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A retrospective validation of the effective and safe treatment of patients on general care wards with high velocity nasal insufflation therapy utilizing prognostic risk scores during COVID-19

Catherine Brenner, [1] Josh Good, [1] Heather Pavlichko, [2] Susan McDonald, [3] Kathy Gerich, [4] Amy Bergeski [4], Matthew S. Pavlichko [1]

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Abstract

Background
Non-invasive positive pressure ventilation (NIPPV) has been a traditional therapy for acute respiratory failure (ARF). However, the use of NIPPV during the COVID-19 pandemic was challenging, while the use of invasive mechanical ventilation produced poor outcomes. An alternative to NIPPV, high velocity nasal insufflation (HVNI) has shown promise in treating ARF effectively.
Objective
This study evaluated whether HVNI can be used to treat ARF safely on the general care ward (GCW) during COVID-19 pandemic surges.
Methods
After introducing HVNI therapy to the facility, an evidence-based scoring system, Modified Early Warning Score (MEWS), was used to risk stratify patients and assist in assigning care level. Initial settings, demographic data, patient outcomes, and health care worker (HCW) virus conversion were measured throughout the study. Treatment failure was defined as the need for invasive mechanical ventilation (IMV) or NIPPV after HVNI therapy. MEWS and ROX index were compared retrospectively using the Pearson product-moment correlation coefficient to identify trends. The Welch two sample t-test (desired power of 90% with alpha=0.05) was used for demographic and outcome analysis.
Results
Two hundred thirty-four patients were treated with HVNI. The GCW failure rate of 18.56% (n=31/167) was lower than the ICU failure rate of 37.31% (n=25/67) but not statistically significant (P 0.175). No elevated risk to patients or HCW was observed. Respiratory rate (GCW 24.85 vs. ICU 30.14; P <0.001), MEWS (GCW 2.34 vs. ICU 3.09; p=0.002), and ROX index (GCW 5.49 vs. ICU 4.68; P 0.002) assessments appear to be adequate predictors of HVNI failure. The Pearson product-moment coefficient comparing MEWS and ROX index identified a moderate negative correlation (-0.434; P <0.001).
Discussion
HVNI therapy is an effective alternative to NIPPV for treating patients with COVID-19 associated ARF. Using measures such as MEWS and/or ROX, strict patient monitoring, and HCW surveillance, HVNI can be safely utilized on the GCW. This has a direct impact when dealing with patient surges where ICU beds and resources are limited. Additional studies are needed to further delineate these concepts.

Keywords: COVID-19, Non-invasive Positive Pressure Ventilation, Acute Respiratory Failure, High Flow Nasal Oxygen, High Velocity Nasal Insufflation, ICU Admission, General Care Ward, MEWS, ROX

Authors
1. BS, RRT. Respiratory Care Services, Department of Pulmonary Medicine, Penn Medicine Lancaster General Health, Lancaster, Pennsylvania, USA
2. BSRT RRT-NPS RRT-ACCS. Respiratory Care Services, Penn E-lert eICU, Penn Center for Connected Care, Penn Medicine, Philadelphia, Pennsylvania, USA
3. MSN RN ACCNS-AG CCRN CEN. Nursing Professional Development, Department of Nursing, Penn Medicine Lancaster General Health, Lancaster, Pennsylvania, USA
4. Department of Medical Affairs, Vapotherm, Inc., Exeter, New Hampshire, USA

Corresponding author: Catherine.brenner@pennmedicine.upenn.edu

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Background

During 2019-20 there were 16,809,539 COVID-19 hospitalizations in the US. [1] The pandemic created surge situations which forced health care providers to reconsider accepted protocols and develop new, more efficient, solutions for patient care. Many hospitals have policies or protocols in place that direct all patients receiving advanced respiratory support into the ICU. The surge conditions of the COVID-19 pandemic forced reconsideration of this approach. Traditionally, non-invasive positive pressure ventilation (NIPPV) has been the most common first line treatment of acute hypoxic and hypercapnic respiratory failure (ARF). [2] Although successful in reducing the need for IMV, use of NIPPV remains challenging for patients, mainly due to mask intolerance and potential for aerosol spread. [3]

High Flow Nasal Oxygen (HFNO) therapies were later developed and have become a more comfortable and patient friendly alternative to NIPPV for many clinical situations. [4] HFNO encompasses a group of devices that deliver heated, humidified, variable mixed oxygen at high flow rates through a nasal interface. Frat, et. al, demonstrated lower mortality for patients with acute hypoxic respiratory failure treated with HFNO compared to NIPPV. [5]

High velocity nasal insufflation (HVNI) is a form of HFNO which specifically utilizes small-bore nasal cannulas to provide high levels of oxygen, at higher velocities compared to other HFNO devices, while still delivering therapy through a heated, humidified delivery interface. In a randomized controlled trial of patients with undifferentiated respiratory distress, including acutely hypercapnic patients presenting to the emergency department, HVNI was shown to be equivalent in efficacy to NIPPV. [6]

Historically, patients on HFNO and HVNI, due to high FiO_2 and flow demands, have been routinely managed in intensive care units (ICU). [5-11] This is due to availability of medical gas attachments, familiarity of clinicians and/or readily available alternative therapies if escalation is required or the patient deteriorates. But ICU admission is not without risk. ICU patients are more likely to develop health care acquired infections, morbidity, delirium, and have a greater cost to the patient and hospital. [11-16]

Hospitals and ICUs have historically been taxed during the fall and winter months due to respiratory related illnesses; however, the COVID-19 pandemic dramatically highlighted the limited capacity of the of ICU care across the country. [17] The ability to care for complex respiratory patients outside of the ICU effectively and safely is imperative in hospital resources and bed management. At least one group has documented safe delivery of HFNO therapy outside of the ICU for the treatment of hypoxia and concluded the practice to be safe following a comprehensive implementation strategy. [18]

Traditionally, the care setting for patients in respiratory distress was based on physician assessment or setting where therapy equipment was deemed safe. To measure patient acuity, assessment risk scores have become popular for clinical decision-making. Scoring tools like MEWS and ROX (Figure 1) have been employed to evaluate patients, assess severity, and monitor changes to support consistent and objective decision-making. [19-22]

Modified Early Warning Score (MEWS)

Physiologic Parameters	3	2	1	0	1	2	3
Respiratory Rate (bpm)		0-8		9-14	15-20	21-29	≥ 30
Oxygen Saturation (%)	0-84	85-89	90-94	95-100			
Temperature (°F)		< 95		95-100.4		100.5-103	≥ 103.1
Systolic Blood Pressure (mmHg)	0-69	70-80	81-100	101-149	150-169	170-179	≥ 180
Heart Rate (bpm)	0-39	40-50	51-59	60-100	101-110	111-129	≥ 130
Level of Conciousness				A	V	P	U
*Adapted from Azimi 20	A=Alert, V=Responds to Voice, P=Responds to Pain, U=Unresponsive						

ROX Index

$$\text{ROX Index} = \frac{SpO2/FiO2}{\text{Resp Rate}}$$

Related to HFNO Failure
- < 2.85 at 2 hours of Tx
- < 3.47 at 6 hours of Tx
- < 3.85 at 12 hours of Tx

Indeterminate Score
- 3.85 - 4.87

Low Risk for Intubation
- > 4.88

Figure 1: MEWS score (top), ROX index (bottom)

Objectives

Capacity challenges during the initial COVID-19 pandemic forced our hospital to explore use of HVNI therapy in general care wards (GCW) and we report our efforts to evaluate safety, efficacy, as well as the utility of simple patient risk scores to aid in clinical decision-making. This study evaluated whether HVNI can be used to treat ARF safely on the general care ward (GCW) during COVID-19 pandemic surges.

Methods

Patient Study Design and Implementation

This study occurred at a 525-bed community hospital in a suburban setting and was approved by the hospital's institutional review board (IRB). The introduction of HVNI (Precision Flow, Vapotherm, Exeter, NH, USA) to hospital clinicians began in the spring of 2020. Clinician education, training, policy, and competency was established. Initiation, weaning, and discontinuing standardization using HVNI was completed prior to the beginning of the study. The routine clinical pathway was created in which the modified early warning score (MEWS)[19,20] was used to determine if participants were suitable for a GCW admission or if they required ICU care. The protocol was written with the intention that patients were to be assigned to the GCW with MEWS $\leq$ 3. Unfortunately, the massive influx of COVID-19 patients did not always allow for this rule to be followed as bed availability was limited.

Data was collected as part of protocolized routine care from November 17, 2020, until January 31, 2021. The data was then extracted and analyzed in a retrospective fashion. Three hundred and two patients were assessed for eligibility; 68 were excluded due to missing data, HVNI to facilitate extubation (not an intended endpoint), LOS < 12 hours, and/or placement on hospice. A total of 234 patient records were analyzed; HVNI therapy was initiated with 167 patients on the GCW and 67 in ICU. The patient data sets were analyzed according to MEWS scores $\leq$ 3 or > 3 in both care areas. (Figure 2)

HVNI therapy failures were defined as those patients that required NIPPV and/or intubation with mechanical ventilation. As stated above, it was vital to separate HVNI failures from overall patient outcomes as they are multifactorial. Do not resuscitate, comfort care, and hospice may have been an unrelated medical decision that was not indicative of HVNI failure, thus excluded from the study analysis.

At the conclusion of the study period, the following data was extracted from the medical record: Patient demographics, vital signs, hospital length of stay (LOS), ICU admission, ventilator need and duration, and disposition. HVNI and patient parameters are provided in (Table 1-5) and compare the bed setting at initiation of therapy. Analysis was conducted using a Welch two sample t-test, using a desired power of 90% with alpha=0.05.

Post hoc analysis also included individual calculation of the ROX index. [21] Recently, the ROX index has been used to identify HFNO failure in the treatment of hypoxic respiratory failure specifically to high flow nasal cannula. The usefulness of the ROX index with HVNI therapy has only been evaluated in two previous small-scale studies. [22-23] Using the same inclusion/exclusion process as described above, the ROX index of $\leq$ 4.88 and > 4.88 (as described by Roca and colleagues as the failure cutoff) was evaluated to compare predictive values to the MEWS score and HVNI failure rates. A Pearson product-moment correlation coefficient was also computed to assess the relationship between the ROX index and the MEWS score when used as triage tools. All data analysis was carried out in the R environment for statistical computing and visualization; R version 4.3.3 (2024-03-01). [24]

Healthcare Worker Considerations

The health and safety of the healthcare providers was also considered. Ensuring the lowest possible spread of infectious aerosol particles was vital to the feasibility of this study. Based on work by Leonard, et. al., to limit aerosol production and to help ensure the safety of clinicians and other patients, [25] the placement of a surgical mask overlying the HVNI nasal cannula was included in the policy. Healthcare worker COVID-19 transmission prevention (recommended personal protective equipment including N-95 masks) and surveillance (including routine temperature checks) was a global hospital strategy and was used to monitor respiratory therapist symptom and positivity rates.

Results

While the MEWS score was intended to be the predominant determining factor of care level, the massive influx of COVID-19 respiratory failure patients and subsequent lack of ICU beds during the study period made the MEWS score a guideline rather than the rule of admission setting (21/167 patients off protocol, 87.43% compliant). There were no significant differences in age, race, or gender distribution amongst the study groups, although it is noteworthy that the population was only 14% non-white and 60% male, which is reflective of the population of the region.

Respiratory rate between those that were assigned to the GCW and ICU were significantly different (25.68 vs. 30.82, p <0.001). MEWS and ROX scores

comparative to setting were statistically significant (P 0.002), both of which were influenced most by the respiratory rate assessment. SpO_2, blood pressure, heart rate, temperature, and patient responsiveness were not statistically different between the GCW group and the ICU group. Starting therapy flow was higher in the ICU group (31.65 lpm GCW vs. 34.78 lpm ICU, P 0.003), but FiO_2 was similar between groups (GCW 77% and ICU 80%, P 0.305). Length of stay was also longer in the ICU group as expected (12.55 days vs. 16.22 days, P <0.05) (Table 5.1).

Of the 234 patients treated with HVNI therapy, 54 (23.07%) progressed to requiring mechanical ventilation. Only two patients crossed over to NIPPV (0.85%) (Figure 3). Those that were treated on the GCW, 31/167 (18.56%) failed HVNI compared to 25/67 (37.31%) in ICU (P 0.175). (Table 6.1).

Duration of HVNI therapy was statistically similar in both groups (137.55 vs. 117.44 hours, P 0.187). (Table 4.1).

Post hoc analysis compared MEWS and ROX in correlation with HVNI failure, with neither predicting failure. Pearson's product-moment correlation showed a moderate negative correlation of - 0.434 (P <0.001) between the ROX and MEWS scores indicating that as one went up the other went down, with statistical significance (Table 3.1). This is an expected finding as the two scoring systems are inversely scaled for severity. The study guidelines, personal protective equipment use, and hospital surveillance practices appear to have been effective. There were no confirmed or suspected cases of COVID-19, based on local hospital definition, acquired by respiratory therapists during the study period.

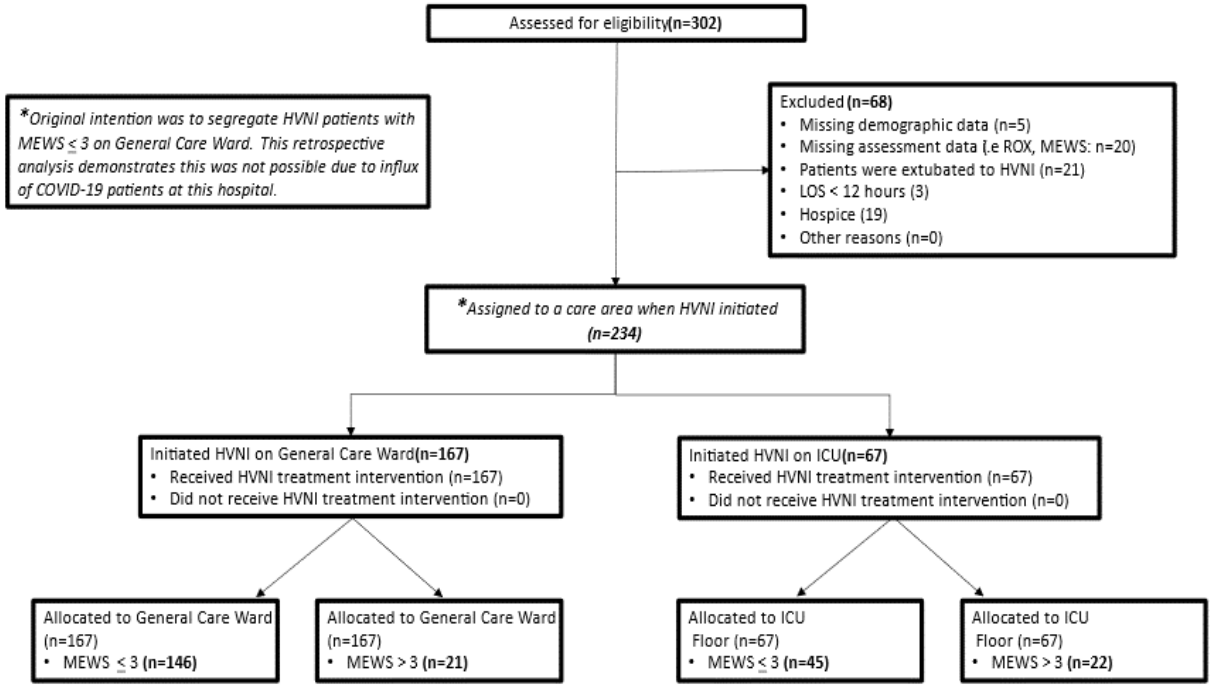

Figure 2. CONSORT Diagram

Table 1.0. Demographics, All Patients

		N= 234
Age	Mean/(SD)	70.83/(14.26)
	Median	73
	Range (min, max)	27, 98
Gender	Male (%)	60.68%
	Female (%)	39.32%
Race	European/Caucasian	86.32%
	Non-Caucasian	13.68%

Table 1.1. Demographic Data, Assigned Bed Setting

		GCW (N=167)	ICU (N=67)	P Value
Age	Mean/(SD)	71.63/(13.58)	68.84/(15.78)	0.10
	Median	74	71	
	Range (min, max)	33,96	27, 98	
Gender	Male (%)	58.68%	65.67%	0.572
	Female (%)	41.32%	34.33%	
Race	European/Caucasian	86.83%	85.07%	0.254
	Non-Caucasian	13.17%	14.93%	

Table 2.0. Vital Sign Data, All Patients

		N= 234
SpO_2	Mean/(SD)	93.56/(3.59)
	Median	94
	Range (min, max)	74,100
Respiratory Rate	Mean/(SD)	27.15/(8.37)
	MEWS Mean	2.06
	Median	25
	Range (min, max)	12,67
Systolic Blood Pressure	Mean/(SD)	131.91/(20.79)
	MEWS Mean	0.08
	Median	131
	Range (min, max)	86,222
Heart Rate	Mean/(SD)	85.27/(17.39)
	MEWS Mean	0.29
	Median	83.5
	Range (min, max)	48,147
Temperature	Mean	98.58/(1.38)
	MEWS Mean	0.9
	Median	98.4
	Range (min, max)	89, 103
¥AVPU - Patient Responsiveness	Alert (0) - N (%)	219(93.56%)
	Verbal Stimulus (1) - N (%)	7(2.99%)
	Pain Stimulus (2) - N (%)	5(2.14%)
	Unresponsive (3) - N (%)	3(1.28%)

Table 2.2. Vital Sign Data, Assigned Bed Setting

		GCW (N=167)	ICU (N=67)	P Value
SpO2	Mean/(SD)	93.79/(3.08)	93/(4.60)	0.143
	Median	94	90	
	Range (min, max)	84,100	74,100	
Respiratory Rate	Mean/(SD)	24.85(7.48)	30.14/(9.33)	<0.001
	MEWS Mean	1.94	2.37	
	Median	24	30	
	Range (min, max)	13,67	12,64	
Systolic Blood Pressure	Mean/(SD)	132.24/(20.37)	131.1/(21.92)	0.779
	MEWS Mean	0.07	0.1	
	Median	132	130	
	Range (min, max)	88,222	86, 210	
Heart Rate	Mean/(SD)	84.3/(16.87)	87.8/(18.52)	0.293
	MEWS Mean	0.26	0.37	
	Median	82	84	
	Range (min, max)	48,147	58, 131	
Temperature	Mean	98.69/(1.24)	98.31/(1.64)	0.506
	MEWS Mean	0.08	0.09	
	Median	98.4	98.5	
	Range (min, max)	96,102.90	89, 103	
¥AVPU - Patient Responsiveness	Alert (0) - N (%)	160(95.8%)	59(88.06%)	0.572
	Verbal Stimulus (1) - N (%)	3(1.8%)	4(5.97%)	
	Pain Stimulus (2) - N (%)	3(1.8%)	2(2.99%)	
	Unresponsive (3) - N (%)	1(0.6%)	2(2.99%)	

Table 3.0. Scoring Values, All Patients

		N= 234
MEWS	Mean/(SD)	2.55/(1.34)
	Median	2
	Range (min, max)	0,8
ROX	Mean/(SD)	5.25/(2.55)
	Median	4.76
	Range (min, max)	1.54,25.38

Table 3.1. Scoring Values, Assigned Bed Setting

		GCW (N=167)	ICU (N=67)	P Value
MEWS	Mean/(SD)	2.34/(1.14)	3.09/(1.62)	0.002
	Median	2	3	
	Range (min, max)	0,8	0, 8	
ROX	Mean/(SD)	5.49/(2.51)	4.68/(2.54)	0.002
	Median	5.06	3.77	
	Range (min, max)	1.96,25.38	1.54, 12.22	
Pearson's	***Correlation***	***-0.434***		
	P Value	***<0.001***		

Table 4.0. Therapy Settings, All Patients

		N= 234
Starting Flow	Mean/(SD)	32.54/(5.64)
	Median	30
	Range (min, max)	20,40
Starting FiO2	Mean/(SD)	77.5/(19.29)
	Median	80
	Range (min, max)	30,100
HVNI Duration (Hours)	Mean/(SD)	131.80/(112.74)
	Median	110.42
	Range (min, max)	0.45,706.17

Table 4.1. Therapy Settings, Assigned Bed Setting

		GCW (N=167)	ICU (N=67)	P Value
Starting Flow	Mean/(SD)	31.65/(5.55)	34.78/(5.26)	0.003
	Median	30	35	
	Range (min, max)	20,40	20, 40	
Starting FiO2	Mean/(SD)	76.68(18.45)	79.55/(21.22)	0.305
	Median	80	80	
	Range (min, max)	30,100	30, 100	
HVNI Duration (Hours)	Mean/(SD)	137.55/(110.61)	117.44/(117.48)	0.187
	Median	116.83	68.75	
	Range (min, max)	1, 706.17	0.45, 479.0	

Table 5.0. Hospital Length of Stay, All Patients

		N= 234
Total LOS	Mean/(SD)	13.60/(11.87)
	Median	10.46
	Range (min, max)	0.65, 105.86

Table 5.1. Hospital Length of Stay, Assigned Bed Setting

		GCW (N=167)	ICU (N=67)
Total LOS	Mean/(SD)	12.55/(9.77)	16.22/(15.72)
	Median	9.87	12.71
	Range (min, max)	0.65 , 64.08	1.28,105.86

Table 6.0. Therapy Failure Rate, All Patients

		N=234
HVNI Failure	N (%)	56 (23.93%)

Table 6.1. Therapy Failure Rate, Assigned Bed Status

		GCW (N=167)	ICU (N=67)	P Value
HVNI Failure	N (%)	31 (18.56%)	25 (37.31%)	0.175
	MEWS $\leq$ 3	29 (19.9%)	14 (31.1%)	0.180
	MEWS > 3	2 (9.5%)*	9 (40.9%)	0.068

Tables Descriptions: SpO_2: oxygen saturation via pulse oximetry; FiO_2: fraction of inspired oxygen; LOS: length of stay. ¥AVPU assessments are based on level of responsiveness. Data is reported as number (%) or median or mean (SD) and range (min, max) for each category. Statistical significance ($p < 0.05$) was determined when comparing patients assigned to GCW and ICU. Pearson correlation based on negative/positive correlation and p-value to compare power of correlation. *21/167 (12.57%) of patients assigned to GCW had MEWS > 3, which was outside of protocol design.

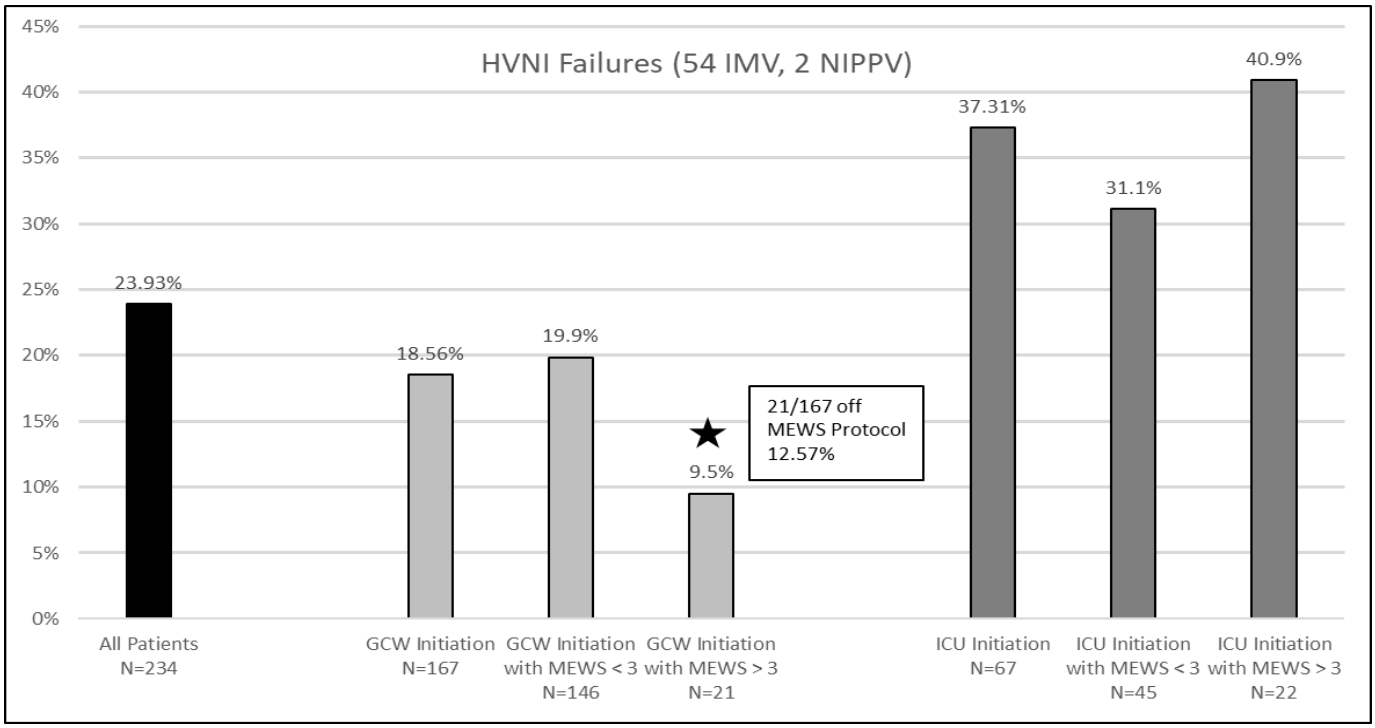

Figure 3. Therapy failures, Assigned Bed Status/MEWS Score. *21/167 (12.57%) of patients assigned to GCW had MEWS > 3, which was outside of protocol design. Yet only two of 21 (9.5%) patients in this category failed therapy.

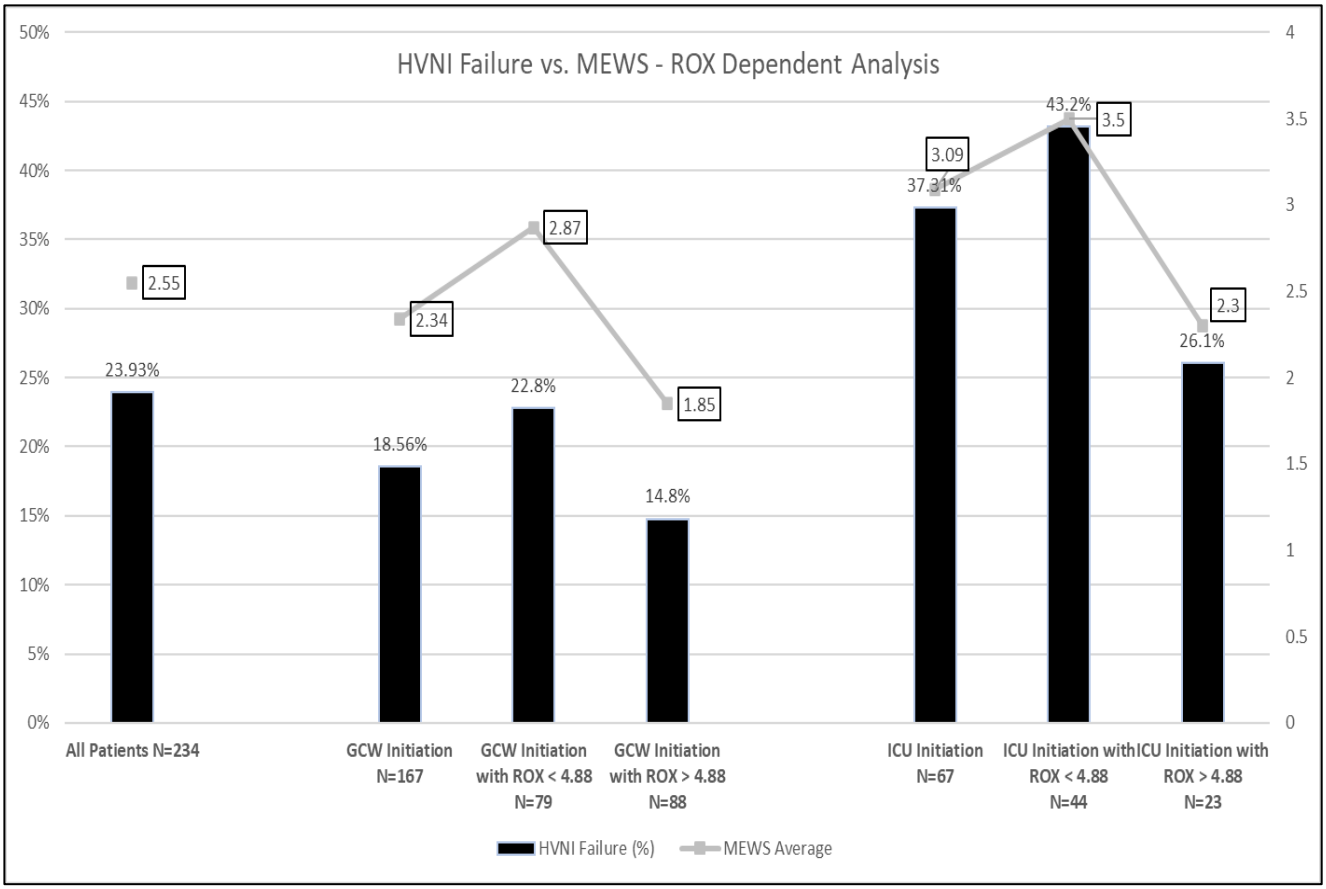

Figure 4. ROX dependent analysis comparing failure vs. MEWS.
Bars = percentage of patient failures with ROX scores < or > 4.88 in patients based on assigned bed status. Lines = Corresponding MEWS score in each category.

Discussion

Although few randomized control trials exist, the influx of retrospective clinical literature on the use of HFNO, in any form, to treat hypoxemic respiratory failure solidified the therapy as a vital tool in the care of the patient with COVID-19. It has been reported in the literature that once HFNO may improve patient outcomes including improved LOS, ventilator free days, and ICU mitigation. [26-28] Benefits should be balanced against the risk of delaying intubation and known poorer outcomes. A validated scoring system would potentially be useful to clinicians as they consider these risks and benefits. One group reported that the systematic use of ROX during the COVID-19 pandemic was a useful tool in avoiding delayed intubation and identifying opportunities to wean HFNO. [29]

During the study, our group intended to cohort patients by MEWS score. However, the overwhelming influx of patients with COVID-19 did not allow us to proceed as planned. Neither MEWS nor ROX predicted HVNI failure in this patient population. Pearson product-moment correlation analysis showed a significant negative correlation between MEWS and ROX of -0.434 P <0.001). Respiratory rate (RR) is the only shared variable between MEWS and ROX suggesting it may be the most important vital sign to assess. Further study might be warranted to measure RR and WOB as the most significant feature of COVID-19 respiratory outcomes. Although these scoring systems have been evaluated with other non-invasive respiratory support technologies, [21-23] this is the first retrospective analysis of a large data set that correlates the MEWS and ROX index with HVNI specifically.

More patients were managed on the GCW than in the ICU, including some with unexpectedly high acuity scores. The failure rate of patients treated on the GCW remained lower than patients in the ICU. Placing safety measures and routine assessments allowed for higher acuity patients to be managed on the GCW. This allowed for the sickest patients to be managed in ICU. When resource management was

imperative (i.e., equipment and labor availability) these practice changes allowed for safe and effective care. This data did not identify any unexpected increased risk to patients being treated with HVNI in general care areas suggesting that polices restricting HVNI therapy on the basis of the therapy alone to ICU environment may be too restrictive. Continued prospective studies are warranted to validate these findings.

The limitations of this study are those of most observational, retrospective cohorts. Treatment failure was difficult to describe retrospectively due to the multifactorial nature of patient care. Many patients in the study group were of advanced age with co-morbid conditions, thus making mortality/morbidity determinations based on therapy impossible to assess. This study population is disproportionally represented by white males, which may limit generalizability. Although, this study and previous studies confirm that HVNI has proven to be a safe and effective therapy for the treatment of patients with respiratory distress due to COVID-19, [26-27] more prospective research is needed.

It is important to note that extensive collaboration with respiratory therapists, nurses, and physicians is vital for the successful use of HVNI outside the ICU. The focused and intentional collaboration, using sound quality improvement/assurance principles, allowed for a change in practice that can translate post COVID-19. As healthcare evolves, managing patients at the lowest level of care while ensuring the highest quality allows for greatest resource management at the lowest cost.

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