**Notes on oxygen consumption**

The intention of this short paper is to increase awareness of factors that help to minimise the flow of oxygen required to achieve adequate oxygenation in a patient with respiratory failure. It considers how to do this for different types of ventilation. Content is for information only and does not provide recommendations on what actions to be taken in particular clinical situations.

**1. Invasive ventilation**

The oxygen consumption per minute of a bedside ICU ventilator is equal to the proportion of added oxygen in the gas mix, multiplied by the volume of gas that leaves the inspiratory port per minute.

* The proportion of added oxygen can range from zero (at set FiO2 = 21%) to 1 (FiO2 = 100%). It is equal to (FiO2-0.21)/0.79. Ventilated COVID-19 patients typically require very high FiO2, often in the range of 60-90%, which is much higher than required by patients ventilated for other reasons.
* The total gas that leaves the inspiratory port is the sum of the volume of gas that enters and leaves the patient (the minute volume) and the volume of gas that bypasses the patient entirely and escapes through the expiratory port (the bias flow).
	+ Minute volume (MV) depends on the size of the patient and is typically something like 100 ml/kg/min, or 7 litres per minute for a 70 kg adult.
	+ Bias flow (BF) depends on the ventilator, but is typically something like 2 litres per minute for the period that the expiratory valve is open, i.e. during exhalation, approximately 70% of the breathing cycle. Check the instructions for use (IFU) for details on the specific model. Some ventilators (particularly Puritan Bennett PB840 and Aeonmed VG70) give a much higher bias flow (up to 7.5 and 30 litres per minute respectively) when the breath triggering is set to flow-triggered mode.

Thus the oxygen consumption is equal to:

 ((FiO2-0.21) / 0.79) \* (MV + (BF \* expiratory time ratio))

For example, at 80% FiO2, minute volume of 7 lpm and a bias flow of 2 lpm, oxygen consumption is:

 ((0.8 - 0.21) / 0.79) \* ( 7 + (2 \* 0.7)) = 6.3 litres per minute.

Things to look out for:

* As above, bias flow can vary depending on breath trigger settings. Check the manual for details. If so, setting the ventilator to pressure trigger mode should reduce overall oxygen consumption, until and unless ventilator-patient synchrony cannot be achieved in pressure trigger mode which can result in an avoidable risk of harm to the patient.
* Some ventilators (including the PB840) consume oxygen while in standby mode (10 litres per minute). If it is to be left unused for more than a few minutes, shutting down these types of ventilator or disconnecting them from the oxygen supply will save on oxygen usage.

**2. Transfer ventilation**

For turbine-driven transfer ventilators with dual-limb circuits (such as the Hamilton T1 and C1), the same relationship holds as for bedside ventilators. For transfer ventilators that entrain air using Venturi effect (e.g. Draeger Oxylog series, TransPAC), the relationship should also hold, but low FiO2 values (<40%) are not possible, as some oxygen flow is needed to entrain air. In addition, the single-limb circuit setup of these devices may theoretically result in a less controlled leak and therefore higher oxygen consumption; that having been said, for the Oxylog 3000+, the IFU quotes the oxygen consumption as being just MV + 0.5 lpm.

**3. Non-invasive ventilation**

Multiple complex factors affect the oxygen efficiency of NIV systems, and therefore the oxygen consumption for any given FiO2. Some of these factors are related to the device model, and others are related to the circuit setup.

These factors include:

* **Flow driver (worse) vs. turbine device (better).** Flow drivers provide a constant flow of gas to the patient throughout the breathing cycle regardless of demand, resulting in waste. Turbine devices only deliver gas as needed to achieve and maintain the intended airway pressure needed for therapy.
* **Location of low pressure oxygen entrainment - directly into the circuit (worse) vs. at inlet in rear of device (better).** Typically, smaller domiciliary devices require oxygen to be entrained into the circuit using an airway adapter, whereas more advanced devices allow oxygen to be delivered via an inlet at the rear of the device. When entrained near the patient, it appears that a larger oxygen flow is necessary to achieve the same FiO2, likely due to poor mixing of gases resulting in disproportionate loss of oxygen through the exhalation port.
* **Low-pressure oxygen entrainment (worse) vs. high-pressure oxygen and on-board blender (better).** Some acute NIV devices allow connection directly to a high-pressure oxygen source but many NIV devices require oxygen to be added from a wall flowmeter into the system via oxygen tubing. These latter devices require low pressure oxygen to be delivered at a constant rate from an oxygen flowmeter into the device or circuit, regardless of demand, resulting in wastage. Where high-pressure oxygen is used, oxygen is only released into the system as needed to maintain the set FiO2.
 A further disadvantage of low-pressure oxygen entrainment is that there is no direct control over the FiO2 delivered to the patient. Such devices are generally only used therefore where inhaled oxygen monitoring is available; this can be achieved using a sidestream capnography device with integrated oxygen monitoring (e.g. GE Carescape E-sCO module), or a handheld oxygen analyser (e.g. Maxtec MaxO2).

 See the paragraph on ‘Oxygen flowmeters’ in section 4 below for further discussion on how to reduce oxygen consumption from low-pressure oxygen entrainment devices.

* **Passive exhalation port / leak port (worse) vs. active exhalation valve (better).** Single-limb devices require an outflow for exhaled gas, in order to prevent it being rebreathed by the patient. Most of the time, this is achieved by an intentional leak (a hole) in the mask or in the circuit near the patient end. This results in a torrential leak of unused breathing gas throughout the breathing cycle, particularly during inspiratory phase when such an outflow is unnecessary. Some advanced devices support an active exhalation valve, built into the circuit, which is controlled by the ventilator via a pneumatic drive line. This may be called an “active circuit” or “ActivePAP” depending on manufacturer. An active exhalation valve stops all outflow during the inspiratory phase, reducing gas wastage and improving inspiratory pressure delivery. Of course, ICU ventilators also use active exhalation valves, and can control the outflow from the valve much more precisely. However, be aware that some ICU ventilators use large bias flows in NIV mode that may equal the flow from an active expiratory valve on a single-limb device. On some ventilators (e.g. GE Carescape R860) this bias flow can be adjusted and may be carefully reduced to the lowest value that is clinically indicated.
* **Poorly-fitting mask vs. well-fitting mask (better).** Leaks around an NIV mask can easily double or triple the volume of gas delivered. Ensuring masks are properly in place will reduce any excess oxygen flow.

The above information can be summarised as a hierarchy of NIV setups, as in the table below:

| **Device type** | **Circuit type** | **Example model** | **Therapies possible** | **Relative oxygen efficiency** |
| --- | --- | --- | --- | --- |
| **Flow driver (oxygen-driven)** | **CPAP circuit with PEEP valve and safety valve** | Whisperflow; Vital Flow 100; Pulmodyne O2-MAX | * CPAP via mask
* CPAP via hood
 | Extremely poor |
| **Flow driver (with gas blender)**  | **CPAP circuit with PEEP valve and safety valve** | Draeger CF 800;O2 + air flowmeters connected with Y-piece | * CPAP via mask
* CPAP via hood
 | Poor |
| **Turbine NIV for domiciliary use (oxygen entrained directly into circuit)**  | **Single-limb with passive exhalation port or vented mask** | Philips Dreamstation, BiPAP S/T; ResMed Stellar, Lumis | * CPAP via mask
* NIV via mask
 | Poor-moderate |
| **Turbine NIV (low pressure oxygen entrained at rear)** | **Single-limb with passive exhalation port or vented mask** | Breas Vivo series, NIPPY 4 | * CPAP via mask
* NIV via mask
* Ventilation via tracheostomy (where licenced)
 | Moderate |
| **Turbine NIV (high pressure oxygen inlet and onboard blender)**  | **Single-limb with passive exhalation port or vented mask** | Respironics Trilogy 202, Trilogy Evo, Vision, V60;  | * CPAP via mask
* NIV via mask
* Ventilation via tracheostomy (where licenced)
 | Moderate-good |
| **Turbine NIV (low pressure oxygen entrained at rear)** | **Single-limb with active exhalation valve** | Breas Vivo 55, 65, NIPPY 4+; PrismaVENT 50-C | * CPAP via mask
* NIV via mask
* Ventilation via tracheostomy (where licenced)
 | Moderate-good |
| **Turbine NIV (high pressure oxygen inlet and onboard blender)**  | **Single-limb with active exhalation valve** | Respironics Trilogy 202, Trilogy Evo | * CPAP via mask
* NIV via mask
* Ventilation via tracheostomy (where licenced)
 | Good |
| **ICU ventilator** | **Dual-limb** | Various | * CPAP via mask
* CPAP via hood
* NIV via mask
* Ventilation via tracheostomy
* Ventilation via ETT
 | Good |

**Therefore, where possible, if seeking to reduce oxygen consumption:**

* Use a turbine device in favour of a flow driver
* Use a device with a high-pressure oxygen inlet hose in favour of a low-pressure inlet port
* Use a device with a low-pressure inlet port in favour of requiring oxygen to be entrained into the circuit
* Use a circuit with an active exhalation valve in favour of a passive exhalation port (leak) or vented mask

**4. Further Notes**

Oxygen flowmeters: avoiding unintended high oxygen consumption

While conventional oxygen flowmeters used in acute care can typically deliver a measured flow of oxygen up to 15 litres per minute, it is possible to increase the flow beyond 15 lpm by continuing to open the valve (by turning it anticlockwise). It should be noted that, in this way, huge flows (potentially approaching 80-100 lpm) can be generated, and this may be considerably more than intended by the clinical team. This far exceeds the flow of oxygen that can be delivered effectively via conventional devices such as face masks, and will result in significant waste. It can also potentially cause high oxygen levels in the local environment (see section on enrichment below).

This situation can be detected (and avoided) by checking the valve settings of any flowmeters that are indicating oxygen flow at their maximum value. One way to do this, where clinically safe and appropriate to do so, is by turning the valve down carefully until the flow just drops below its maximum value and then turning it up again to regain the required maximum setting.

Enrichment

Any oxygen delivered to a patient and not used to achieve oxygenation is generally released into the ambient air, regardless of the apparatus or mode of ventilation. This results in oxygen enrichment of around the patient and in the room and increases the risk of a devastating fire, especially in smaller, poorly ventilated spaces. Optimising oxygen efficiency, therefore, also reduces the risk of fire.

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