“Narrow” Thinking About Difficult Weaning: Don’t Forget the Endotracheal Tube

Liberating a patient from mechanical ventilation (often referred to as weaning) remains a major challenge in critical care. Studies performed in the 1990s suggested the process was simpler than previously supposed. Those studies indicated that 65–85% of patients recovering from acute respiratory failure of various causes passed their initial unsupported (or minimally supported) spontaneous breathing trial (SBT) and could be extubated, most successfully.^{1–3} These observations were enlightening in showing that only a minority of patients required the traditional approach to weaning: a slow, methodical, often time-consuming, stepwise reduction in ventilatory support. Yet these studies were also quite deceptive in suggesting that the process was simple and straightforward.

More recent reports, using definitions proposed by a consensus conference, indicate that liberation is frequently not so simple (Table).⁴ As an example, Funk et al, studying 257 patients, found that only 59% experienced simple weaning, while 26% were difficult and 14% prolonged.⁵ A much larger, multicenter observational study of 2,714 patients found that only 55% of weaning was simple.⁶ Together these studies indicate that more than 40% of all mechanically ventilated patients who improve to the point where weaning is initiated, prove to be difficult to wean.

An appreciation of the difficulty and complexity of liberation highlights 2 important areas to be addressed: How can we identify and then reverse the pathophysiologic processes that make it more difficult to liberate a patient from mechanical ventilation? How can we best identify the earliest time that a patient is ready for spontaneous breathing?

There is considerable evidence to suggest that the endotracheal tube (ETT) can impede liberation from mechanical ventilation. By increasing the work of breathing (imposed work of breathing), the ETT may unfavorably tip the balance between the load on the respiratory system and the capacity of the system to confront that load (load-capacity imbalance). Bench studies demonstrate that narrowing the internal diameter of the ETT increases the work of breathing.^{7,8} The observation is not unexpected, as tube resistance varies inversely with tube radius raised to the fourth power. Thus, a small reduction in ETT internal diameter could result in a large increase in resistance, thus increasing the work needed to overcome that resistance. That said, the clinical relevance of this has been ques-

Table. Definitions of Simple, Difficult, and Prolonged Weaning

Weaning Type	Definition
Simple	First spontaneous breathing trial (SBT) successful, extubation successful
Difficult	Fails first SBT and requires up to 3 SBTs before successful (and 7 days or less from first SBT to successful SBT)
Prolonged	Fails at least 3 SBTs or requires > 7 days from first SBT to successful SBT

tioned because the relatively low inspiratory flow rates generated during spontaneous breathing appear to result in only modest increases in work of breathing when breathing through a narrower ETT.⁹ This suggests that the effect of a narrow tube will be clinically relevant only at internal diameters narrower than typically used.

In addition, some authors have found that work of breathing associated with inspiration through an ETT is no greater than that encountered after the tube has been removed.¹⁰ Unfortunately, such studies fail to shed light on the issue, as they examine only patients who passed the SBT (despite the narrower tube) and went on to extubation. Patients failing the SBT (eg, those who might encounter high imposed work of breathing from the tube) are not included. Moreover, recent work demonstrates that ETT diameters may narrow more severely than previously suspected, and do so more rapidly than anticipated. Wilson and colleagues, studying ETTs after extubation, found that organized secretions narrowed the tube lumen and might affect patient tolerance for weaning.¹¹ Half the time the tube behaved like one with a 1 mm narrower internal diameter; up to 15% of the time that narrowing was the equivalent of a tube 3 mm narrower. In this latter instance, tube diameter may decrease to the point where the degree of narrowing is physiologically important.

Several studies indicate that the ETT can contribute to intolerance for spontaneous breathing (weaning intolerance or iatrogenic weaning failure). Studies of patients in a trauma ICU found an association between elevated measured imposed work of breathing and weaning intolerance (manifested as tachypnea).^{12,13} In fact, these investigators found that when the physiologic work of breathing (equal to total minus imposed work of breathing) was in the

normal range, patients could be extubated successfully. Ezingear et al placed 31 patients failing a 30 min T-tube trial on pressure support (7 cm H₂O), finding that 21 tolerated the additional 30 min trial and 17 were successfully extubated.¹⁴ It is tempting to speculate that some patients in this group were failing because of excessive imposed work of breathing related to the ETT, and this additional load was offset by the application of low level pressure support. If that is the case, what explains the failure of automatic tube compensation, an approach designed to deliver a varying level of pressure support to overcome imposed work of breathing (without overcompensating), to outperform SBTs conducted on CPAP, T-tube, or a set level of pressure support?^{15–17} With automatic tube compensation the level of pressure support delivered is a function of the pre-intubation characteristics of the ETT. As noted earlier, those characteristics may quickly and substantially change after the ETT is in place. Failure to detect this change in ETT internal diameter may explain why automatic tube compensation has not been of benefit, compared to other SBT approaches. Finally, in acute on chronic respiratory failure from COPD, noninvasive ventilation may allow for successful extubation of patients not tolerating SBTs.^{18,19} It is possible that some of these patients were failing because of the excess work of breathing imposed by the ETT.

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The concept that the ETT can substantially increase work of breathing is strengthened by the observations of Valentini and co-workers in this edition of *RESPIRATORY CARE*.²⁰ The authors studied the effect of tracheotomy tube diameter on diaphragmatic effort in 10 difficult to wean subjects. The authors compared breathing through tracheotomy tubes with different internal diameters by randomly studying their subjects with and without the inner cannula. When compared to the 8 mm internal diameter tube, breathing through the narrower (6.5 mm internal diameter) inner cannula resulted in significantly increased diaphragmatic effort, as assessed by measurement of the pressure-time product, which increased by 28%, most likely a result of the 41% increase in measured resistance. The authors further noted an increased tension-time index of the diaphragm, a direct measure of the balance between load and capacity, during breathing with the inner cannula in place. The authors also performed an in vitro study that showed changes in resistance were similar in ETTs; resistance was increased with a 6.5 mm, compared to an 8 mm, internal diameter ETT.

Of the many physiologic parameters used to assess readiness for an SBT, the rapid shallow breathing index, or frequency to tidal volume ratio (f/V_T), is the most com-

prehensively investigated. Load-capacity imbalance is a common cause of failed SBTs and is associated with a pattern of rapid shallow breathing. The one randomized controlled trial of f/V_T failed to show improved outcome; use of the f/V_T to guide weaning decisions did not shorten the duration of mechanical ventilation.²¹ Other conditions are associated with the pattern of rapid shallow breathing, including supine position, anxiety, fever, and female sex. These factors may explain why some patients with rapid shallow breathing tolerate an SBT and are successfully extubated. We have previously shown that mechanically ventilated medical ICU patients with narrow ETTs (≤ 7 mm in diameter) have a higher f/V_T than those with larger tubes (> 7 mm).²² Mehta and colleagues made similar observations, finding a higher f/V_T in patients with 7–7.5 mm ETTs, compared to those with 8 mm tubes.²³ In studying the effects of breathing through a narrowed tracheotomy tube, Valentini et al also examined the effect on f/V_T . In agreement with our work and that of Mehta et al, Valentini found a higher f/V_T when breathing occurred through the 6.5 mm inner cannula, compared to the 8 mm internal diameter without the cannula (f/V_T 93 vs 77). Four of 10 patients had an f/V_T above the threshold of 100 associated with weaning failure, but in 3 of these the elevated f/V_T occurred only when breathing through the inner cannula. If the imposed work of breathing is contributing to intolerance for spontaneous breathing, the elevated f/V_T will be accurately associated with weaning failure (eg, a true negative test predicts failure and the patient fails). Conversely, should such a patient be given a trial of extubation and tolerate it, the test would be classified as false negative.

The study by Valentini and co-workers reminds us that we must consider the physiologic effects of the artificial airway as we attempt to liberate the patient from mechanical ventilation. Measurements showing increased airways resistance may, in the absence of factors suggesting the problem resides in the native airways, indicate that the ETT or tracheotomy tube has become excessively narrowed. For clinicians using the f/V_T in their weaning decision-making algorithm, rapid shallow breathing in a patient with difficult weaning, without another explanation, should raise the possibility that the ETT is the culprit.

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