counter to our experience and common sense.

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The authors respond:

We thank Branson and Rodriquez for their letter.[1] We agree there were mistakes in one of our tables that we missed during editing, and that there is considerable disagreement about terminology. However, we also believe that most of the issues they raise were covered in the paper.

Branson and Rodriquez are correct that the positive end-expiratory pressure (PEEP) ranges for the Pulmonetic LTV1000 and Crossvent 3 are 0–20 cm H_2O and 0–35 cm H_2O, respectively, and we thank them for pointing this out. We do, however, take exception to what they describe as inaccuracies with respect to various ventilation modes.

It is unfortunate that no standardized nomenclature exists for classifying ventilation modes. Ventilator manufacturers use various names to describe their devices' modes. Consider 2 commonly used ventilators, the Puritan Bennett 840 and the Dräger Evita 4. The Evita 4 offers a continuous-mandatory-ventilation mode that allows timed or patient triggering of constant-volume breath delivery, as well as the PCV + Assist mode that allows timed or patient triggering of pressure-controlled breaths.[2] Both of those modes may be defined as a form of assist/control ventilation (ie, all breaths are delivered by the ventilator at a set minimum rate [mechanical breaths], but the patient may trigger the ventilator and thus cause a rate greater than the set rate).[3] Contrast this to controlled mechanical ventilation, in which all breaths are delivered by the ventilator at a set rate and patient triggering is not allowed.

With the Puritan Bennett 840 the clinician must first select a ventilation mode, and we will again use the example of assist/control, followed by the selection of a mandatory breath type, such as volume control or pressure control.[4]

In the neonatal arena, the Dräger Babylog has a mode in which the ventilator delivers a set number of non-synchronized, time-cycled, pressure-limited breaths, and the patient is allowed to breath spontaneously in between the breaths from a clinician-adjustable, continuous gas flow. Although we have known this ventilation mode for many years as intermittent mandatory ventilation (IMV), on the ventilator the manufacturer describes it as CMV.[5]

We did not evaluate any of these ventilators during spontaneous ventilation, which we clearly identified as a major limitation of our study. Consequently, we relied on the manufacturers' documentation regarding triggering and spontaneous breathing capabilities.

Several years ago, Chatburn and Primiano, in an attempt to promote standardization of nomenclature, published an extensive description of ventilation modes.[6] However, no consensus on the use of that nomenclature has been established. Neither the engineers who design ventilators, the marketing and sales people, nor clinicians use Chatburn and Primiano's nomenclature. In the absence of such consensus, it has been our practice to describe ventilation modes as controlled, assist/control, synchronized intermittent mandatory ventilation (SIMV), or spontaneous, and the breath-delivery types as volume-controlled, pressure-controlled and/or pressure-supported. In our paper we intentionally disregarded the manufacturers' descriptions of modes and applied the above classification system. Thus, since the Percussionaire delivers a set number of mechanical breaths to a patient making no spontaneous respiratory efforts, it was classified as

a controlled mode. And because spontaneous efforts are met with unsupported air entrainment, it was also classified as having an IMV mode. We used similar logic in classifying the Vortran. It functions in a controlled mode with a patient who does not have a spontaneous respiratory rate. However, upon further inspection, despite the manufacturer's claim that "spontaneous breathing patients may entrain room air," the one-way valve is pressurized during normal operation and does not allow spontaneous breathing. It functions only as a fail-safe valve, allowing spontaneous breathing of room air if gas flow to the system is lost (eg, empty cylinder).

The Parapac devices provide a mode identified as synchronized mandatory minute ventilation (SMMV), which is intended to allow spontaneous breathing but also provides mandatory breaths at the set tidal volume (V_T) in the event the patient does not meet the minute volume requirement. To more carefully evaluate this, we set the tidal volume at 1,000 mL and the respiratory rate at 10 breaths/min. If the patient has a small spontaneous V_T ($\leq$ 200 mL), the ventilator delivers the set V_T at the set rate (IMV). If the spontaneous V_T is > 200 mL but less than the set V_T, the ventilator delivers the set V_T at a rate lower than the set rate. And if the spontaneous breaths equal the set V_T, no mandatory breaths are delivered. This is consistent with the manufacturer's description: "The tidal volume required to completely inhibit the ventilator is fixed at 450 mL, but the frequency is determined by that set on the ventilator."[7]

Regarding the Crossvent 3, a V_T and pressure limit are set. If the pressure limit is above the pressure needed to deliver the set V_T, the set volume is delivered every breath (volume ventilation)! However, if the pressure is set lower than the pressure needed to deliver the set V_T, the excess volume is vented to the atmosphere and the set pressure is held for the remainder of

the inspiratory time (pressure ventilation)! In no case did we indicate that any ventilator provides both controlled mechanical ventilation and assist/control ventilation, as Branson and Rodriquez indicated.

Gas consumption was defined as the amount of time the ventilator functioned on one full E-size oxygen cylinder (capacity 660 L of oxygen) at a V_T of 1,000 mL and a respiratory rate of 10 breaths/min, on 100% oxygen. We performed this test once with each ventilator. In theory the maximum time of operation would be 66 min, assuming there were no leaks in the system, no bias flow or other diversion of gas by the ventilator, 100% of the gas was devoted to minute volume, the cylinder contents were correct, and the ventilator functioned as expected throughout the test.

As is well known, the actual content of oxygen cylinders differs considerably. However, the reason for the less-than-expected duration of operation of the Impact/Uni-Vent Eagle 754 was its inability to maintain set parameters during this aspect of the evaluation. A peculiar finding with the Impact/Uni-Vent Eagle 754 was that before the cylinder became depleted, the ventilator alarmed "O_2 LOW/FAIL" and substantially decreased the V_T of alternate breaths. We identified this as the point at which the ventilator was unable to maintain set parameters.

To more carefully address Branson and Rodriquez's concern, we recently repeated this portion of the test with the Impact/Uni-Vent Eagle 754, with 3 different ventilators, at the previously described settings, and with and without PEEP set at 5 cm H_2O. All cylinders were verified to be full, with pressure range 2,000–2,300 psi. Predicted duration of operation was 60–69 min. All 3 ventilators exhibited similar changes in V_T delivery, but at various cylinder pressures. The range of duration of normal operation was 22–61 min. The cylinder-pressure range when the malfunction began was

300–1,100 psi, and the delivered V_T of alternate breaths decreased to approximately 50% of the set value. Continued operation eventually resulted in further variance in delivered V_T in all breaths. Performance was unaffected by the addition of PEEP.

Regarding the animal studies, all the ventilators that failed to ventilate the injured lung model failed because of the development of auto-PEEP, which prevented further increase in the rate. We should have explained this in more detail. The lung model we used is the same that had been used by us in numerous other animal studies and is stable for longer than 4 hours, which exceeded the time needed to evaluate the group of 5 ventilators.[8-10] Could the sequence of ventilators evaluated have affected their ability to ventilate and the development of auto-PEEP? Absolutely. This is in fact one of the reasons we did not use this failure as a "strike" against a ventilator in the final analysis

In the introduction of our paper we listed the 6 criteria we used to select the most suitable ventilator for use in the out-of-hospital setting; we focused on forward military positions. As we stated above, because of the size of some of the injured animals, we disregarded the failure to ventilate injured lungs in our final evaluation. The specific criteria that separated the Newport HT50 and Impact/Uni-Vent Eagle 754 from the VersaMed iVent and Pulmonetic LTV1000 was the duration of the internal battery. We did not consider the attachment of additional battery capabilities, and we stated that both the VersaMed iVent and Pulmonetic LTV1000 would also be considered at the same level as the Newport HT50 and Impact/Uni-Vent Eagle 754 if their internal battery life was longer.

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Preparing soldiers for medical air evacuation
U. S. Army Air Force photo
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