Comparison of Maximal Inspiratory Pressure, Tracheal Airway Occlusion Pressure, and Its Ratio in the Prediction of Weaning Outcome: Impact of the Use of a Digital Vacuometer and the Unidirectional Valve

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OBJECTIVE: To investigate the predictive value of the maximal inspiratory pressure obtained by a digital vacuometer using a unidirectional valve (P_{ImaxUV}) as to weaning outcome, and to compare its performance with the respiratory drive using airway occlusion pressure at 0.1 second ($P_{0.1}$), and $P_{0.1}/P_{ImaxUV}$. METHODS: Patients on mechanical ventilation for > 24 hours who fulfilled the weaning criteria were prospectively enrolled. Measurements of P_{ImaxUV} and $P_{0.1}$ were accomplished with a digital vacuometer with a unidirectional valve that allows only exhalation. Measured values were electronically recorded and stored on the digital vacuometer measurement device. Cutoff points for the used parameters were: absolute values of P_{ImaxUV} > 30 cm H_2O, $P_{0.1}$ < 2.3 cm H_2O, and $P_{0.1}/P_{ImaxUV}$ < 0.10. Receiver operating characteristic curves were calculated to compare the predictive values of the indexes. RESULTS: One hundred three subjects completed the test. The areas under the receiver operating characteristic curve were 0.79 ± 0.04, 0.65 ± 0.05, and 0.74 ± 0.04 for P_{ImaxUV}, $P_{0.1}$, and $P_{0.1}/P_{ImaxUV}$, respectively. The area under the receiver operating characteristic curve for P_{ImaxUV} was higher than for $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$, but statistical significance was only found against $P_{0.1}$ (P = .007). CONCLUSIONS: Every studied index had only a modest performance regarding prediction of weaning outcome. Of note, P_{ImaxUV} values obtained by digital technology using a unidirectional valve performed better than historically reported using a conventional techniques, surpassing $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$ in this regard. *Key words: mechanical ventilation; weaning; maximal inspiratory pressure; respiratory drive; ICU; roc curves.* [Respir Care 2012; 57(8):1285–1290. © 2012 Daedalus Enterprises]

Introduction

Maximal inspiratory pressure (P_{Imax}) can be defined as the maximum pressure generated during inspiration against an occluded airway. Measurement of P_{Imax} has been used in the clinical setting to globally assess the inspiratory muscle strength for a long time.[1,2] Although some ventilator-dependent patients may display poor cooperation when executing voluntary maneuvers, high absolute values of P_{Imax} have been associated with successful weaning in some studies.[3,4]

The P_{Imax} performance has been reported in general as having low predictive value to assess the weaning success. In this setting, low performance does not seem to be an exclusivity of P_{Imax}, considering that most of studied in-

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The authors have disclosed no conflicts of interest.

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DOI: 10.4187/respcare.01489

dexes have demonstrated not more than modest accuracy to predict the weaning outcome.[2,5-8]

Marini and co-workers suggested an approach for standardization of the operational procedure to measure P_{Imax} in such setting. They used a unidirectional valve to permit exhalation while inhalation was blocked, thereby allowing patients to perform the maximal inspiratory effort at a lung volume approaching residual volume.[9] P_{Imax} values using a unidirectional valve (P_{ImaxUV}) are expected to be maximal.

However, even using such a standardized approach, the reproducibility of P_{Imax} values in ventilator-dependent patients has been reported to be poor.[6,10-12] A clear disadvantage of this approach, which employs an analogic vacuometer, is the direct visual inspection and the manual computation of the P_{ImaxUV} values, which lacks accuracy due to the inherent investigator dependence.[10-12]

Despite such limitations, some parameters have been found to be useful as to prediction of weaning outcome.[2,5,7,8,13] Of special interest for the present study, low absolute values of both airway-occlusion pressure 0.1 s after the start of inspiratory flow ($P_{0.1}$)[14,15] and $P_{0.1}/P_{ImaxUV}$ have been associated with successful weaning.[8]

In view of that, we resort to an approach in which the acquisition of P_{Imax} and $P_{0.1}$ measurements are obtained with a digital device that automatically records consecutive inspiratory muscle activity. Our main objective was to investigate the value of the P_{ImaxUV} obtained with a digital vacuometer as a weaning outcome predictor, and to compare its performance with $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$ in this regard.

QUICK LOOK

Current knowledge

Maximal inspiratory pressure (P_{Imax}) is defined as the maximum pressure generated during inspiration against an occluded airway. Measurement of P_{Imax} is clinically used to globally assess inspiratory muscle strength and predict the success/failure of discontinuation of mechanical ventilation.

What this paper contributes to our knowledge

P_{Imax} values obtained by digital technology with unidirectional valve performed better than historically reported values using a conventional technique without a unidirectional valve.

Methods

Patients who were clinically stable and ready to undergo a weaning trial by their primary physicians were enrolled in this prospective observational study. Patients were selected from 2 critical care units in Niterói, Rio de Janeiro, Brazil. The study was approved by the ethics committee of human research of Universidade Federal Fluminense under the number 259/09. An informed consent was obtained from each subject, whenever possible, or from the subject's next of kin.

To be included, subjects had to be older than 18 years and on mechanical ventilation for at least 24 hours. Patients were accepted for enrollment if they met the guidelines of the American Thoracic Society/European Respiratory Society (2007) to start weaning trials,[13] in which the inclusion criteria are: resolution of disease acute phase for which the patient was intubated, adequate cough or absence of excessive tracheobronchial secretion, stable cardiovascular status (heart rate $\leq$ 140 beats/min, systolic blood pressure 90–160 mm Hg, no or minimal vasopressors), stable metabolic status, adequate oxygenation (S_{aO_2} $> 90\%$ on $F_{IO_2} \leq 0.4$ or $P_{aO_2}/F_{IO_2} > 150$ mm Hg) with PEEP $\leq$ 8 cm H_2O, adequate pulmonary function (respiratory rate [f] $\leq$ 35 breaths/min or $f/V_T < 105$ breaths/min/L), no substantial respiratory acidosis (pH > 7.30), adequate mentation or Glasgow coma score > 10 (only for subjects with endotracheal tube).

Exclusion criteria were as follow: tracheal stenosis, intracranial pressure > 20 mm Hg, sedation, post-abdominal surgery with evisceration risk, overt cardiac failure or hemodynamic instability, and signs of infection during weaning process. The ventilators used were the 840 (Nellcor/Covidien, Boulder, Colorado) and Servo S (Maquet, Rastatt, Germany).

Procedures

Before spontaneous breathing trials with a T-piece for 30 min with an F_{IO_2} of 0.40, measurements were performed for a 20-second period. Three parameters were analyzed: P_{ImaxUV}, $P_{0.1}$, and $P_{0.1}/P_{ImaxUV}$. P_{Imax} and $P_{0.1}$ were obtained using a unidirectional valve method and a digital vacuometer (MVD 300, Globalmed, Porto Alegre, Rio Grande do Sul, Brazil). The device has a scale of 300 cm H_2O with a 1 cm H_2O interval, and was designed to perform measurements at each 0.1 s. Prior to testing, all subjects were on pressure support ventilation mode (12–20 cm H_2O) and were not on sedatives. The head of the subject's bed was elevated to 45 degrees and the cuff of the artificial airway was hyperinflated to prevent air leakage during measurement.[12] The subject had the airway cleared of secretions by suctioning with standard tracheal suction procedures after pre-oxygenation for 2 minutes with F_{IO_2} of 1.0. After a brief rest period, pre-oxygenation was repeated. The subject was then disconnected from mechanical ventilation and allowed to breathe spontaneously for 10 seconds before connecting the artificial air-

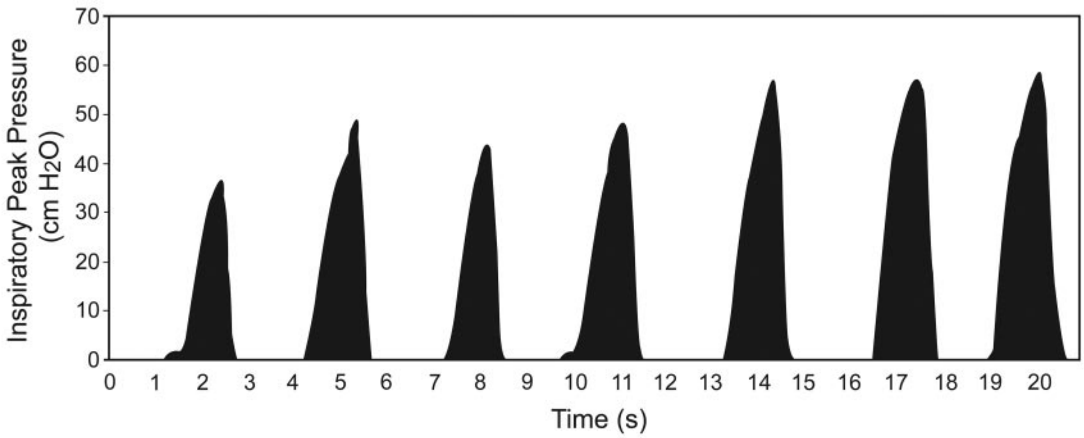

Fig. 1. Typical register showing that the maximal inspiratory peak pressure (59 cm H_2O), along approximately 21 seconds of observation, was achieved at approximately 20 seconds.

way to the digital vacuometer when the subject was at functional residual capacity.[12,16] The subject was continuously monitored by pulse oximetry and electrocardiogram, and had continual respiratory physiotherapist attention. Measurements were digitally recorded, allowing easy access to values of parameters whenever needed. Figure 1 shows a typical plot of inspiratory pressure against time obtained during a test. For the present study, respiratory drive ($P_{0.1}$) was calculated as an average of the measured inspiratory pressure 0.1 s after the initiation of the inspiration for the first 3 cycles, and $P_{0.1}/P_{ImaxUV}$ as the ratio of absolute values of $P_{0.1}$ and P_{ImaxUV}. The subjects were not coached for the maneuver. Thresholds for the 3 parameters were calculated from their respective receiver operating characteristic (ROC) curves. Weaning was considered successful if spontaneous breathing was sustained for > 48 hours after withdrawal from mechanical ventilation. The decision to return to mechanical ventilation was made by the respiratory physiotherapist and physician in charge (who was blinded to the results of the indexes evaluated), based on the clinical and laboratory signs of poor tolerance, as mentioned below.

The trial was stopped if at least one of the following intolerance criteria was present: $S_{aO_2} < 90\%$ or $P_{aO_2} < 60$ mm Hg with $F_{IO_2} > 0.4$; $P_{aCO_2} > 50$ mm Hg or increased by 8 mm Hg or more; arterial pH < 7.33 or decreased by 0.07 or more; respiratory rate > 35 breaths/min or increased by 50% for 5 min or longer; heart rate >140 beats/min or a sustained increase or decrease in $> 20\%$; mean blood pressure > 130 mm Hg or < 70 mm Hg; or presence of agitation, diaphoresis, disorientation, or depressed mental status.

The subjects who demonstrated one of these signs during the spontaneous breathing trial or within 48 hours after the discontinuation from mechanical ventilation were considered not weaned and were returned to ventilatory support.[13]

Statistical Analysis

The performance of the indexes to predict weaning outcome was evaluated by sensitivity, specificity, positive predictive value, negative predictive value, likelihood ratio of positive test, likelihood ratio of negative test, and diagnostic accuracy. The predictive performance of each index was also evaluated through the calculation of the area under the ROC curve (Fig. 2). The area under the curve (AUC) was compared using the Hanley and McNeil method.[17] *P* values $< .05$ were considered significant. Statistical analysis was performed employing statistics software (SPSS 18.0, SPSS, Chicago, Illinois). Comparison between ROC curves was accomplished using statistics software (MedCalc 11.4.2.0, Mariakerke, Oost-Vlaanderen, Belgium).

Results

From 128 initially screened subjects, 103 were selected for the study. Reasons for exclusion were: Glasgow coma score < 10 ($n = 4$, in subjects on orotracheal tube), reinfection ($n = 6$), hypoxemia and bradycardia during the test ($n = 3$), tracheomalacia ($n = 5$, in subjects with tracheostomy), laryngospasm ($n = 2$, in subjects on orotracheal tube), and informed consent not obtainable ($n = 5$). General features of the 103 subjects evaluated are summarized in Table 1. Forty-two (40.8%) subjects had an endotracheal tube and 61 (59,2%) tracheotomy, with internal diameters varied from 7.5 mm to 8.5 mm. The averages of respiratory drive $P_{0.1}$, P_{ImaxUV}, and $P_{0.1}/P_{ImaxUV}$ in the 103 subjects were 2.98 ± 1.02 cm H_2O, 32.01 ± 18.15 cm H_2O, and 0.11 ± 0.05 cm H_2O, respectively. From the 103

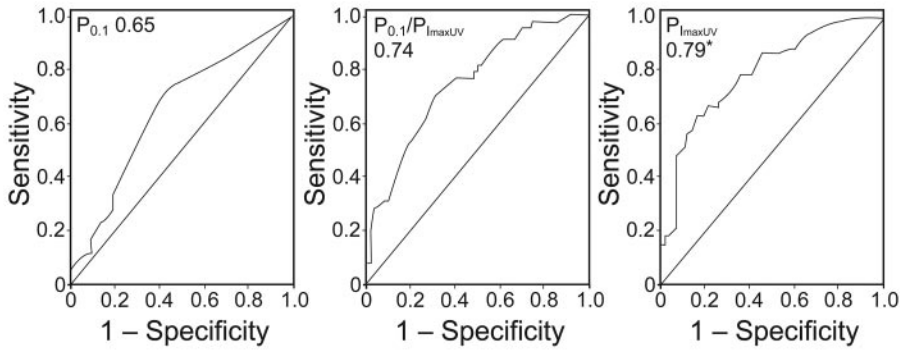

Fig. 2. Receiver operating characteristic curves for airway occlusion pressure at 0.1 second ($P_{0.1}$), maximal inspiratory pressure obtained by a digital vacuometer using a unidirectional valve along 20 seconds of airway occlusion (P_{ImaxUV}), and $P_{0.1}/P_{ImaxUV}$ as predictors of successful weaning. * $P = .007$ versus $P_{0.1}$

Table 1. General Features of Studied Patients

Male/female	58/45
Black/white	68/35
Age, mean ± SD y	60.8 ± 19.8
Mechanical ventilation, mean ± SD d	17.5 ± 17.3
APACHE II score, mean ± SD	17.9 ± 5.7
Conditions Precipitating ICU Admission, no. (%)	
Brain trauma/stroke	43 (41.7)
Sepsis	23 (22.3)
COPD/heart failure	17 (16.5)
Acute myopathy	12 (11.7)
Abdominal surgery	4 (3.9)
Miscellaneous conditions	4 (3.9)

Table 2. Quality Indicators of the Indexes Used to Predict the Weaning Outcome

Index	Cutoff	Sensitivity	Specificity	PPV	NPV	LR+	LR−	DA
P_{Imax}	30	0.63	0.84	0.84	0.62	3.89	0.44	0.72
$P_{0.1}$	2.33	0.73	0.56	0.70	0.60	1.66	0.48	0.66
$P_{0.1}/P_{Imax}$	0.10	0.68	0.70	0.76	0.61	2.26	0.45	0.69

P_{Imax} = maximal inspiratory pressure in 20 s
$P_{0.1}$ = airway occlusion pressure at 0.1 second
PPV = positive predictive value
NPV = negative predictive value
LR+ = likelihood ratio of positive test
LR− = likelihood ratio of negative test
DA = diagnostic accuracy

studied subjects, 60 subjects were weaned. General features are summarized in Table 1.

Quality indicators of the 3 indexes used to predict the weaning outcome are in Table 2. Cutoff values (calculated from the ROC curves) for P_{ImaxUV}, $P_{0.1}$, and $P_{0.1}/P_{ImaxUV}$ were 30 cm H_2O, 2.33 cm H_2O, and 0.10, respectively. P_{ImaxUV} showed the best diagnostic accuracy, with 0.72, followed by $P_{0.1}/P_{ImaxUV}$, with 0.69, and $P_{0.1}$, with 0.66.

The AUC of the 3 indexes are in Figure 2. The largest AUC was found for P_{ImaxUV}, but statistical significance was only found toward $P_{0.1}$ (0.797 ± 0.044 vs 0.650 ± 0.056, $P = .007$). The P values for comparisons between P_{ImaxUV} and $P_{0.1}/P_{ImaxUV}$, and between $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$ were 0.16, and 0.18, respectively.

Discussion

Values of P_{Imax} have been suggested as useful to predict successful weaning, but its performance varies substantially among studies.[2-8] Despite such discrepancy, P_{Imax} remains a helpful parameter in the decision for weaning.[13] In our study, we reevaluated the predictive performance of P_{ImaxUV} in comparison to $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$ in a new setting: measurements were performed using a digital vacuometer and a unidirectional valve. The employment of digital technology that automatically records the test results allowed us to prevent the observer from influencing the data collection, to revisit the data whenever needed, and to collect P_{ImaxUV} and $P_{0.1}$ values at one step. The use of such technology was found to be very simple with the potential of being easily incorporated in daily ICU clinical practice.

From the ROC curves, calculated cutoff values for P_{ImaxUV}, $P_{0.1}$, and $P_{0.1}/P_{ImaxUV}$ were 30 cm H_2O, 2.3 cm H_2O, and 0.10, respectively. It is interesting to mention that the cutoff value found for P_{ImaxUV} matches the value cited in most relevant studies.[3,4,5] The same did not happen regarding $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$, whose calculated cutoff values were lower than traditional ones.[7,8,14-16,18-20]

When comparing performance of the 3 studied indexes regarding prediction of successful weaning, a higher sensitivity was found for $P_{0.1}$ (73% vs 63% and 68% for P_{ImaxUV} and $P_{0.1}/P_{ImaxUV}$, respectively). However, the best accuracy was found for P_{ImaxUV} (72% vs 66%, and 69% for $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$, respectively) reflecting the low specificity of $P_{0.1}$ (56% vs 84% and 70% for P_{ImaxUV} and $P_{0.1}/P_{ImaxUV}$, respectively). It should be pointed out that the low specificity of $P_{0.1}$ in the present study can be partially accounted for by the prolonged time of mechanical ventilation (mean 17.5 d) and the high number of subjects with neuromuscular diseases and brain trauma or stroke in our sample. This can be associated with low values of $P_{0.1}$ that are not indicative of good prognosis.[6,8] Substantiating these findings, the highest value of the AUC of the ROC curves was found for P_{ImaxUV}.

Our findings are markedly different from previous studies in which low specificity, low diagnostic accuracy, and low AUC of the ROC curves have been reported for P_{Imax} in this regard.[2,5,8] The use of new tools in the present study may have accounted for these differences. In contrast to studies that employed total occlusion, and manual registration of visually inspected P_{Imax} values on an analogic vacuometer, which typically carries poor precision, we resorted to a unidirectional valve and digital registration of P_{ImaxUV} values, which enables measurements at each 0.1 s with a precision of 1 cm H_2O.

Many indexes are cited in the literature as useful to predict weaning outcome.[2,5,7,8,13,20] The most used and recommended one is f/V_T, proposed by Yang and Tobin.[5] In a recent study, the integrative weaning index exhibited better performance than f/V_T, but these results await confirmation.[21] In the present study the performance of the P_{ImaxUV} was still below the ones reported for those 2 indexes, but was enough to place this easy to obtain parameter among the top 3 to 4 predictors of weaning outcome.

Some limitations of our study deserve comments. An innovative technique was used to obtain $P_{0.1}$ values in our study. The gold standard technique to measure this parameter involves insertion of an esophageal catheter.[22,23] As an alternative, some commercially available ventilators are equipped with software that can directly provide $P_{0.1}$ values.[8,22,23] Our innovative way of measurement produced values of $P_{0.1}$ of 2.98 ± 1.02 cm H_2O, which were very close to the ones obtained in a previous report (2.97 ± 1.68 cm H_2O).[8] Further studies are needed to compare values collected by the technique used in the present study with the ones obtained by more traditional ways.

Conclusions

In conclusion, P_{ImaxUV} values obtained by digital technology using a unidirectional valve performed better than historically reported conventional techniques, surpassing $P_{0.1}$ and $P_{0.1}/P_{ImaxUV}$ in prediction of weaning outcome. However, it should be acknowledged that the present study revealed modest ROC values for every tested index.

ACKNOWLEDGMENTS

The authors thank the respiratory physiotherapists and physicians of the ICU of the Hospital e Clínica São Gonçalo and Hospital Estadual Azevedo Lima, for their collaboration and dedication in our study.

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