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Editorial

Low cost devices to help in COVID-19

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This edition of Trends in Anaesthesia and Critical Care contains an intriguing paper by Kumar et al. [1] on the use of a low flow nasal cannula under a non-rebreather mask to increase delivered oxygen concentration to patients in respiratory distress from COVID-19. This setup is relatively cheap and uses less oxygen and much less sophisticated equipment than devices such as non-invasive ventilation and high flow nasal cannulae. Of note, the authors do not claim that their method is a substitute for these more sophisticated devices. Rather they quote the impact on two COVID-19 patients with significant respiratory failure who eventually recovered after application of this simple therapy, and postulate that it might find application in settings where resources are limited.

At first sight, it might appear that addition of a low flow nasal cannula would make very little difference. After all, the flow rate supplied by the cannula in the cases described by Kumar et al. was only 6 l/min whereas the flow supplied to the mask was substantially greater at 15 l/min. In addition, the patients were breathing at high respiratory rates (>30 breaths/min) and their peak inspiratory flow would very likely have been well in excess of 20 l/min. Under these circumstances, it seems unlikely that the small additional flow from the cannula could have made much difference. However, as we shall see later, even this small flow could have the potential to make a substantial difference to the inspired oxygen concentration of the patient while also washing out some CO_2 from the mask and airway. For patients who are *in extremis* with significantly compromised gas exchange as a result of respiratory diseases such as COVID-19, this may well be just enough to improve the patient's chances of overcoming the disease.

Over the years there has been continued interest in the FiO_2 provided by this kind of mask, albeit few publications. In 2007 Wagstaff and Soni [2] compared the oxygen delivery performance of various devices using an artificial lung implemented with a ventilator and attached to a mannequin. They found that the FiO_2 delivered by non-rebreather masks can fall to as low as 40% for higher tidal volumes and respiratory rates. In their setup the non-rebreather mask actually performed worse than a standard Hudson mask. Subsequent publications compared the performance of non-rebreather masks with other devices in preoxygenation scenarios [3,4] with achievable FEO_2 (the authors did not measure FiO_2 directly in their experiments) varying widely between 50% (with flows of 15 l/min) to >80% (with flows of 60–70 l/min). Of course, if high flow is to be used then for patient comfort and compliance it is probably better to use a high flow nasal cannula [5].

A major contributor to the low FiO_2 values seen with low flows is leak under the skirt of the mask. As early as 2003, Boumphrey et al. [6] reported FiO_2 values with a rebreather mask as high as 97% with flows of 15 l/min, but only if the mask was fitted carefully over the face of the patient. This makes sense. The physics which pertains during inspiration tells us that in order for the patient to draw on the oxygen that is stored in the bag, it is necessary to create a low pressure on the patient side of the one-way valve connecting the bag to the mask [7]. If low flows of the order of 15 l/min are used, then the bag will fill relatively slowly during the expiration phase and so the gas in the bag is unlikely to be much above atmospheric pressure at the start of inspiration. Indeed, it may be essentially *at* atmospheric pressure. If this is the case, then the patient is likely to create a small negative pressure within the mask on inspiration, and this negative pressure draws gas from the bag into the mask through the one way valve. Unfortunately, if there is a leak around the mask skirt, the small negative pressure in the mask will *also* draw room air into the mask under the skirt, thereby diluting the oxygen from the bag and reducing the delivered FiO_2.

For those of us who like to calculate these things it is fortunate that – to a very rough first approximation – the diluting flow coming in under the skirt is likely to be quite closely related to the flow from the bag through the one-way valve into the mask. Assuming that the mask delivers a particular value of FiO_2 and the patient flow rate is known, we can then apply the dilution equation backwards to calculate the flow coming through the valve and also the diluting flow coming in under the skirt.

Armed with this knowledge, we can then estimate what is likely to happen if flow at a constant 6 l/min of 100% oxygen is supplied through a nasal cannula and added to the flow from the bag and the diluting flow under the skirt. The relative values of the flows will change as the patient inspires at a greater or lesser rate, but we can still calculate – at each part of the inspiratory phase – how much oxygen, nitrogen and other gases are going into the patient. By integrating over the inspiration phase the aggregate FiO_2 supplied to the patient over the whole of inspiration can be estimated.

Fig. 1 shows an example result from such a calculation. Here, we have taken a stylised inspiratory flow pattern which closely mirrors the flow measured on breathing through a flowmeter. Assume that a patient with this flow pattern breathes through a non-rebreather mask provided with an oxygen flow rate of 15 l/min, and that the 'normal' leak of the mask would provide an FiO_2 of 70%. Adding in 6 l/min of 100% oxygen from the cannula would obtain the

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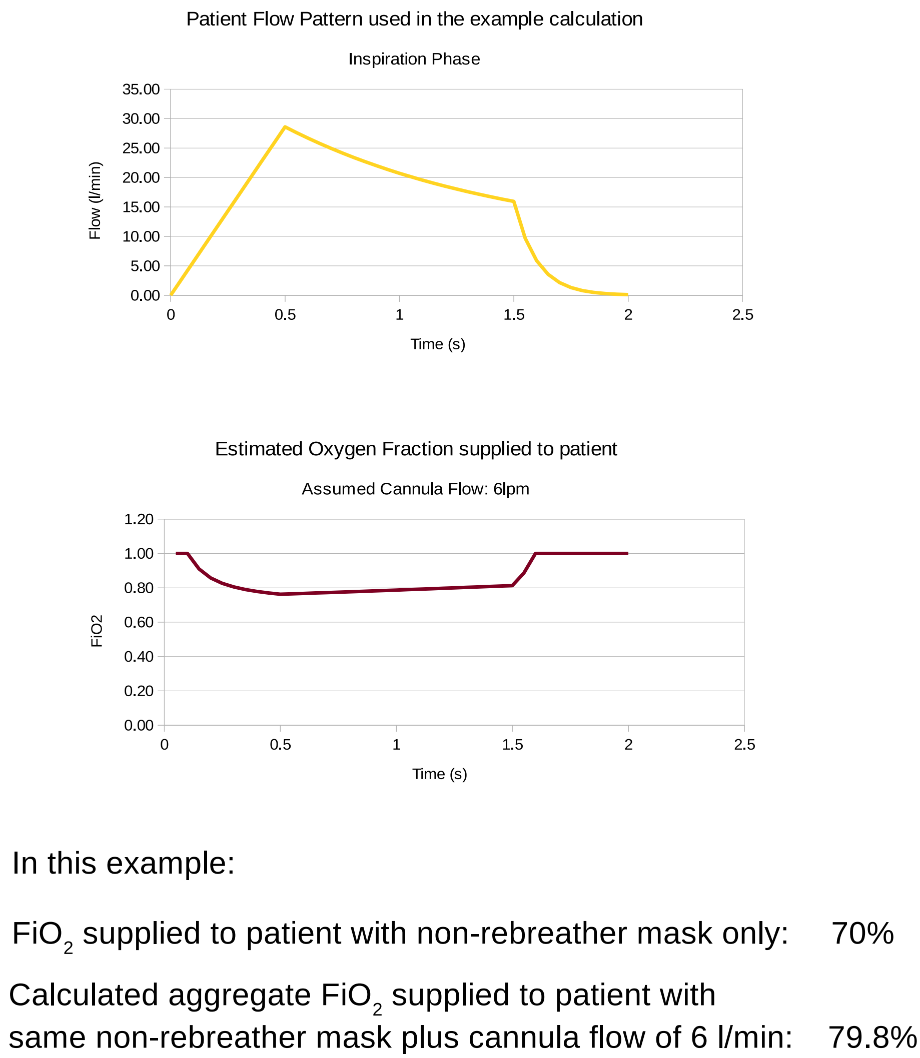

Fig. 1. Calculation of improvement in supplied FiO_2 by using supplemental oxygen at 6 l/min supplied via a nasal cannula under a non-rebreathing mask.

FiO_2 profile shown over the inspiratory phase (lower graph). Integrating the oxygen supplied gives an aggregate FiO_2 supplied over the inspiratory phase of nearly 80% - somewhat higher than the 70% achieved with the mask alone. Table 1 shows the results for different initial mask efficiencies related to skirt leak. The gain in FiO_2 with the cannula is greater if the mask on its own is less efficient. Of course, the actual figures obtained will vary substantially depending on leak and patient flow profile, but the cannula could potentially make a significant difference to the FiO_2 supplied.

We can also estimate the amount of CO_2 washout that will occur. Note that the cannula is applied to the nose, under the mask. All flow from the cannula will thus displace CO_2-rich gas from both the airway and the mask, particularly during the period at the end of expiration when flow is very low. Assuming the same expiratory flow profile (accepting this is unlikely to be exactly the case but is taken simply for the purposes of illustration), then the overall deadspace washed out by the cannula flow is likely to be of order of 40 ml or so. While not by any means equal to the total deadspace in the patient/mask system, it does nonetheless represent a useful gain in breathing efficiency.

Of course, these are theoretical calculations only and rely on several quite broad assumptions. However, they appear to support the improvements in oxygenation and breathing efficiency reported by Kumar et al. [1]. They only report on two cases. It is

Table 1
Estimated FiO_2 with mask alone, and with cannula flow added.

FiO_2 supplied by mask alone	Aggregate FiO_2 with 6 l/min cannula flow added
40%	59.7%
50%	66.4%
60%	73.1%
70%	79.9%
80%	86.6%
90%	93.3%

also clear that the degree of improvement will likely vary substantially from patient to patient – dependent on mask fit, breathing characteristics, and so on. However, in the current dire COVID situation – particularly in countries where resources in terms of equipment and oxygen supply are limited – there certainly seems to be enough evidence here to warrant further careful investigation of this technique.

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