

# Timed Inspiratory Effort Index, a New Diagnostic Method to Assess Endurance and Inspiratory Muscle Strength in Patients under Mechanical Ventilation

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## Abstract

**Introduction:** Mechanical ventilation is a critical component of modern intensive care medicine, but the process of discontinuing mechanical ventilation could be difficult in some cases. Several studies demonstrated that the combination of diaphragmatic inactivity and mechanical ventilation periods over than 18 hours is associated with atrophy of human diaphragm myofibers. Thus, the disuse atrophy of human diaphragm myofibers could be a major contributor for weaning failures.

Indeed, its proper assessment of the respiratory muscle impairment depends on the use of appropriate tests. The predicting weaning indexes are still the most commonly used tests in clinical practice at ICUs around the world, because they are more widely known and easy to use in different diseases.

**Objective:** The aim of the present article is to describe advantages, procedures, and clinical applicability of a new method called timed inspiratory effort index, or TIE index, to assess inspiratory muscle strength and specifically address the diagnosis of muscle fatigue in patients under mechanical ventilation.

**Methods:** This short review about a new method to assess endurance and inspiratory muscle strength of patients with respiratory weakness and undergoing weaning from mechanical ventilation.

**Main recommendations:** The analysis of respiratory muscle function through the TIE method translates a new feature to the intensive care fast, easy, accurate, reproducible and secure. In addition, to aid in the differential diagnosis of respiratory muscle fatigue directly predict weaning, may lead the most appropriate respiratory muscle training in prolonged weaning patients.

**Conclusion:** In summary, nowadays, the TIE index can be considered one of the most appropriate methods to evaluate the various interactions in a critical patient under mechanical ventilation. Therefore, TIE index performance as a weaning predictor is among the best rates ever reported in literature.

**Keywords:** Respiratory muscles; Muscle weakness; Diaphragm; Respiratory function tests; Diagnostic tests

## Introduction

Mechanical ventilation is a critical component of modern intensive care medicine, but the process of discontinuing mechanical ventilation could be difficult [1]. Several studies have shown that the combination of diaphragmatic inactivity and mechanical ventilation for periods more than 18 hours is associated with atrophy of human diaphragm myofibers [2]. Thus, the disuse atrophy of human diaphragm myofibers could be a major contributor to the weaning problems that occur in some patients [3].

An alarming data has related patients requiring prolonged mechanical ventilation, defined as more than 21 days [4-6], account for more than 13% of ventilated patients [7] and 37% of intensive care unit (ICU) costs [8]. Because of changes in US reimbursement practices, these patients are usually transferred to specialized weaning centers, also known as long term acute care hospitals [9,10], in which the costs increased by 267%, reaching \$1.3 billion in 2006 [11]. With the US population aging, demands for intensivists services are predicted to increase 38% over the next decade [12]. Consequently, the number of ICU patients in prolonged weaning ventilation will increase substantially [13]. To this specific group of patients, the successful weaning is around 51%, and the mortality rate is around 66% in one year [14].

The aim of the present article is to describe advantages, procedures, and clinical applicability of new method called timed inspiratory effort index, or TIE index, to assess inspiratory muscle strength and specifically address the diagnosis of muscle fatigue in patients under mechanical ventilation.

## Main considerations about predicting weaning respiratory indexes

The predictor weaning indexes are used in clinical practice of ICUs around the world. Two of them, the ratio of respiratory rate by the tidal volume or rapid shallow breathing index ( $f/V_t$ ) and maximum inspiratory pressure (MIP), were incorporated into the routine of most

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units and are recommended by the 6<sup>th</sup> consensus American Thoracic Society (ATS) consensus and European Respiratory Society (ERS) on the subject [2]. MIP and  $f/V_t$  indexes are mainly recommended for patients with weaning difficulty [2,15].

In fact, the MIP was the first respiratory rate reported in the literature as a weaning predictor. However, due to a short observation period, employment of an analog vacuumeter without unidirectional valve and the lack of standardization, the performance as a weaning predictor were not too good in most studies [16-22].

The MIP evaluation in patients under mechanical ventilation is traditionally performed with airway occlusion by 20 seconds. This strategy aims to retain  $PaCO_2$  during the occlusion period to stimulate the respiratory center, independent of voluntary brain control. Examiner can observe every inspiratory incursion, and the increasing stimulus, until reaching the maximum inspiratory peak [23].

An intrinsic obstacle for this strategy is the necessity to monitor the performance time. Hardly, only one observer could evaluate each inspiratory capacity incursion and, at the same time, monitor the duration of the procedure. In 2002, for example, Soo Hoo and Park employed airway occlusion for up to 20 seconds and measured the MIP with analog vacuumeter. It was observed that, although professionals from the same team performed the MIP measures, their results were not homogeneous. Multiple consecutive measures were required to improve the accuracy of the test [24].

Due to a number of factors, such as study design (prospective or retrospective), weaning method and definition of success or failure, the MIP measurement accuracy as a weaning predictor has varied widely among different studies. In general, studies have shown sensitivity to approximately 80% cropping values above -30 to -20 cm  $H_2O$  [17,18,23]. Since success in weaning depends on other factors, specificity has been very low in all studies (approximately 25%) meaning that patients who fail in weaning do not necessarily have a reduced MIP [25].

In an attempt to make MIP measure more reproducible, in 1986, Marini et al. [16] after the evaluation of 20 patients artificially ventilated, described the method of the expiratory unidirectional valve, a device coupled to the opening of the airways, which only allowed exhalation. Thus, patients were required to make a progressively greater inspiratory effort as they approached the residual volume when the MIP observed could reach the maximum amount that patient could generate. Despite this result, the MIP values measured in critically ill patients are usually underestimated and have low reproducibility [26].

The identification of reliable forms of assessment of respiratory muscle strength may contribute to better monitoring of mechanical ventilation weaning process and the establishment of treatment strategies. In 2007, Guimaraes et al. [27] evaluated 30 patients artificially ventilated with an analog vacuumeter, comparing the simple occlusion method with the unidirectional valve mentioned above in 20, 30 and 40 seconds. They concluded that in non-cooperative patients, larger MIP was obtained with the method of the unidirectional valve occlusion during 40 seconds compared to the other evaluated protocols.

In 212, de Souza et al. [28] evaluated MIP values under unidirectional valve, for 60 seconds period using a digital vacuumeter. The maximum value during the observation period occurred more often between 40 and 60 seconds, suggesting that the observation time is a determinate factor to achieve the MIP [28].

Therefore, a longer time of inspiratory occlusion with the use of a unidirectional valve to reach the peak stress is needed [28]. Thus,

the search for an index with better weaning predictor consider the combination of parameters: measurement of maximal inspiratory muscle strength with the time that it is achieved in a period not exceeding 60 seconds of airway occlusion, to idealize the timed inspiratory effort index, or TIE index (Figure 1).

In two other publications, the TIE index showed better accuracy than the other indexes cited in the literature. In which not only pointed out the most appropriate time to wean, but also showed precisely the weakness and low resistance to fatigue, especially in patients with prolonged mechanical ventilation (ROC AUC=0.90), and neurological and neuromuscular diseases (ROC AUC=0.96) [21,22]. Inferring the fact that, this innovative method the evaluation of respiratory muscle system, you can also follow the rehabilitation process of the inspiratory muscles of patients in difficult and prolonged weaning [22].

Despite promising initial results with the TIE ratio, we are currently developing the study of its variability and intra and inter-observer reproducibility to assess whether the examination only once reflects the actual patient's condition in ICU [29]. The use of reproducibility evaluation method is needed to improve training and technical execution performance. This approach can positively influence the assessment results and decision-making at the bedside.

#### Latest results about TIE index

In the study of de Souza et al. [29], the results were excellent, in which the coefficients of variation of Bland-Altman and Kappa agreement were respectively 15.78% and 0.88 for intra-observer group, and 17.38% and 0.91 for inter-observer group. These values show a low percentage of variability and excellent agreement between measurements. Again, the method described showed an excellent characteristic of reproducibility [29].

The areas under the ROC curve of the TIE index evaluated in groups intra-observer was (AUC of 0.97 vs. 0.94,  $P=0.97$ ) and inter-

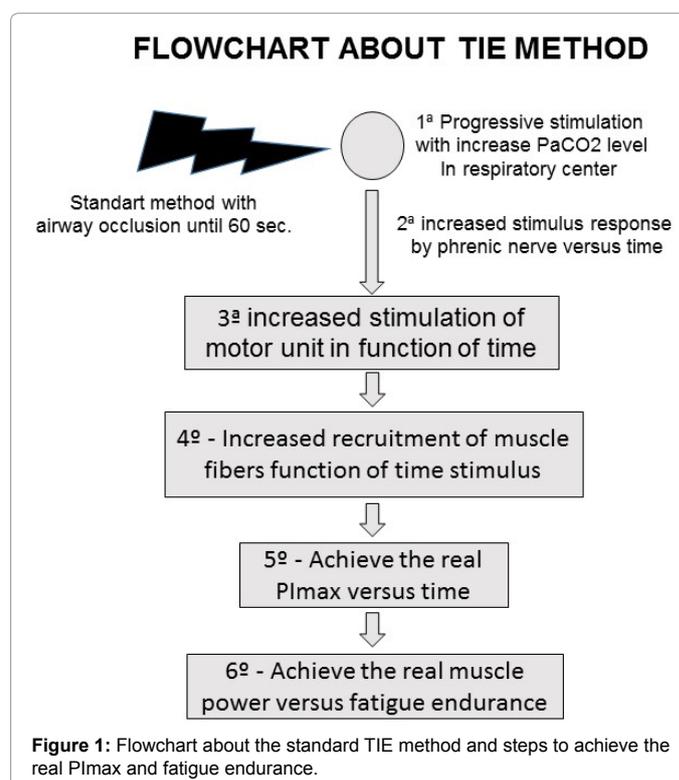


Figure 1: Flowchart about the standard TIE method and steps to achieve the real PImax and fatigue endurance.

observer was (AUC of 0.94 vs. 0.91,  $P=0.55$ ) to predict the weaning outcome. No significant statistical differences were found between the areas of ROC curve in both groups.

The TIE index shows that both the intra as in inter-group has no values statistical differences between the first and second exam. This fact, confirms the proposed method is not influenced both by examined and by the examiner, in which providing greater reliability and applicability for the implementation of the proposed examination. Therefore, the TIE index can be validated for the prediction of weaning, and it is a great tool for clinical utility [29].

## Procedures

### How to measure the TIE index?

For TIE index measurement is a digital vacuumeter required, with a scale of at least  $-200$  cm  $H_2O$  increment of  $1$  cm  $H_2O$  and  $100$  ms time interval for each pressure measurement. It is essential that the patient could be monitored throughout the examination process for a reliable assessment. Due to the fact that the test in question exposes the patient to a large respiratory effort with possible reduction in oxygenation. Thus, for an appropriate measure of the TIE ratio, the patient should be positioned supine with the head elevated between  $45^\circ$  and  $60^\circ$ , the hyper inflated cuff to prevent leaks, clean endotracheal tube, and hyper oxygenation for two minutes with fraction of inspired oxygen ( $FiO_2$ ) up to  $100\%$  [21,22].

After Hyper oxygenation, disconnecting the ventilator will be held and, after  $10$  seconds of spontaneous breathing, manually will be attached to the end of a normal expiration (at functional residual capacity) the artificial airway connector of the digital vacuumeter, occluded keeping the airways during an interval of  $60$  seconds, recording the values corresponding to each inspiratory effort [21,22].

The TIE ratio is calculated as the ratio between maximal inspiratory pressure, and the time to reach it for  $60$  seconds of observation. For successful weaning values, greater than  $1.0$  cm  $H_2O/s$  is needed. A typical record of inspiratory pressures by time is shown in Figure 2 [21,22].

### Clinical applicability

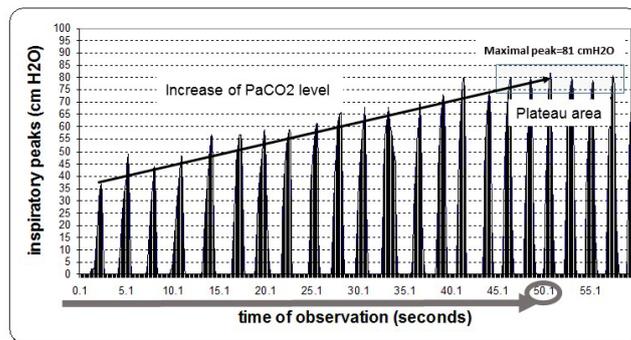
The determination of TIE index in patients under mechanical ventilation is important in the diagnosis of inspiratory muscle weakness, which can occur in pulmonary, cardiac, sepsis, neuromuscular diseases and others. In addition, the measurement of TIE index can aid in the differential diagnosis of dyspnea and obstructive lung disease of unknown origin; in assessing response to physiotherapy and rehabilitation; in prescribing and monitoring respiratory muscle training; and in critically ill patients in assessing the possibility and success of weaning from mechanical ventilation [30].

The better performance of the TIE index in the special article did not come as a surprise considering that the index is derived from parameters (respiratory drive and time to response), which can be crucially impaired in patients with muscle weakness acquired in ICU. This finding may be critical to weaning prediction in such patients in which the performance of other indexes like  $f/Vt$ , MIP and  $P0.1$  are recognized to be poor [21,22,29,30].

In summary, nowadays, the TIE index can be considered the more adequate to evaluate the various interactions in a critical patient on ventilation mechanical. Finally, we confirm that your performance as a weaning predictor is among the best rates ever reported in the literature [21,22,29,30].

## What is the TIE index?

R: TIE = Maximal peak / time to achieve the inspiratory peak



In this example, the TIE index =  $81/50.1$ , or TIE index =  $2.18$

**Figure 2:** A typical graph record of inspiratory pressures by time showing the end stage of TIE method to achieve the maximal peak and the calculus of TIE index.

## Advantages and recommendations

The respiratory muscle impairment is present not only in respiratory diseases but also in various other diseases and especially in critical ill patients. Indeed, its proper assessment depends on the use of appropriate tests. The predicting weaning indexes are still the most commonly used tests in clinical practice at ICU, because they are more widely known and because of their ease of use in different diseases.

Therefore, the advantages to the analysis of respiratory muscle function through the TIE method translates a new feature to the intensive care fast, easy, accurate, reproducible and secure. In addition, It is recommend the use of TIE method to the differential diagnosis of respiratory muscle fatigue to directly predict weaning, may lead the most appropriate respiratory muscle training in prolonged weaning patients [21,22,30].

## Disadvantage and limitation

All patients with the considerations ahead, must be exclusion criteria to measure the TIE index: tracheal stenosis, intracranial pressure  $>20$  mmHg, use of sedation, agitation, autonomic nervous system dysautonomia, severe hypoxemia, overt cardiac failure or hemodynamic instability, and signs of systemic infection/reinfection during the weaning process [21,22].

The limitation to measure of TIE index will be in the use of digital vacuumeter. This device must has a range  $0$  to  $300$  cm  $H_2O$  with a  $1$  cm  $H_2O$  interval, and is designed to perform measurements each  $100$  ms [20,21,22].

## Conclusion

In summary, nowadays, the TIE index can be considered one of the most appropriate methods to evaluate the various interactions in a critical patient under mechanical ventilation. Therefore, the performance of TIE index as a weaning predictor is among the best rates ever reported in literature.

Finally, in near future, patients with strongly suspect of ventilatory muscle weakness and great difficulty of understand these wining events, will undergo in additional assessment with the new TIE method, and gone have a correct individualized treatment target.

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