peripheral temperature measurements), ABG results, basic metabolic panel results, hemoglobin, Positive End Expiratory Pressure (PEEP), FIO_2 , tidal volume, receipt of vasopressors (i.e., epinephrine, norepinephrine, phenylephrine, dopamine, or vasopressin) at the time the ABG was obtained, and whether the patient met consensus criteria for ARDS other than hypoxemia. Specifically, site investigators individually reviewed chest radiographs and the medical record to assess whether ARDS criteria (acute onset of bilateral lung opacities not fully explained by effusions, lobar/lung collapse, or nodules) other than hypoxemia were met. ARDS was then considered present if the $\text{PaO}_2/\text{FIO}_2$ met relevant thresholds. Given resource constraints, we did not require a specific ABG sampling strategy or collect denominator data on the total number of ABGs performed in participating hospitals.

Data were uploaded to the Clinical Coordinating Center (CCC) at Massachusetts General Hospital, where quality analysis and cleaning were undertaken according to standard procedures. Each participating Institutional Review Board (IRB), including the CCC IRB, approved this study with waiver of informed consent on the basis of compliance with 45 CFR 46.116d.

Statistical analysis

Because imputation is considered to be most accurate for $\text{SpO}_2 \geq 96\%$, based on the sigmoidal shape of the hemoglobin-oxygen dissociation curve⁽¹⁴⁾ and our prior empirical observations,⁽¹²⁾ we separately analyzed ABGs with an associated $\text{SpO}_2 \geq 96\%$. Because PIO_2 (partial pressure of inspired oxygen) varies by both FIO_2 and barometric pressure, we adjusted $\text{PaO}_2/\text{FIO}_2$ ratios at the Utah site (altitude $\sim 1300\text{m}$) by the ratio of local to sea level barometric pressure (0.845). We used the Ellis non-linear,⁽¹³⁾ Rice linear,⁽⁶⁾ and Pandharipande log-linear⁽⁷⁾ equations for imputation, as we did in our prior, retrospective work.⁽¹²⁾ (The equations are displayed in Table E1.) For purposes of description, we generated Bland-Altman plots of the difference between imputed and measured $\text{PaO}_2/\text{FIO}_2$ as a function of measured $\text{PaO}_2/\text{FIO}_2$ both for all patients and among patients in whom $\text{SpO}_2 \geq 96\%$. Secondly, we calculated the error of the imputations, as well as the proportion of patients in whom the absolute error of the imputation was less than 25 (e.g., if the actual $\text{PaO}_2/\text{FIO}_2$ is 100, then the imputed $\text{PaO}_2/\text{FIO}_2$ is between 75 and 125) or 50 (e.g., if the actual $\text{PaO}_2/\text{FIO}_2$ is 100, then the imputed $\text{PaO}_2/\text{FIO}_2$ is between 50 and 150).

For hypothesis testing, we compared the root mean squared error (RMSE; log transformed given its log normal distribution) of the imputation for each technique, using a paired t test and utilizing generalized estimating equations to account for the fact that some patients contributed multiple ABGs to the analysis.⁽¹⁹⁾ We also calculated area under the receiver

operating characteristic curve (AUC) at two diagnostic thresholds for $\text{PaO}_2/\text{FIO}_2$ (150 and 300) for the different imputation techniques. (We note that because linear and log-linear techniques impute $\text{PaO}_2/\text{FIO}_2$ from $\text{SpO}_2/\text{FIO}_2$ monotonically, their AUCs are identical to each other and to raw $\text{SpO}_2/\text{FIO}_2$; because the non-linear technique imputes from SpO_2 itself, its AUC can differ.) We used the threshold of 150 rather than the consensus threshold of 100 for severe ARDS because it is the threshold used in the PETAL Network's Reevaluation of Systemic Early Neuromuscular Blockade (ROSE) trial ([ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT02509078) NCT02509078) of neuromuscular blockade in moderate-severe ARDS, (20) following the ACURASYS trial threshold.(21) We compared AUCs using the method of DeLong.(22)

We considered whether other variables would improve the imputation of the $\text{PaO}_2/\text{FIO}_2$, from the point of view of the AUC for predicting that the $\text{PaO}_2/\text{FIO}_2$ was under 300 or under 150. Using linear regression models, we considered PEEP, serum bicarbonate, minute ventilation, FIO_2 , age, ABG performed during the day (as opposed to at night), SpO_2 , pulse oximeter location (at the time the ABG was obtained), serum chloride, serum creatinine, and serum sodium (the last three were included in case markers of renal dysfunction or electrolyte imbalance were related indirectly to shifts in the hemoglobin-oxygen dissociation curve), to see whether they improved the accuracy of the imputation.

In a secondary analysis, among the patients for whom more than one ABG was available, we evaluated whether knowledge of the error of measurement on the first ABG improved the imputation for the later ABGs. We attempted multiple complementary techniques to incorporate the first-ABG imputation error into later imputations, including adding the error term, adding a proportion of the error term (derived from linear regression), and the ratio of measured to imputed $\text{PaO}_2/\text{FIO}_2$ ratios.

Analyses were performed in the R Statistical Package version 3.2.3.(23)

RESULTS

We studied 1034 ABGs in 703 patients at 9 hospitals across the United States, among which 650 ABGs were associated with $\text{SpO}_2 \geq 96\%$. Patient characteristics are displayed in Table 1. Characteristics of the ABG and associated oximetry measurements are displayed in Table 2. The mean measured $\text{PaO}_2/\text{FIO}_2$ ratio was 226. Relevant laboratory results and ventilator settings are displayed in Tables E2–E3 of the Supplemental Digital Content. Mean PEEP was 7.8 cm H_2O ; mean tidal volume, corrected for ideal body weight, was 6.9 ml/kg.

As displayed in Figure 1, Bland-Altman plots suggested that non-linear imputation was accurate, albeit with decreasing accuracy at higher $\text{PaO}_2/\text{FIO}_2$ ratios. This appeared true, especially for measured $\text{PaO}_2/\text{FIO}_2$ ratio ≥ 150 and for $\text{SpO}_2 \geq 96\%$. In Table 3, we quantitatively describe the performance of the different imputation techniques. Non-linear imputation had lower RMSE than log-linear or linear imputation methods for all ABGs and for ABGs where $\text{SpO}_2 \geq 96\%$ (all $p < 0.001$).

All imputation methods displayed good to excellent discrimination, as outlined in Table 4, with AUCs ranging from 0.77 (95% CI 0.73–0.81) to 0.96 (95% CI 0.94–0.97) for different

thresholds and sub-populations. Non-linear imputation had a significantly higher AUC than linear/log-linear imputation ($p < 0.001$), with AUCs ranging from 0.86 (95% CI 0.82–0.89) to 0.96 (95% CI 0.94–0.97). The superiority of non-linear imputation was true for $\text{PaO}_2/\text{FIO}_2$ 150 and $\text{PaO}_2/\text{FIO}_2$ 300. AUCs were consistently higher for the lower threshold (150) than for the higher threshold (300). The observed AUCs were compatible with good sensitivity and specificity. At the $\text{PaO}_2/\text{FiO}_2$ 150 threshold, the sensitivity and specificity for non-linear imputation were 0.87 (95% CI 0.83–0.90) and 0.91 (95% CI 0.88–0.93), respectively. At the $\text{PaO}_2/\text{FIO}_2$ 300 threshold, sensitivity and specificity were 0.90 (95% CI 0.88–0.92) and 0.67 (95% CI 0.61–0.73), respectively.

The results were generally similar for the 650 ABGs associated with SpO_2 96% (see Tables 3, E4). In this group, AUC analysis yielded similar results, except for patients who otherwise met ARDS criteria at the $\text{PaO}_2/\text{FiO}_2$ 300 threshold, where discrimination was only good: AUCs were 0.77 to 0.81. The decrease in AUC appeared related to the relatively small number of individuals with SpO_2 96% who also had $\text{PaO}_2/\text{FiO}_2 > 300$ and otherwise met criteria for ARDS. Among ABGs in patients that otherwise met ARDS criteria, restricting to ABGs with SpO_2 96% again demonstrated the superiority of non-linear imputation (Table 3).

In our analysis to understand whether certain variables (e.g., skin pigmentation, oximeter sensor location, oximeter manufacturer, vasopressor use, PEEP, and others, as outlined in methods) were associated with changes in the accuracy of imputation, models incorporating those predictors yielded negligible improvement in the accuracy of the imputation. The AUC of the imputations increased at most by 1%. Notably, only 5.6% of ABGs were associated with an inadequate pulse oximeter waveform.

Similarly, when evaluating whether results from an initial ABG result could improve the accuracy of imputation for later ABGs, none of the techniques materially improved the accuracy of imputation.

DISCUSSION

In this large, prospective, multi-center study of clinical ABGs obtained in mechanically ventilated ICU patients, we externally validated prior retrospective observations that a non-linear imputation is best for estimating the degree of hypoxemia from pulse oximetry. While all tested imputations had reasonable accuracy among mechanically ventilated patients, a non-linear, physiologically based approach appeared best overall, especially when the $\text{PaO}_2/\text{FIO}_2$ ratio is low. Among patients who otherwise met ARDS criteria, accuracy was highest when restricted to ABGs where SpO_2 96%.

The AUC analysis, which is most relevant to screening for the presence of hypoxemia consistent with ARDS, confirms that physiologically based, non-linear imputation of $\text{PaO}_2/\text{FIO}_2$ is superior to other imputation techniques. These estimates are less accurate for patients with higher SpO_2 and $\text{SpO}_2/\text{FIO}_2$ values. Contrary to our initial expectation, no variables were associated with greater or lesser accuracy to a substantial degree, suggesting that routine use of this technique would not require measurement of additional variables. In

this respect, our findings differ from prior studies suggesting a relationship between PEEP and the accuracy of $\text{PaO}_2/\text{FIO}_2$ imputation.(6, 7) Because only one in twenty of study ABGs were associated with a low quality pulse oximeter waveform, we suspect that it is reasonable to restrict such imputations to situations where the waveform is of adequate quality. Based on physiological principles and our subgroup analysis, it also seems reasonable to restrict evaluation to ABGs where $\text{SpO}_2 \geq 96\%$, perhaps by downward titration of FIO_2 in patients with high SpO_2 .

Our study has two key strengths differentiating it from prior studies of the imputation of $\text{PaO}_2/\text{FIO}_2$ from $\text{SpO}_2/\text{FIO}_2$ among patients with and at risk for ARDS, including our own retrospective work:(12) it is prospective—with real-time correlation of SpO_2 and PaO_2 —and is multi-center. Our study design allowed us to evaluate, in a generalizable fashion, the accuracy of imputation and the relevance of the oximeter waveform, the oximeter type(24) and location, as well as skin pigmentation,(24, 25) body temperature, and other relevant parameters.

Our study has limitations. Because of resource limitations, we were unable to record all ABGs in study ICUs and were unable to obtain outcome data for study patients. We are thus unable to exclude ascertainment bias, which could affect generalizability, and we cannot determine whether inaccurate imputation is associated with mortality or other patient outcomes. For the patients in whom an ABG was associated with $\text{SpO}_2 \geq 96\%$ the prevalence of $\text{PaO}_2/\text{FIO}_2 > 300$ was so uncommon, especially among patients who met other criteria for ARDS, that the AUC was a less reliable measure of accuracy. The error associated with non-linear imputation was still lower than for the other imputation techniques. Nevertheless, identification of mild ARDS may be somewhat more difficult on the basis of $\text{SpO}_2/\text{FiO}_2$. While the non-linear imputation equation is too complex to calculate easily by hand, we provide a lookup table (Table E5); a similar lookup table has been employed in the ROSE study protocol for screening.

CONCLUSIONS

Because the association between SpO_2 and PaO_2 is physiologically sigmoidal, the use of a non-linear imputation strategy appears preferable to other strategies for estimating $\text{PaO}_2/\text{FIO}_2$ from pulse oximetry. Such an imputation strategy displays good discrimination for ARDS at relevant diagnostic thresholds, albeit with lower specificity for mild ARDS, particularly when SpO_2 is allowed to remain $>96\%$ with high FIO_2 . The use of linear or log-linear imputation methods can no longer be recommended.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank the nurses and respiratory therapists at Intermountain Medical Center, Cleveland Clinic, Brigham and Women's Hospital, Baystate Medical Center, OHSU Hospital, Ohio State University Wexner Medical Center, University of Michigan Hospital, Harborview Medical Center, and Henry Ford Hospital who graciously participated in this work.

Source of Funding: The sponsor (the National Heart, Lung, and Blood Institute) funds the PETAL Network for which this work was performed. The sponsor had no role in the analysis or reporting of the data. This study was supported by the National Institutes of Health, National Heart Lung and Blood Institute, Prevention and Early Treatment of Lung Injury Network, contracts U01HL123010, U01HL123004, U01HL123022, U01HL122989, U01HL123008, U01HL123027, U01HL123020, U01HL123018, U01HL123031, U01HL123033, U01HL122998, U01HL123023, U01HL123009. Samuel M. Brown is supported by the National Institutes of Health, Heart Lung and Blood (R21HL123433).

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Figure 1. Bland-Altman plots of imputed vs. measured $\text{PaO}_2\text{:FIO}_2$ ratios

Bland-Altman plot of the difference between measured and imputed $\text{PaO}_2\text{:FIO}_2$ ratios. Black represents non-linear, red linear, and blue log-linear imputation results.

Table 1**Patient Characteristics**

Characteristic	Values
Female sex, k/n (%)	292/703 (41.5)
Age, years ($\pm$ SD)	57.5 $\pm$ 16.3 (n = 703)
Height, cm ($\pm$ SD)	170.1 $\pm$ 11.1 (n = 696)
Weight, kg ($\pm$ SD)	88.6 $\pm$ 28.8 (n = 698)
Average PaO ₂ /FIO ₂ for each patient ($\pm$ SD)	225.7 $\pm$ 111.9 (n = 703)
PaO ₂ /FIO ₂ ratio, values by threshold [§]	
PaO ₂ /FIO ₂ > 300, k/n (%)	166/703 (23.6)
PaO ₂ /FIO ₂ 300, k/n (%)	537/703 (76.4)
PaO ₂ /FIO ₂ 200, k/n (%)	322/703 (45.8)
PaO ₂ /FIO ₂ 150, k/n (%)	188/703 (26.7)
PaO ₂ /FIO ₂ 100, k/n (%)	58/703 (8.3)
# of SpO ₂ measurements	
1 measurement, k/n (%)	460/703 (65.4)
2 measurements, k/n (%)	155/703 (22.1)
3 measurements, k/n (%)	88/703 (12.5)

[§]Represents the average of PaO₂/FIO₂ ratios for each patient

Table 2

Oximetry and arterial blood gas results

Oximetry.	
Variables	Values
Patient Located in ICU, k/n (%)	1023/1034 (98.9)
ABG Done during the Day, k/n (%)	714/1034 (69.1)
Pulse Oximeter Location	
Earlobe, k/n (%)	110/1013 (10.9)
Finger, k/n (%)	806/1013 (79.6)
Toe, k/n (%)	64/1013 (6.3)
Forehead, k/n (%)	18/1013 (1.8)
Other, k/n (%)	15/1013 (1.5)
Pulse Oximeter Type	
Disposable Sensor, k/n (%)	523/1029 (50.8)
Reusable Sensor, k/n (%)	470/1029 (45.7)
Flex Sensor, k/n (%)	2/1029 (0.2)
Forehead (transreflectance) Sensor, k/n (%)	10/1029 (1.0)
Other, k/n (%)	24/1029 (2.3)
Pulse Oximeter Manufacturer	
Masimo, k/n (%)	785/1034 (75.9)
Nellcor, k/n (%)	230/1034 (22.2)
Stryker, k/n (%)	19/1034 (1.8)
SpO ₂ , %	95.0 ± 4.4 (n = 1034)
SpO ₂ (where SpO ₂ ≥ 96%), %	92.8 ± 4.0 (n = 650)
Adequate Pulse Oximeter Waveform, k/n (%)	973/1031 (94.4)
Skin Pigmentation	
Light, k/n (%)	281/1033 (27.2)
Light/Medium, k/n (%)	429/1033 (41.5)
Medium, k/n (%)	169/1033 (16.4)
Medium/Dark, k/n (%)	70/1033 (6.8)
Dark, k/n (%)	84/1033 (8.13)
ABG Results.	
Variables	Values
pH	7.36 ± 0.11 (n = 1034)
PCO ₂ , mmHg	42.3 ± 12.6 (n = 1034)
PaO ₂ , mmHg	98.1 ± 51.4 (n = 1034)
SaO ₂ , %	93.8 ± 4.4 (n = 932)
Hgb, g/dL	9.8 ± 2.2 (n = 891)
Methemoglobin, %	0.8 ± 0.4 (n = 533)
Carboxyhemoglobin, %	1.4 ± 0.7 (n = 536)

Oximetry.

Variables	Values
Temperature at time of ABG, °C	37 ± 1 (n = 1030)
On a vasopressor at time of ABG, k/n (%)	388/1034 (37.5)

ICU: Intensive Care Unit; ABG: arterial blood gas; Hgb: hemoglobin

Table 3

Comparison of error by imputation technique

Imputation technique	Mean absolute error	Standard deviation of error	P value (comparison with non-linear imputation)*	Proportion of ABGs with error [§] < 25 mmHg (%)	Proportion of ABGs with error [§] < 50 mmHg (%)
All ABGs (N=1034)					
Non-linear	54.3	69.6	NA	48.7	68.8
Linear	63.5	73	<0.001	33.1	59.7
Log-linear	60.3	66.1	<0.001	28.6	61.7
ABGs with SpO ₂ 96% (N=650)					
Non-linear	30.2	45.4	NA	65.1	84.9
Linear	41.2	44.6	<0.001	40.9	72.3
Log-linear	40.7	36.9	<0.001	31.5	73.5
ABGs where other ARDS criteria are met (N=417)					
Non-linear	43.9	61.5	NA	55.9	75.8
Linear	47.3	58.2	<0.001	40.5	71
Log-linear	48.1	49.6	<0.001	28.1	69.1
ABGs with SpO ₂ 96% where other ARDS criteria are met (N=297)					
Non-linear	26.4	44.9	NA	68.7	88.9
Linear	36.9	44.3	<0.001	45.5	77.4
Log-linear	40.6	37.1	<0.001	27.9	74.7

* From a paired t-test of log-transformed root-mean-square error

[§] Absolute value of error

ABG: arterial blood gas; ARDS: Acute Respiratory Distress Syndrome

Table 4

AUC for severe ARDS and any ARDS

Imputation method	All ABGs (N = 1034)		Severe ARDS (PF ratio 150)		Other ARDS criteria are met (N = 421)		Other ARDS criteria are NOT met (N = 613)	
	Area	95% CI	Area	95% CI	Area	95% CI	Area	95% CI
	Nonlinear	0.95 (0.94, 0.97)	0.94 (0.92, 0.96)		0.96 (0.94, 0.97)		0.92 (0.90, 0.94)	
Linear/log-linear	0.92 (0.90, 0.93)		0.91 (0.88, 0.94)		0.92 (0.90, 0.94)			
All ARDS (PF ratio 300)								
Nonlinear	0.87 (0.85, 0.90)		0.87 (0.81, 0.93)		0.86 (0.82, 0.89)			
Linear/log-linear	0.80 (0.76, 0.83)		0.84 (0.77, 0.91)		0.76 (0.72, 0.81)			

AUC: Area under the receiver operating characteristic curve; ABG: Arterial blood gas; ARDS: Acute Respiratory Distress Syndrome