The Unidirectional Valve Is the Best Method To Determine Maximal Inspiratory Pressure During Weaning*

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Objectives: Although maximal inspiratory pressure (MIP) is used as an index of inspiratory muscular strength, there is no consensus on how to measure it. We compared, during weaning from mechanical ventilation, two methods of measurement to determine which shows the greater values (MIPbest) and is more reproducible. One method measured MIP when negative pressure was maintained for at least 1 s after a forceful expiration, and the other method measured MIP with a unidirectional expiratory valve (MIPuni).

Design: The study had a crossover design, and patients randomly performed three measurements of each method (t1). The procedure was repeated by the same observer after 20 min (t2). The maximal value in each method was considered.

Setting: ICU, Hospital A.C. Camargo, São Paulo, Brazil.

Patients: Fifty-four consecutive patients undergoing short-term mechanical ventilation who became eligible for the study when their physicians decided to restore spontaneous breathing.

Results: MIPbest values were arrived at using MIPuni 75% of the time either in t1 or t2. MIPuni yielded a higher average of MIPbest values in t1 and t2 (p < 0.0001). The effort-to-effort coefficient of variation of one method compared with the other during t1 and t2 was similar (p > 0.2 for t1; p > 0.8 for t2). Also, when comparing t1 and t2, the coefficients of variation were similar for each method (p > 0.62).

Conclusions: Because MIPuni displayed the maximal values, it is the best method for estimating MIP in patients undergoing short-term mechanical ventilation. The reproducibility of consecutive measurements was similar between the methods, even after a short period of time. (CHEST 1999; 115:1096–1101)

Key words: maximal inspiratory pressure; mechanical ventilation; respiratory monitoring; respiratory muscle; ventilator weaning

Abbreviations: ANOVA = analysis of variance; MIP = maximal inspiratory pressure; MIPbest = maximal value of inspiratory pressure obtained after three measurements; MIPsta = maximal inspiratory pressure measured when a negative pressure was maintained for at least 1 s after a forceful expiration to residual volume; MIPuni = maximal inspiratory pressure measured with a unidirectional expiratory valve; RV = residual volume.

Maximal inspiratory pressure (MIP) is an effective method for evaluating inspiratory muscle strength.1 It is used as a diagnostic tool,2 as a predictive mechanical index,3–7 and as a part of other indexes (e.g., tension time index). However, the lack of guidelines for the measurement of MIP in mechanically ventilated and spontaneously breathing patients contributes to irregular results and infrequent use of MIP. There is no consensus on the best method for measuring it.

The most common method is to measure MIP when a negative pressure was maintained for at least 1 s after a forceful expiration to residual volume (MIPsta).1–3,6,8–14 In this method, MIP is measured with the patient near the residual volume (RV) after a maximal expiration. The pressure is maintained for at least 1 s against an occluded airway, and expirations are repeated until they are technically satisfactory. It is not easy to perform the measurement in mechanically ventilated patients because the patients may not assimilate instructions well, may be sluggish or noncompliant, and as a result it may not be clear whether accurate measurements of the MIP have
been accomplished. Marini et al \cite{15} described a method in which MIP was measured with a unidirectional expiratory valve (MIPuni) where low resistance was used to selectively permit exhalation while inspiration was blocked. This caused patients to initiate successive efforts from respiratory volumes progressively closer to the RV, a known factor that helps to generate a more negative pressure. However, reproducibility was not assessed, and it is not clear whether the patients were studied immediately prior to extubation.

We hypothesized the following: MIPuni would yield larger values, considering that patients would be closer to the RV and would have a greater hunger for air (because the respiratory drive increases as occlusion continues); and MIPuni would yield more reproducible consecutive measurements because it requires less coordination between patient and observer, it involves a physiologic response (increased respiratory drive with blocked inspiration), and its larger values could lessen the coefficient of variation. Given the above hypotheses, we designed a protocol to study which of the two methods would yield the larger value and be more reproducible during the weaning of patients from short-term mechanical ventilation.

**Materials and Methods**

**Patients**

In order to achieve an 80% power test and a 5% significance level with a crossover design, we studied 54 consecutive patients who were undergoing short-term mechanical ventilation in an oncologic ICU. Patients were eligible for the study when their physicians decided to restore spontaneous breathing. All patients were hemodynamically stable and were able to trigger the ventilator in pressure support ventilation, assist/control, or synchronized intermittent mechanical ventilation modes. No patients had contraindications for undertaking forceful inspiratory maneuvers (i.e., suspected intracranial hypertension or flail chest). Patients were studied immediately prior to extubation.

**Materials**

We used an aneroid manometer (Record; São Paulo, Brazil) capable of registering pressures up to $-150$ cm H$_2$O. The manometer was calibrated immediately before the beginning of the protocol and two times during 90 days (the length of the protocol). To measure MIPsta, the manometer was attached to a T tube, which had one end free and the other end attached to the patient’s endotracheal tube or tracheostomy. When we performed MIPuni, one side of the manometer was attached to the patient’s endotracheal tube or tracheostomy, and the other side was attached to a unidirectional, low-resistance valve that only allowed expiration.

**Protocol**

The protocol was randomized and used a crossover design. Prior to the measurements, respiratory tract and oropharyngeal secretions were suctioned. The patients then were placed in a semi-recumbent position at 45°. None of the ventilator parameters were changed during the measurement period. The patient was disconnected from the ventilator and was attached to the aneroid manometer. According to a computer-generated random table, either MIPuni or MIPsta was used for the first three measurements, after which the investigator performed another three measurements using the other method (t1). Then, 20 min later, patients were reconnected to the ventilator with the same parameters, and the same investigator repeated the two series of three measurements using the same methods in the same order as during the first time period (t2).

MIPuni was measured by connecting patients to the manometer during a 20-s period and recording the maximal value. After maximal expiration, MIPsta was recorded with the free end of the T tube manually occluded. The peak negative pressure, if maintained for at least 1 s, was recorded during maximal inspiration. During both procedures, all patients were encouraged to make maximal efforts. The protocol was conducted in accordance with the ethical standards of our institution’s committee on human experimentation.

**Data Analysis**

To determine which method would display the MIPbest, we analyzed the maximal value of each set of triplicate measurements. Comparisons between the means of the maximal values of MIP in t1 and t2 as well as the study of the residual effect of one method over the other, were performed through one-way analysis of variance (ANOVA) with Bonferroni adjustment for multiple comparisons. The coefficients of variation (variance/mean) for each method were compared using a paired Student’s t test.

**Results**

The population characteristics are shown in Table 1. The majority of the patients studied were surgical patients undergoing short-term mechanical ventilation. Of the largest values, most were obtained using the unidirectional valve (76% in the first setting and 81.5% in the second) and < 10% were obtained using the “static” method (Fig 1). Because in each set of measurements (t1 and t2) the methods were performed sequentially with a short time interval, we first analyzed whether there was any residual effect

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of one method on the other. We found this not to be the case (ANOVA, \( p < 0.05 \)). The averages of the MIP\textsubscript{best} values resulting from both methods and in both periods differed significantly (ANOVA, \( p < 0.0001 \) with Bonferroni adjustment). During t1, the average (± SD) MIP\textsubscript{uni} value was 64.39 ± 20.45 cm H\textsubscript{2}O, and the average MIP\textsubscript{sta} was 50.33 ± 16.93 cm H\textsubscript{2}O (ANOVA, \( p < 0.001 \) with Bonferroni adjustment). The average MIP\textsubscript{best} in each method was the same in t1 and t2 (\( p > 0.79 \) for MIP\textsubscript{sta} and \( p > 0.54 \) for MIP\textsubscript{uni}). In t1 and t2, the MIP\textsubscript{best} values recorded by MIP\textsubscript{uni} were approximately 28% higher than those recorded by MIP\textsubscript{sta} (Fig 2).

The effort-to-effort coefficient of variation (three consecutive measurements) during t1 was 13.03 ± 9.39% for MIP\textsubscript{uni} and 13.76 ± 9.65% for MIP\textsubscript{sta} (Student's \( t \) test, \( p > 0.2 \)). During t2, the effort-to-effort coefficient of variation of MIP\textsubscript{uni} was 11.81 ± 9.85% and 10.66 ± 7.36% for MIP\textsubscript{sta} (Student's \( t \) test, \( p > 0.8 \)). The coefficient of variation for the maximal value of MIP\textsubscript{uni} between t1 and t2 was 10.88 ± 9.27%. The value for MIP\textsubscript{sta} was 11.59 ± 9.61% (\( p > 0.62 \)), showing good reproducibility of measurements at short intervals (Table 2).

**Discussion**

We designed this study to determine which of the two methods is the best way to measure MIP in a mechanically ventilated patient. To accomplish this, we compared both the absolute values obtained in each method and the reproducibility of these values over short time intervals and with consecutive measurements. Two studies\textsuperscript{16,17} compared MIP\textsubscript{uni} with a modified MIP\textsubscript{sta} (occlusion was maintained for 20 s). Although both demonstrated larger values for MIP\textsubscript{uni}, reproducibility was not studied, and they used a manometer with a maximum measurable pressure of 60 cm H\textsubscript{2}O, which was less than the mean observed during our study. Also, in one of the studies, patients were not studied at the moment of extubation.\textsuperscript{17}

In our study, MIP\textsubscript{uni} displayed significantly larger values than MIP\textsubscript{sta}. There are some possible explanations for this finding. These include an increase in the respiratory drive during the maneuver and an improved effectiveness of the respiratory system. An increase in the respiratory drive could have been caused by our blocking the patient's inspiration and adjusting the stimulation to a higher level after the previous “inefficient” inspiration. Indeed, when facing an increased mechanical load, the respiratory drive increases to maintain adequate alveolar ventilation.\textsuperscript{18} In normal persons, the chemical stimulus to breathe increases exponentially as the duration of apnea increases,\textsuperscript{19}and the duration of breath-holding is shortest at low lung volumes.\textsuperscript{20} In MIP\textsubscript{sta}, in contrast, the drive was more dependent on the patient’s collaboration than on the patient’s physiologic response. Another possible reason for the increased MIP is that MIP\textsubscript{uni} was probably performed...
at a pulmonary volume closer to the RV, which is, as previously described, a factor in increasing inspiratory pressure. During MIPuni, patients should have used a smaller pulmonary volume because we used a valve that blocked inspiration, and the maneuver lasted 20 s, thereby forcing patients to progressively reduce pulmonary volumes. Lack of coordination between patient and observer is an additional difficulty in using MIPsta. Notwithstanding these possible explanations, we cannot draw a definite conclusion about the reason that MIPuni showed significantly higher values than MIPsta because we have not measured the pulmonary volumes and respiratory drive.

The usual number of measurements for MIP estimation is three, although more maneuvers could be necessary to achieve maximal results; usually 10 or more are necessary. Despite the fact that there are studies showing that 10 or more maneuvers are necessary, which is in part due to a “learning effect,” these maneuvers were conducted with ambulatory patients and without a unidirectional valve. Because mechanically ventilated patients are more susceptible to fatigue, respiratory distress, and poor cooperation, the results in ambulatory patients might not be applicable to ICU patients.

Other factors limiting the depth of a maximal inspiration are the antagonistic actions of abdominal muscles, glottic closure, and respiratory weakness preventing the patient from reaching the RV. However, glottic closure did not occur in the present study because patients had an endotracheal tube or tracheostomy when the study was conducted.

Because MIPuni involves less coordination between patient and observer, encompasses a physiologic response (increased drive after a previous inefficient inspiration) thereby demanding less patient cooperation, and is closer to MIP, we expected
that this method would be more capable of consec-
tively reproducible results than MIPsta; however,
this was not the case. Consecutive measurements
showed good reproducibility, both when MIPsta was
used in previous studies\textsuperscript{10,11} and when both methods
were used in our study, with coefficients of variation
that averaged 10 to 13\% when the study was per-
formed by a single observer. However, using differ-
et observers\textsuperscript{25} and patients that are more ill does not
guarantee good reproducibility. Aldrich and
Spiro\textsuperscript{9} showed that maximal and submaximal efforts
using MIPsta have the same reproducibility. This is
most likely due to the discomfort evoked by the
muscular activity required for MIP efforts having a
certain reproducible threshold. Nevertheless,
both methods increased their reproducibility after 20
min, although this was not statistically significant
(Table 2).

We used a time period of 20 min between tests
because the measurement of MIP is a brief maneu-
ver that requires strength and often causes high-
frequency fatigue, and that is usually followed by
rapid recovery within 10 min.\textsuperscript{20} All patients tolerated
both procedures well, and no side effects, particu-
larly negative pressure pulmonary edema, were ob-
served during the study.

Is MIP a useful measurement in the ICU? It can
be used as an index in weaning patients from me-
chanical ventilation or as a diagnostic tool. Some
studies\textsuperscript{3} reported MIP to be a good index with which to
decide when to wean patients from mechanical
ventilation, whereas other studies not only failed to
confirm this, but also showed that MIP was less
accurate in predicting success than other indexes.\textsuperscript{7,27}
However, when muscular weakness or neuromuscu-
lar disease was the only or principal cause of respi-
atory failure (eg, Guillain-Barré syndrome and
polymiositis), MIP could be used as the principal
weaning index.\textsuperscript{2} MIP is also useful for quantifying
the degree of respiratory muscle strength in patients
with dyspnea, respiratory failure, or weaning fail-
ure.\textsuperscript{12} A problem in using MIPuni as a diagnostic tool
is the lack of normal values because most studies
performed with healthy volunteers used MIP-
sta.\textsuperscript{1,13,14} However, this is less important when
MIPuni is used as a weaning index because its
described power is derived from statistical methods,
generally, receiver operating characteristics curves.\textsuperscript{7,28}

The major limitation of the present study is the
type of patient included. The majority were surgical
patients undergoing short-term mechanical ventila-
tion. Only three patients presented with an MIP
\( \leq -20 \text{ cm H}_2\text{O} \), a value recognized as borderline for
successful weaning. This only occurred when we
used MIPsta. Therefore, extrapolations from our
results must be done with caution.

In conclusion, MIPuni displays values that are
30\% higher than those of MIPsta; hence, it discloses
values probably near the real MIP. The reproduc-
ibility and safety of both methods are good and are
equal to consecutive and short time interval mea-
surements. Based on our findings, the use of MIPsta
as a diagnostic component or as a predictive index
must be re-evaluated.

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