Published in final edited form as:
J Crit Care. 2011 October ; 26(5): 510–516. doi:10.1016/j.jcrc.2010.08.015.

Oxygen saturation/FiO2 ratio is a simple predictor of noninvasive positive pressure ventilation failure in critically ill patients

Carol Spada, RRT[1], **Rikesh Gandhi**[2], **Sanjay R. Patel, MD, MS**[3], **Paul Nuccio, MS, RRT, FAARC**[1], **Gerald L. Weinhouse, MD**[4,5], and **Po-Shun Lee, MD**[2,5,*]

[1] Respiratory Care Department, Brigham & Women's Hospital, Boston, MA.

[2] Translational Medicine Division, Brigham & Women's Hospital, Boston, MA.

[3] Division of Pulmonary, Critical Care and Sleep Medicine, University Hospitals Case Medical Center, Case Western Reserve University, Cleveland, Ohio.

[4] Pulmonary & Critical Care Division, Brigham & Women's Hospital, Boston, MA.

[5] Harvard Medical School, Boston, MA.

Abstract

Purpose—Noninvasive positive pressure ventilation (NPPV) can improve outcomes of critically ill patients. Early and simple predictors of NPPV outcome could improve clinical management of patients with respiratory failure.

Materials and Methods—A prospective observational study was conducted in a medical intensive care unit (ICU) of a tertiary medical center. Patients requiring NPPV were included and followed. Clinical data including respiratory mechanics at the time of NPPV initiation, and clinical outcomes were recorded. Data were analyzed to identify variables that distinguished NPPV success or failure.

Results—A total of 133 patients were included in the study. NPPV success rate was 41%. Patients diagnosed with malignancy had only 29% NPPV success rate. Among patients without malignancy, higher oxygen saturation, oxygen saturation/FiO_2 (SF) ratios, and SF/minute ventilation (MV) ratios were associated with NPPV success. Receiver operating curve analyses identify SF < 98.5 to be a specific (89% specificity, P=0.013) predictor of NPPV failure. Furthermore, for patients requiring at least 24hr of NPPV support, tidal volume (TV)/predicted body weight (PBW) ratio inversely correlated with respiratory improvement.

Conclusions—For patients without malignancy, SF ratios at the time of NPPV initiation discriminated NPPV success and failure, and could be used to help guide the management of critically ill patients who require ventilatory support.

[*]Corresponding Author Po-Shun Lee, MD 1 Blackfan Circle Karp Research Building, 6th Floor Brigham & Women's Hospital Boston, MA 02115 Tel# 617-355-9012 Fax# 617-355-9016 plee4@partners.org.

Keywords

Mechanical ventilation; Respiratory Insufficiency; Non-Invasive Positive-Pressure Ventilation; Clinical Markers; Hypoxemia; Critical Care

1. Introduction

Mechanical ventilation is an essential component of critical care for patients suffering from acute respiratory failure. However, several aspects of invasive mechanical ventilation can detrimentally impact clinical outcomes. Complications of invasive mechanical ventilation include ventilator-associated pneumonia (VAP), increased sedation use, and mechanical trauma of the upper airway[1-3]. Noninvasive positive pressure ventilation (NPPV) has received increasing consideration in the intensive care unit (ICU) because of these potential benefits over invasive ventilatory support. Randomized controlled studies have offered support for the use of NPPV in chronic obstructive pulmonary disease (COPD) patients[4] and in the immunocompromised hosts[5]; however the use of NPPV in a more general population of patients with acute respiratory failure is less certain with several reports having suggested that patients with hypoxemic respiratory failure are less likely to benefit from NPPV [1,6,7]. Therefore, predictors of NPPV success would be valuable in selecting patients who would more likely benefit from NPPV. Other investigators have identified P/F (PaO2/FiO2) ratio, various injury severity scores, academia, and temporal changes of physiologic variables as predictors of NPPV outcomes[8-10]; however, these parameters require invasive and/or extended periods of monitoring and observations. We conducted a prospective observational study to identify noninvasive parameters at the time of NPPV institution that can serve as predictors of NPPV outcomes in the intensive care setting.

2. Methods

Study Design

All patients with respiratory failure receiving NPPV support in the medical ICUs at the Brigham & Women's Hospital between May 2007 and March 2009 were included in the study. Routine practice in our ICU is that the respiratory therapists select the mask type or interface, and the initial NPPV settings aiming to provide adequate support. Subsequently, the therapist records respiratory mechanics, including exhaled tidal volumes, and ventilator settings from the ventilator (Vision BiPAP, Respironics, Murrysville, PA) every 4 hours. Then ventilator system was humidified by Fisher & Paykel 850 humidifier (Fisher & Paykel Healthcare, Irvine, CA) with heated wire. Initial data after NPPV initiation and stabilization (typical lasting several minutes) were used for this study. Patient demographics, vital signs, clinical data and outcomes were extracted from medical records. Clinical management of the patient was entirely made by the caring physicians without any influence by this observational study; therefore, the decisions to initiate NPPV or to intubate patients were entirely based on clinical judgments of the caring physicians. The study was approved by the Brigham & Women's Hospital Institutional Review Board, Partners Human Research Comitttee with waived informed consents because the study was strictly observational without any impact to clinical care and in compliance with the Helsinki Declaration.

Classification

Diagnosis of COPD and malignancy were determined from medical records. Immunocompromised states were defined as active immunosuppressant therapy (e.g. prednisone at > 5mg/day), diagnosis of malignancy, or positive HIV test. NPPV success was

defined as surviving ICU discharge without invasive mechanical ventilatory support. Cases not meeting these criteria were classified as NPPV failure.

Statistics

Pre-selected parameters for analysis were oxygen saturation% (O2 Sat), tidal volume in ml without and with predicted body weight in kg (PBW) correction (TV and TV/PBW), respiratory rate per minute (RR), minute ventilation in liters (MV), inspiratory and expiratory positive airway pressures in cmH2O (IPAP and EPAP). Pre-selected combination variables for analysis were O2 Sat /FiO2 ratio (SF), SF/MV ratio, RR/TV(L) ratio, and SF/EPAP ratio. For patients with multiple ICU admissions and NPPV initiations, only the initial admission was considered.

Summary data are presented as mean ± SD where appropriate. Differences between groups were compared with the Chi square test for dichotomous variables and the Student *t* test for continuous variables. Logistic regression was performed to identify factors correlating NPPV outcomes in univariate and multivariate analyses (SAS version 8.0 ,SAS Institute, Cary, NC). Receiver operating curve (ROC) characteristics were performed using Prism 4 (Graphpad Software, La Jolla, CA). $P<0.05$ was considered significant.

3. Results

Patient Characteristics

A total of 133 patients were included in the study. The general characteristics of these patients are summarized in Table 1.

Our study population spent almost half of the initial 24hr period on NPPV (average 13hr) and only 41% of our patients improved on NPPV compared to the 70% NPPV success rate reported by a large multicenter ICU study[9]. The high failure rate in our study was likely reflecting high severity of disease and the relatively high percentage of cancer patients (43%) in our medical ICU population.

The initial respiratory-related data are presented in Table 2. Our patients typically required high FiO2 support (average 0.75), resulting in an average SF ratio of 151, again reflecting a very ill patient population.

Variables associated with NPPV outcome

We then examined the relationship between NPPV success and demographic variables as well as underlying medical conditions and pre-defined initial respiratory mechanics using univariate regression analysis (Table 3).

Patients carrying the diagnosis of COPD were more likely to benefit from NPPV (71% of patients with COPD improved), consistent with published studies[11,12]. Patient without malignancy were 2.7 times more likely to improve compared to those with malignancy, with only 29% of cancer patients improving, demonstrating the poor outcomes of cancer patients in the ICU. Among the initial respiratory mechanics and NPPV setting variables, only O2 Sat and SF/MV ratio were found to be significant positive predictors of clinical improvement, while SF ratio showed a trend toward statistical significance. Other parameters, such as RR, TV, MV that have been reported to be NPPV success predictors were not significant discriminators of outcomes in our study[10].

When we re-examined each variable while controlling for COPD and malignancy status in multi-variable regression analysis, only oxygen saturation remained significant.

Patients with or without malignancy

Because our population had a relatively high percentage of cancer patients and their outcomes appears to be dramatically different from those of non-cancer patients, we performed separate analyses stratifying on malignancy status. Table 4 shows the clinical data of patients with and without malignancy. Patients with malignancy were more likely to fail NPPV than those without malignancy. Cancer patients appeared to be much sicker at the time of NPPV initiation, as reflected by higher amounts of FiO2 and EPAP support, leading to higher lower SF, SF/MV, and SF/EPAP ratios. We further examined how respiratory mechanics and NPPV setting variables may be differentially associated with clinical improvement according to malignancy status. Table 5 shows that several variables incorporating respiratory mechanics, NPPV settings and oxygen saturation, including O2 Sat, SF and SF/MV ratios, were predictive of NPPV success in those without malignancy. However, for patients with malignancy, no variables were found to be predictive of NPPV success.

Predictors of NPPV failure in non-cancer patients can be helpful in clinical decision-making and avoiding emergent intubation. We therefore performed ROC analysis on SF and SF/MV predicting non-cancer patients' chance of failure on NPPV (Figure 1). SF (AUC=0.6875, P=0.005) and SF/MV (AUC=0.6571, P=0.019) were similar with only modest predictive ability. However, a cutoff of SF <98.5 is 40% sensitive and 89% specific in predicting NPPV failure with a likelihood ratio of 3.7. A cutoff of SF/MV <6.4 is 29% sensitive and 89% specific in predicting NPPV failure with a likelihood ratio of 2.57. Thus, while not sensitive, these easily calculated variables provide a fairly specific assessment of NPPV failure in patients without cancer presenting with acute respiratory failure.

Impact of tidal volume on respiratory status

Excessive TV can be injurious to ARDS patients receiving mechanical ventilation[13], and is reported to be associated with development of ARDS in respiratory compromised patients receiving mechanical ventilation[14-16]. While the initial TV and TV/PBW ratio did not correlate with NPPV outcomes (Table 3), we reasoned that total time exposed to NPPV may also be a factor. Examining only those patients (N=30) who were on NPPV for at least 24hr, we analyzed the relationship between the average TV/PBW and the changes of SF ratio at 24hr compared to initial, as reflected by SF(24hr)/SF(Initial) ratio. Figure 2 shows that average TV/PBW negatively correlated with changes in SF ratios (Pearson R=-0.372, p=0.0429), suggesting excessive TV may be injurious to spontaneously breathing patients receiving NPPV support, leading to worsen respiratory status as reflected by decreasing SF ratios. In addition we found average TV/PBW did not correlate with average MV, RR, IPAP, EPAP, FiO_2, or O_2Sat (p-values > 0.12, $R^2 < 0.07$, Pearson's Correlation), further supporting high TV having direct detrimental effect in NPPV patients, independent of respiratory demand or oxygenation status.

4. Discussion

NPPV can be an essential component for providing respiratory support to critically ill patients. Patient selection is critical in ensuring optimal use of NPPV[6]. We found that patient co-morbidity plays a significant role in predicting NPPV success; specifically, patients with malignancy had a dramatically lower chance of improvement on NPPV reflecting generally worse outcomes of critically ill cancer patients with respiratory failure[17,18]. Further, we did not find any respiratory mechanic variables predictive of NPPV success in cancer patients, suggesting that critically ill cancer patients with respiratory failure may require much higher levels of support compared to those non-cancer patients with similar respiratory impairment. This is in contrast to a recent report by Adda et

al suggesting that high respiratory rate (RR) is an independent predictor of NPPV failure in cancer patients[19]. One possible explanation is the differences in the timing of RR measurement between the studies. In the study by Adda et al, while the RR was recorded when the patient was supported by NPPV, the exact timing is unclear. It is possible that Adda et al's RR data were derived at later time points of NPPV support, and reflected diverging respiratory mechanics observed between patients who respond or fail NPPV support[9]. Furthermore, RR was specifically used as an indicator for NPPV failure and for instituting invasive ventilation in their ICU; therefore, it is perhaps not surprising that RR would prove to be predictive in that study.

It is important to note that our data do not necessarily suggest that NPPV should be avoided in cancer patients, because it is possible that cancer patients who received NPPV support still had better outcomes compared to those supported by invasive mechanical ventilation[18]. Our data suggest that it is perhaps more difficult to predict NPPV outcomes in cancer patients. Moreover, in our study, cancer patients had lower initial SF and SF/MV ratios, suggesting that at the time of NPPV, their respiratory status were worse compared to those of non-cancer patients. Based on this observation, we suggest that cancer patients with respiratory distress may deteriorate more rapidly than other patients, leading to a relative delay of NPPV initiation. This may explain the poorer outcomes and the lack of outcome predictors in cancer patients with respiratory failure. More vigilant monitoring and earlier institution of NPPV in cancer patients with respiratory symptoms may improve clinical outcome, and merit further investigation.

For patients without malignancy and requiring NPPV support in the ICU, we found that initial parameters incorporating the degree of hypoxemia and oxygen support with or without minute ventilation normalization correlated with NPPV success or failure. In particular, oxygen saturation (from pulse oximeter) to FiO2 ratio (SF) could potentially be used to identify patients at high risk of failing NPPV support. SF has first been reported to be associated with mortality in hematopoietic stem cell transplantation (HSCT) recipients with pulmonary infiltrates[20]. Subsequent studies have validated that SF ratios correlate with PaO2/FiO2(PF) ratios [21-23]. Because delay in intubation could adversely impact outcomes [24], and SF ratio can be quickly determined noninvasively, we suggest that in patients with respiratory failure requiring NPPV support, an initial SF ratio of less than 98.5 should prompt clinicians to consider invasive ventilation sooner.

In contrast to a previous study[10], we did not find parameters reflecting initial ventilatory demands, such as TV, or MV, to be associated with NPPV outcome. Our data suggest that patients with more significant hypoxemia were more likely to fail NPPV while the degree of ventilatory requirement had no predictive value. This may suggest that NPPV provided adequate ventilatory support in our patient population. It is interesting to note that despite having very poor SF ratios, our patients only received very modest EPAP support (6±2 cm H2O). Optimizing EPAP support in NPPV management thus deserves further consideration and investigation.

Lower PBW-normalized TV is protective in mechanically ventilated ARDS patients[13], and studies have suggested that in patients with respiratory failure requiring mechanical ventilation, higher tidal volume may increase the risk of subsequent ARDS development[14-16]. However, the impact of TV in spontaneously breathing patients requiring NPPV support is uncertain. While Rana et al described higher TV significantly associated with NPPV failure, the relationship is lost when TV is normalized to PBW, suggesting ventilatory demand as the underlying reason of the relationship instead of injurious tidal volume[10]. We report here for the first time that in patients managed with NPPV for at least 24hr, TV/PBW inversely correlated with changes in SF ratios, suggesting

lower tidal volume may also be protective in patients supported by NPPV for extended amount of time. More study is required to confirm this possibility.

Our study has several limitations. First, our study had a fairly high number of cancer patients in this single institution study, and our findings may be not generalized. Second, our database lacks the specific diagnosis, such as pneumonia or ARDS, attributed to the respiratory failure. Third, we did not have information on the technical aspect of NPPV application, such as patient comfort and air leak. Fourth, this was a single institution study and results could be unduly influenced by institutional practice routines. Lastly, validation study was not performed to prospectively test proposed outcome predictors in NPPV patients. Additional studies are needed to confirm and extend our findings.

5. Conclusions

In conclusion, we propose that a simple index of oxygen saturation/FiO2 ratio (SF) at the time of NPPV initiation could be used to identify patients at high risk of NPPV failure. Avoiding delayed or emergent intubation could potentially improve outcomes of critically ill patients requiring respiratory support. Furthermore, our data suggest lower tidal volume may be protective in at risk patients who required more than 24hr of NPPV support.

Acknowledgments

We thank the tremendous respiratory therapists at the Brigham & Women's Hospital for assisting in patient identification and data gathering which made this study possible. Part of the study has been presented by Carol Spada in abstract form at the International Respiratory Congress in Anaheim, CA on December 14, 2008.

This work was supported by American Heart Association Scientist Development Grant 0735620N (PSL) and National Institute of Health HL081385 (SRP). The funding agency played no role in the study or the manuscript. The authors have no conflicts of interest to declare.

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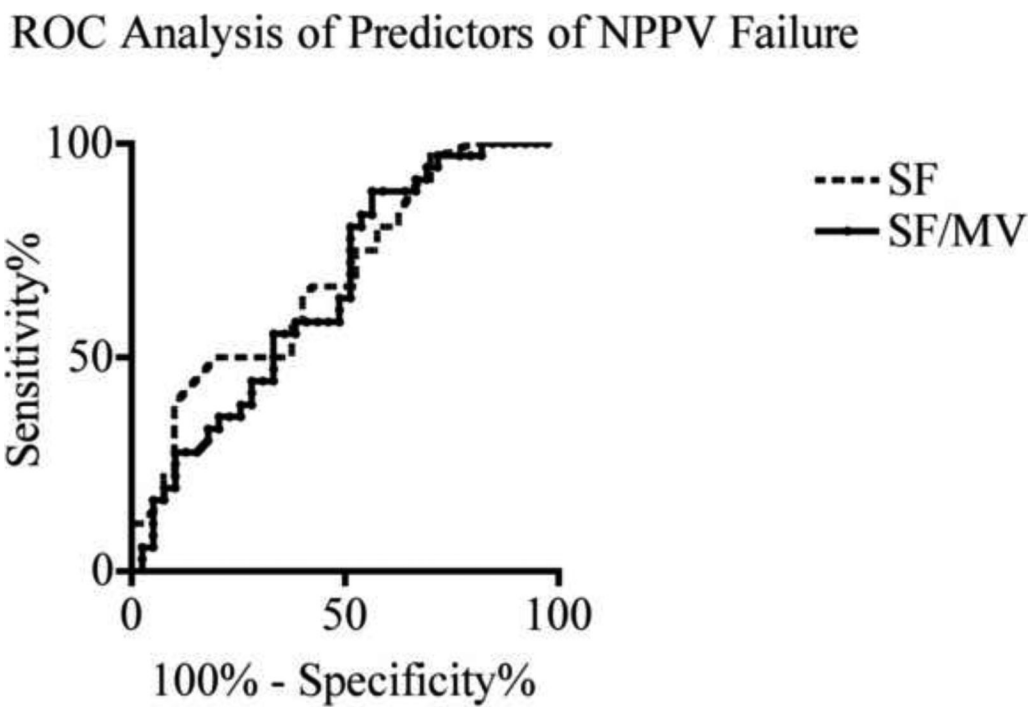

Figure 1. Receiver operating curves of SF and SF/MV in discriminating NPPV failures

SF (Oxygen saturation/FiO_2) yielded an area under the curve (AUC) of 0.6710, P=0.013, and SF/MV had an AUC of 0.6464, P=0.033. A cutoff of SF <98.5 is 40% sensitive and 89% specific in predicting NPPV failure with a likelihood ratio of 3.7. A cutoff of SF/MV <6.432 is 29% sensitive and 89% specific in predicting NPPV failure with a likelihood ratio of 2.57.

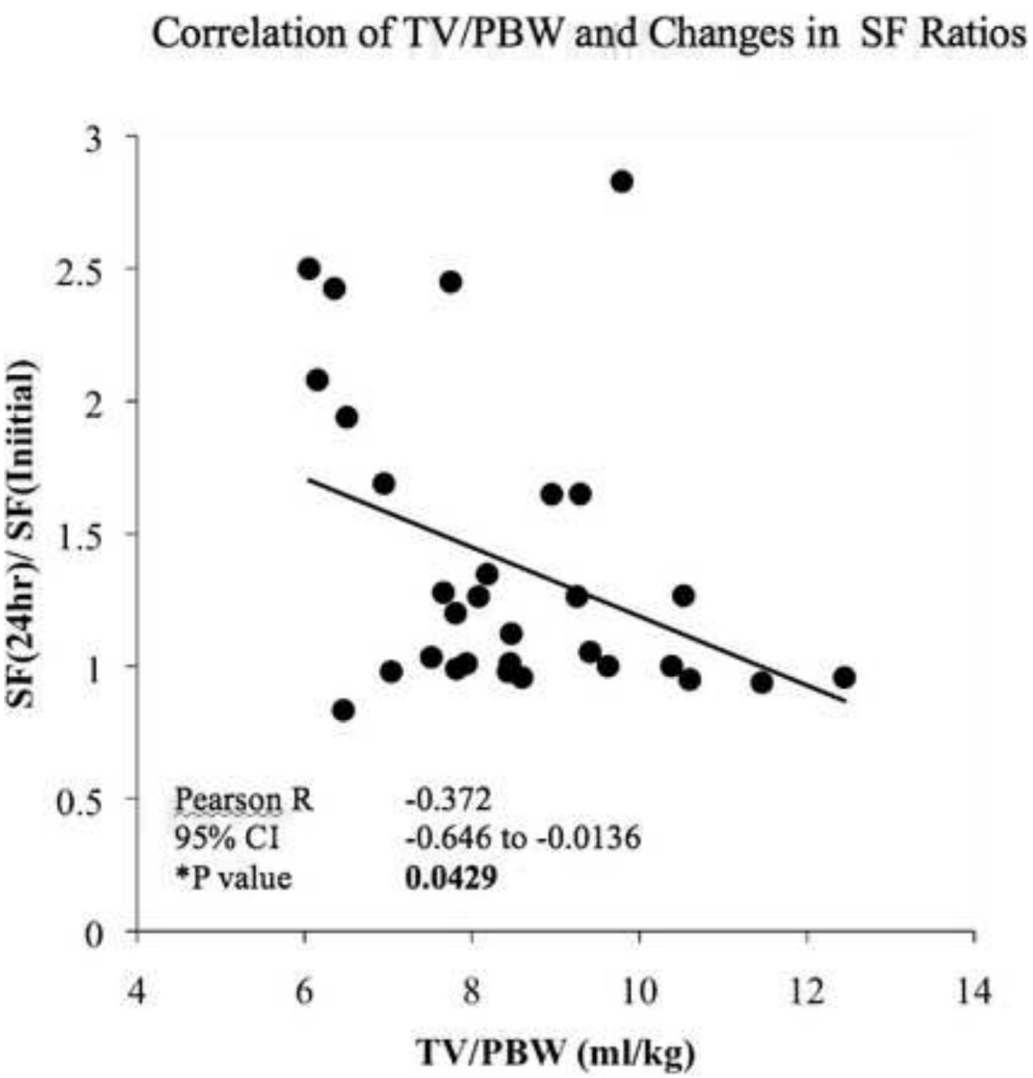

Figure 2. Correlation of TV/PBW and 24hr changes in SF ratios

In 30 patients on NPPV for at least 24hr, the average tidal volume (TV)/ predicated body weight (PBW) inversely correlated with changes of SF (Oxygen saturation/FiO_2) as reflected by SF(24hr)/SF(Initial), with a Pearson R=-0.372, p=0.0429.

Table 1

Patient Characteristics

Category	Number
Total	133
COPD	26 (20%)
Malignancy	55 (43%)
Immunocompromised	88 (68%)
Female	70 (53%)
Age (Yr)	62 ± 16
Hr on NPPV within 1st 24hr	13±8
NPPV Success	55 (41%)

Table 2

Initial respiratory data of the study population.

Variable	Mean ± Std
TV (ml)	520±181
TV/PBW (ml/kg)	8.6±2.7
MV (L)	15±9
RR (per min)	28±9
IPAP (cm H_2O)	12±3
EPAP (cm H_2O)	6±2
FiO_2	0.75±0.27
O_2Sat(%)	97±3
SF	151±69
SF/MV	13±11
RR/TV(L)	59±31
SF/EPAP	27±15

Table 3

Predictors of NPPV success.

Variable	OR	CI (95%)	P-Value
Non-COPD	**0.31**	**0.126-0.763**	**0.0108***
Non-Malignancy	**2.716**	**1.297-5.69**	**0.0081***
Non-Immunocompromised	1.93	0.911-4.087	0.0859
Female	0.889	0.445-1.774	0.7384
Age (Yr)	1.015	0.993-1.038	0.1786
TV (ml)	1	0.999-1.002	0.6134
TV/PBW (ml/kg)	1.054	0.929-1.196	0.41
MV (L)	0.987	0.945-1.031	0.5578
RR (per min)	0.972	0.933-1.013	0.1768
IPAP (cm H_2O)	0.961	0.862-1.072	0.4746
EPAP (cm H_2O)	1.012	0.856-1.196	0.886
FiO_2	0.498	0.138-1.794	0.2862
O_2Sat(%)	**1.166**	**1.028-1.322**	**0.0171***
SF	1.004	0.999-1.009	0.1444
SF/MV	**1.041**	**1.004-1.078**	**0.0291***
RR/TV(L)	0.994	0.982-1.006	0.3258
SF/EPAP	1.013	0.990-1.037	0.2659

Table 4

Comparisons between patients with or without malignancy.

	Malignancy		
Variable	**NO**	**YES**	**P-Value**
NPPV Success/Total	**39/74**	**16/55**	**0.0073***
Female/Total	41/74	25/55	0.2635
Hr on NPPV within 1st 24hr	13±8	13±8	0.9778
Age (Yr)	63±17	58±14	0.11
TV (ml)	522±178	530±184	0.8081
TV/PBW (ml/kg)	8.9±2.9	8.3±2.5	0.2669
MV (L)	14±10	16±6	0.3224
RR (per min)	26±8	29±9	0.1786
IPAP (cm H_2O)	12±3	12±3	0.7239
EPAP (cm H_2O)	**6±1**	**7±3**	**0.0126***
FiO_2	**0.70±0.28**	**0.83±0.23**	**0.0066***
O_2Sat(%)	97±3	97±3	0.8071
SF	**163±74**	**130±52**	**0.0062***
SF/MV	**16±13**	**10±7**	**0.0025***
RR/TV(L)	57±28	61±32	0.4511
SF/EPAP	**30±16**	**22±13**	**0.0031***

** Four patients with missing diagnosis information were excluded from this analysis.

Table 5

Predictors of NPPV success in patients with or without malignancy.

	No Malignancy (N=74)			Malignancy (N=55)		
Variable	**OR**	**CI (95%)**	**P-Value**	**OR**	**CI (95%)**	**P-Value**
Female	0.875	0.349-2.194	0.776	0.907	0.281-2.927	0.8708
Age (Yr)	1.009	0.982-1.036	0.5275	1.035	0.989-1.083	0.1413
TV (ml)	1.000	0.998-1.003	0.9457	1.000	0.997-1.004	0.757
TV/PBW (ml/kg)	1.046	0.891-1.229	0.5802	0.985	0.779-1.245	0.8983
MV (L)	0.992	0.949-1.037	0.7258	0.984	0.892-1.085	0.7451
RR (per min)	0.971	0.918-1.028	0.3091	0.991	0.929-1.057	0.7893
IPAP (cm H_2O)	0.945	0.0822-1.086	0.4251	0.987	0.821-1.185	0.8847
EPAP (cm H_2O)	1.000	0.729-1.372	0.9983	1.138	0.908-1.425	0.2623
FiO_2	0.206	0.039-1.099	0.0644	16.267	0.678-390.3	0.0854
O_2Sat(%)	**1.268**	**1.066-1.508**	**0.0072***	1.087	0.890-1.329	0.4136
SF	**1.007**	**1.000-1.014**	**0.0428***	0.989	0.974-1.005	0.1629
SF/MV	**1.064**	**1.009-1.121**	**0.0209***	0.951	0.853-1.060	0.3606
RR/TV(L)	0.998	0.982-1.015	0.828	0.995	0.975-1.015	0.6321
SF/EPAP	1.026	0.995-1.058	0.1035	0.958	0.904-1.016	0.1538

** Four patients with missing diagnosis information were excluded from this analysis.

J Crit Care. Author manuscript; available in PMC 2012 October 1.