INNOVATION

The Ventrain Device: A Future Role in Difficult Airway Algorithms?

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The Ventrain is a small, manually operated, single-use, inspiratory flow-adjustable ventilation device that generates positive pressure during inspiration and, through a Bernoulli effect within the device, active suction during expiration. It was designed to provide emergency ventilation during airway obstruction via narrow-bore cannulae. The device has been used successfully in elective procedures lasting >1 hour. It remains to be seen if its theoretical advantages in "can't intubate, can't oxygenate" (CICO) scenarios translate to reliable clinical benefit and allow inclusion in future airway algorithms. We advocate for regular simulation training and the detailed reporting of clinical experience with this encouraging new tool. (A&A Practice. 2019;13:362–5.)

GLOSSARY

CICO = can't intubate, can't oxygenate; **FONA** = front of neck access; **TTJV** = transtracheal jet ventilation

Pulmonary ventilation via narrow-bore catheters or cannulae is challenging due to the high resistance to gas flow. Traditionally, jet ventilation is required to inject gas under pressure, but the lack of sufficient bidirectional flow demands a patent upper airway to ensure effective passive expiration and to avoid barotrauma and hemodynamic collapse. The Ventrain (Ventinova Medical B.V., Eindhoven, the Netherlands) combines high-pressure source lung ventilation with active aspiration of gas during expiration. The device, which provides manual flow-controlled ventilation, originated in the Netherlands from industrial injectors used on automated assembly lines and underwent testing in bench studies as well as in animals. Although initially intended for ventilation via needle cricothyrotomy in the emergency "can't intubate, can't oxygenate" (CICO) situation, to date, the Ventrain has been used mainly in the operating room during elective airway surgery. It is currently approved for emergency use within the European Union, the United States, Australia, and New Zealand. In this article, we describe the structure and function of this interesting tool and briefly speculate on whether it might have a future role in difficult airway algorithms.

DESCRIPTION

The Ventrain is a small, manually operated, single-use, inspiratory flow-adjustable ventilation device driven from a high-pressure oxygen source. It generates positive pressure during inspiration and, through a Bernoulli effect within the device, active suction during expiration. It was designed to provide ventilation through a narrow-bore catheter in emergencies where conventional ventilation via mask, supraglottic airway, or tracheal tube fails.[1] There are 2 connections: an inlet tube (length, 213 ± 20 cm; internal diameter, 3.0–4.5 mm) and a short sidearm (length, 20 ± 1 cm; internal diameter, 5.20 ± 0.15 mm) that connects via a male Luer Lock to the airway catheter/cannula. The dimensions of the internal channels are not available. A Luer Lock connection on the sidearm allows intermittent measurement of end-tidal CO_2 concentration and can provide a continuous nonquantitative capnograph. Oxygen should be supplied from a pressure-compensated flowmeter or pressure-regulated cylinder to maintain stable flows and avoid problematic backpressure seen with anesthesia machines.[2] Internally, the inlet channel narrows to a diameter of 0.7 mm before directly splitting into a T shape (Figure 1). Gas is diverted either along the inspiratory/expiratory sidearm to the airway or along the exhaust channel to an opening on the upper surface. Acceleration of oxygen flow across the inlet constriction generates subatmospheric pressure over the sidearm, resulting in active suctioning during expiration. A bypass channel runs internally from the proximal inspiratory/expiratory limb, just below the T junction, to open on the lower surface. The internal dead space volume is 5 mL.

Figure 2 describes the 3 operational phases: inspiration, expiration, and equilibration (see also Supplemental Digital Content, Video, http://links.lww.com/AACR/A283, which demonstrates use of the Ventrain in the skills laboratory). VIDEO+ During inspiration, the upper and lower openings are occluded by the thumb and index fingers, respectively. In laboratory studies conducted on a model of airway occlusion, a driving pressure of 2.3 bar was observed at flows of 15 L/min.[1] Insufflation pressure proximal to the airway catheter was measured at 138 cm H_2O. However, in pigs with a closed airway, peak airway pressure was limited at 30–35 cm H_2O.[4] Tidal volume depends on oxygen flow rate, inspiratory time, and the impedance to airflow of the airway catheter and respiratory system. When pulmonary

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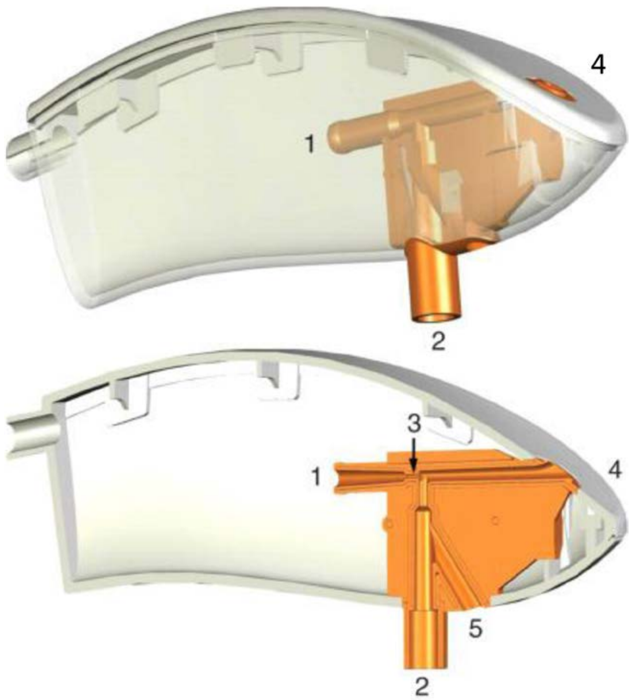

Figure 1. Internal structure of the Ventrain device. 1, Conical oxygen inlet channel. 2, Inspiratory/expiratory channel connecting to the sidearm. 3, Constriction (0.7 mm) producing downstream subatmospheric pressure. 4, Exhaust channel opening. 5. Bypass channel acting as on/off switch used to equilibrate lung volume. Reproduced with permission from Hamaekers et al.[1]

compliance and airway resistance (components of impedance) are normal, insufflation lasting 1 second produces tidal volumes of approximately 250 mL (flow, 15 L/min). The manufacturer provides a guide to flow and tidal volume as illustrated in the Table. Respiratory frequency is determined by the duration of the manual inspiratory/expiratory cycle.

During expiration, the upper exhaust aperture is opened by lifting the thumb, while maintaining the lower aperture closed. Gas from the lungs is entrained with fresh oxygen via the exhaust port. Minimum pressures of −97 cm H_2O have been measured in the sidearm when the airway is totally occluded. An inspiratory/expiratory ratio of 1/1 results in similar inspiratory and expiratory tidal volumes. Clinical monitoring of chest wall excursions during ventilation is essential.

During equilibration, both apertures are open allowing lung volume to stabilize near functional residual capacity, while fresh oxygen escapes via the exhaust. This avoids inadvertent hyperinflation or excessive suctioning on the lungs and should be performed every 5–10 breaths. The manufacturers recommend the Ventrain be used as a temporizing measure for a maximum of 20 minutes.

DISCUSSION

Clinical experience with the Ventrain is accumulating. The device has already been used in patients with airway obstruction for periods ≥60 minutes by experienced anesthesiologists in an elective setting. Both transtracheal cannulae[5,6] (sometimes preemptively placed for airway rescue)

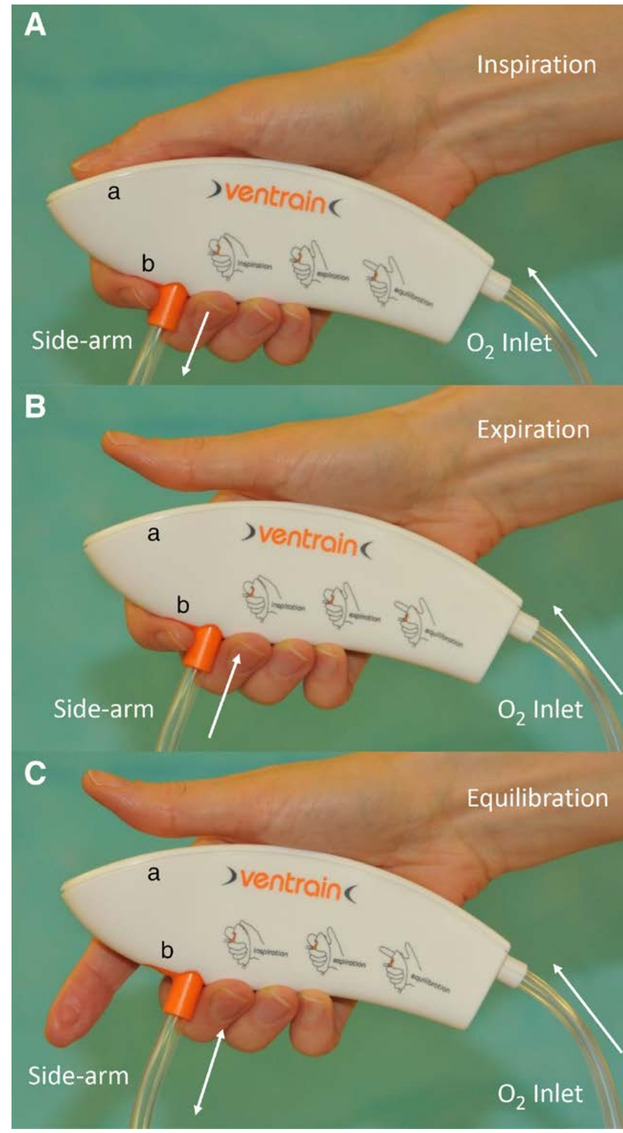

Figure 2. Operation of the Ventrain device. A, Inspiration. The exhaust aperture (a) and bypass aperture (b) are occluded with the thumb and index fingers, respectively. Oxygen flow accelerates under high proximal driving pressure across a narrow constriction and is diverted along the inspiratory channel, via the sidearm to the airway. B, Expiration. The exhaust aperture (a) is opened by lifting the thumb while maintaining the bypass aperture (b) closed. Subatmospheric pressure downstream from the inlet constriction results in active aspiration of gas from the lungs, which is entrained with the fresh oxygen flow via the exhaust. C, Equilibration. Opening both apertures allows fresh oxygen to escape via the exhaust. Gas flow via the bypass channel, to or from the lungs, allows lung volume to equilibrate to near functional residual capacity. This equilibration phase should last 5 s after every 5–10 respiratory cycles. Reproduced with permission from Morrison et al.[3]

and exchange catheters[3] have been used for ventilation. Use in pediatric anesthesia has also been described.[7,8] Although originally intended for narrow-bore transtracheal ventilation in a CICO situation, experience in this area is limited.[9] Many hospitals now include this device in their difficult airway cart, even if it has not yet been incorporated into official guidelines on difficult airway management. The rarity of a CICO event (1:12,500 general anesthetics[10]) and ethical

Table. Approximate Tidal Volumes (mL) Expected After Manual Inspiration Lasting 1 s, With a Given Flow

Flow (L/min)	Expected Tidal Volume (mL) After Manual Inspiration Lasting 1 s
2	33
4	67
6	100
10	167
12	200
15	250

constraints mitigate against randomized controlled trials for this indication. To further our knowledge, therefore, it is essential that anesthesiologists report their experiences by publishing their cases or entering details in registries such as the Airway App.[11]

In pigs, the Ventrain outperforms traditional transtracheal jet ventilation (TTJV) during partial and complete airway obstruction.[4] The most successful reports with the Ventrain have been in the operating room during elective use for obstructive airway pathology, but as Noppens[12] pointed out, premature use of the device by inexperienced anesthesiologists in unselected patients may have a negative impact on its future applications.

Even if this promising technology can be endorsed for elective use, a future role in CICO scenarios is more contentious. In this setting, needle cricothyrotomy remains an option for restoring oxygenation in many airway algorithms (eg, American Society of Anesthesiologists, Difficult Airway Society, Canadian Airway Focus Group). The 2015 Difficult Airway Society guidelines for managing unanticipated difficult intubation in adults favor surgical cricothyrotomy as the final step in an airway crisis; however, the use of needle cricothyrotomy by experienced, trained personnel is acknowledged. The arguments for preferring surgical emergency front of neck access (FONA) with a scalpel/bougie/tube technique are compelling: it is a relatively straightforward, standardized procedure; it uses simple, easily accessible equipment; and it allows conventional ventilation with capnometry via a cuffed tracheal tube. Moreover, a number of national anesthesia databases (Denmark, the United Kingdom, the United States, and Canada) confirm better success rates with a surgical approach. In the 4th National Audit Project, needle cricothyrotomy failed in approximately 60% of cases, and scalpel techniques were almost universally successful, although the procedures were performed by surgeons. For many anesthesiologists, however, the psychological barrier of making an incision and performing a cricothyrotomy, especially in an obese neck, remains a considerable hurdle and may delay timely rescue. Interestingly, in a survey of attitudes to emergency FONA, only ≈10% of responding Canadian anesthesiologists opted for open surgical or scalpel/bougie cricothyrotomy as their first choice approach.[13] Furthermore, Timmermann et al[14] have questioned abandoning narrow-bore cricothyrotomy, emphasizing the role of human factors in determining the preferred approach for emergency FONA. Instead, this group advocated continued training in both techniques.

Much of the morbidity associated with narrow-bore cricothyrotomy relates to TTJV. This is fraught with problems, even in experienced hands, and can easily lead to barotrauma. In a meta-analysis of elective as well as emergency CICO and emergency non-CICO cases, Duggan et al[15] concluded that complications occurred 6–7 times more frequently with emergency CICO (51% of the 90 cases reported). Barotrauma was 4–5 times more likely with emergency CICO. The Ventrain's unique technology, however, associated with lower peak inspiratory pressures and the possibility of capnography monitoring, may make ventilation with the device inherently safer than with TTJV. Nevertheless, a major concern with both techniques is the need for a correctly placed airway cannula. Kinking, malpositioning, and dislodgement are all known complications. Furthermore, during a crisis, cognitive and motor skills become impaired, and this may have a detrimental effect on the manual operation of the Ventrain. Anesthesiologists should therefore undergo regular skills training in transtracheal cannulation and operation of the device if the full benefits of this potentially life-saving technology are to be realized.

Needle cricothyrotomy is the recommended FONA technique in 1- to 8-year-old children (Difficult Airway Society guidelines). Although CICO is a rare event in this age group, critical upper airway obstruction may arise from respiratory infection or anaphylaxis. In these situations, needle cricothyrotomy with an appropriately sized cannula and adjusted Ventrain flow rate may be indicated.

In summary, the Ventrain has many theoretical advantages over TTJV. The device has a role to play in elective airway management, but it remains unclear whether clinical benefits will arise in the CICO scenario and allow inclusion in airway algorithms. We advocate regular simulation training with this technique. Furthermore, to better define its future place in anesthetic practice, anesthesiologists are encouraged to report details of their clinical experiences.

DISCLOSURES

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Contribution: This author helped prepare, edit, and revise the manuscript.
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Contribution: This author helped prepare, edit, and revise the manuscript, and prepare the supplemental digital content (video).
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