# In Response

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injury to the left main stem bronchus offered a potential solution to a very challenging clinical situation. In their patient, the posterior membranous aspect of the proximal left main bronchus had been inadvertently disrupted intraoperatively by a double-lumen endotracheal tube, thus requiring a right thoracotomy to facilitate the left bronchial injury site. To ventilate the left lung distal to this bronchial injury, the authors passed the blocker through the left lumen of the double-lumen endotracheal tube, advancing it beyond the bronchial breach. After inflating the blocker balloon, they attached the Ventrain ventilator device to the blocker's proximal end and were then able to use the Ventrain to alternatively inflate and actively deflate the left lung, thus providing some "ventilation" for the 20 minutes taken to repair the bronchus. Accordingly, they reported that the partial pressure of carbon dioxide ($Paco_2$) rose to 87 mmHg by the end of the 20-minute repair. Although the partial pressure of oxygen measured at the same time (94 mmHg) indicated that the patient had been adequately oxygenated, the significant hypercapnia suggested that the patient was grossly underventilated (and arguably might not have been ventilated at all).

Use of the Ventrain device has been reported in a number of different situations,[2,3] including a report where emergency ventilation using the device was achieved in a porcine model of complete upper airway obstruction.[3] In that animal study, the Ventrain was operated via a 3-mm internal diameter, 100-cm long Airway Exchange Catheter (Cook Medical Inc) which allowed for adequate ventilation (ie, normal blood gases). In contrast, the narrow 7-F lumen blocker that Evers et al[1] used had an internal diameter of only 1 mm, making it likely very difficult to provide adequate actively assisted expiration (a fundamental feature of Ventrain ventilation). As the $Paco_2$ in anesthetized and apneic patients has previously been reported to rise at a rate of 3.4 $mmHg \cdot CO_2 \cdot minute^{-1}$,[4] the 20 minutes required to repair the bronchus would have expected to lead to an approximate 60 mmHg increase in $Paco_2$ from the pre-Ventrain baseline, even if the patient was apneic. Importantly, this increase would have resulted in a $Paco_2$ close to the final value that they actually reported. As for the partial pressure of oxygen, the adequate oxygenation may simply have been a result of providing some small amount of oxygen insufflation into the distal bronchus to match the metabolic demands and alveolar oxygen uptake (ie, approximately 250 $mL \cdot minute^{-1}$ oxygen consumption[5]).

So although using the Ventrain through a 7F blocker may have allowed the oxygenation needed to safely complete a 20-minute surgical procedure, this might similarly have been accomplished if free flow of oxygen had been provided to the bronchus without any ventilation at all.[3] Although the authors should rightly be enthusiastic about the potential for this combined Ventrain and Arndt blocker technique, it should perhaps be tempered pending more investigation of the adequacy of its ventilation capability in clinical practice.

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## In Response

Thank you for sending through the comments kindly made by Professor Grocott on our article.[1] We found his comments very interesting, apposite, and helpful, and are most grateful for his interest in our report.

In our case report, we described the thoracoscopic repair of an iatrogenic lesion of the left main bronchus. This lesion was noticed by the surgeon because the inflated bronchial cuff of the left-sided double lumen tube was bulging through it. Repair was challenging because the right lung had to remain deflated to optimize visibility. But also the bulging bronchial cuff had to be deflated. Positive pressure ventilation through a double lumen tube with both cuffs deflated is inadequate. Therefore, to maintain oxygenation, we placed a 7F Arndt blocker behind the lesion and oxygenated the left lung with the Ventrain device. After the 20 minutes lasting closing procedure, the $Paco_2$ rose to 87 mm Hg while the $Pao_2$ was 94 mm Hg.

In his letter, Professor Grocott stated that the maintained $Pao_2$ indicated that the patient has been adequately oxygenated but that the significant hypercapnia suggested that the patient was grossly underventilated (and arguably might not have been ventilated at all). So although using the Ventrain through a 7F blocker (ID 1.12 mm) may have allowed the oxygenation needed to safely complete a 20-minute surgical procedure, this might similarly have been accomplished if free flow of oxygen had been provided to the bronchus without any ventilation at all.

We absolutely agree with Professor Grocott that during the repair of the left main stem bronchus ventilation was inadequate to clear all carbon dioxide produced but we disagree that ventilation was totally absent. Stock et al[2] sampled the $Paco_2$ in anesthetized subjects and found that the $Paco_2$ increased 12 mm Hg in the first minute and then raised 3.4 mm $Hg \cdot minute^{-1}$ between minute 2 and 5. If we would extrapolate this linear increase in $Paco_2$ to 20 minutes apnea, the calculation shows that the $Paco_2$ would increase 76.6 mm Hg. A $Paco_2$ increase of 76.6 mm Hg after 20 minutes related to the measured $Paco_2$ of 87 mm Hg would implicate that the $Paco_2$ before repair would be ~10 mm Hg. We did not assess an arterial blood gas sample before we started the Ventrain use but we retrospectively determined the $P_{ET}CO_2$ from the anesthetic report and found that it was 37 mm Hg.

Stock et al[2] in the obstructed patient and Eger and Severinghaus[3] in the unobstructed patients during apneic oxygenation determined that the rate of rise of $Paco_2$ averages 12–13.4 mL in the first minute (if the patient is not hyperventilated before apneic oxygenation) and 3–3.4 mL/min each minute thereafter.

As mentioned above there was subnormal removal of carbon dioxide in this case. A further contributory factor to this was the set phases of ventilation with intermittent equilibration as prescribed in the Ventrain User Manual, to prevent damage to the lung by hyperinflation.

When working with Ventrain, it is basically possible to estimate the volume of gas that has been insufflated each time by using intermittent capnometry.[4] A sidestream capnographer can draw a sample from the breathing gas during equilibration and the value can be read off the display. That way one knows whether to use a higher or lower flow of the pressure-compensated oxygen source. However, the time required for the expiration depends on the resistance of the ventilation system, in particular on the ventilation catheter.

If the upper respiratory system is partially or completely obstructed, a very high intrapulmonary pressure could build up, eg, if the Ventrain was operated outside the limits specified in the manual. The circulation could then be impeded and the cardiovascular system may even collapse.

This problem can be avoided by allowing for sufficiently extended equilibration periods, although admittedly at the expense of a reduction of the achievable minute volume. Equilibration is facilitated by the deactivating and thereby functional disconnection of the device. This results in a slow, passive equilibration of the intrapulmonary and atmospheric pressures. An alternative to this is, as recently described, intermittent measurement of intrapulmonary pressure, eg, with a cuff pressure manometer.[5] In our case, we introduced frequent equilibration pauses. However, these pauses did indeed further contribute to hypoventilation.

Had our patient been in the supine position, or even better still supine with an elevated upper body or in the reverse Trendelenburg position, we would have very possibly used oxygen insufflation but the additional pressure obtainable with Ventrain was a key factor in our considerations in this case. Clearly both techniques have their place in the anesthesiologist's armamentarium.

We again thank Professor Grocott for his comments and particularly applaud his closing remarks. More study on insufflation techniques—particularly in elective clinical settings such as airway surgery and larynx inspection under general anesthetic—is certainly necessary.

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