USE OF AN OXYGEN RESERVOIR WITH A POCKET MASK

by Paul Botkin

ABSTRACT:

Rescue workers commonly ventilate patients who may have contagious diseases, so bag-valve-masks (B-V-Ms) and pocket masks have been adopted as protective devices. B-V-Ms deliver almost 100% oxygen but are commonly cited in the medical literature for making unintubated patients vomit into their lungs and for being difficult to use effectively, while pocket masks deliver less oxygen and require the ventilator to come into close proximity to a patient's face. An oxygen reservoir with a pocket mask combines the best features and eliminates the drawbacks of both devices, enhancing the versatility and the protective effects of a pocket mask, and enabling a ventilator with a pocket mask to meet the A.H.A.'s recommended ventilation standards in an unintubated patient. And given the rapid spread of the use of AEDs in prehospital settings, it is noted that the oxygen reservoir should offer a considerable improvement in the success rate of defibrillation attempts. The discussion of hypercarbia describes experiments in which CPR was performed for one minute before defibrillation was attempted. When the CPR was given using 100% oxygen, researchers achieved a success rate (return of spontaneous circulation) of 75%. When that oxygen was cut with 5% carbon dioxide the success rate fell to 13%, required more defibrillation attempts with higher voltage, and resulted in more post-resuscitation ventricular arrhythmias (i.e. demonstrating a "cardioplegic" effect of carbon dioxide on the heart). Use of a reservoir effectively cuts the carbon dioxide delivered with a pocket mask to zero.

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The American Heart Association recommends[1] that patients being ventilated should be given 100% oxygen at tidal volumes of 0.8-1.2 L.

Arterial blood gas measurements show that, even when ventilated in hospital with “adequate” (i.e. above 0.8 L) volumes of 80% oxygen, 55% of properly intubated patients undergoing CPR could not be adequately oxygenated.[2] Such unsatisfactory blood gas values in “vigorously breathed”[3] patients are strongly associated with, and attributed to, pulmonary edema[2-4] caused by a combination of reduced (one-quarter to one-third of normal[5]) cardiac output, and high pulmonary venous pressures. These observations “emphasize the importance of persistent ventilatory insufficiency in the development of refractory acidosis,”[4] which retards oxyhemoglobin saturation.[ibid] Patients needing ventilation will often have been running at a respiratory and possibly a metabolic[1,4] acidosis for some time, so the need for adequate alveolar ventilation and enhanced oxygenation is urgent and the relative adequacy of the respiratory support may be critical. Failure to meet at least the minimum recommended ventilatory standards, especially during CPR, can therefore be expected to have an adverse effect on patient outcomes.

A comparison of pocket masks with bag-valve-masks (B-V-Ms) shows that they have respective advantages and disadvantages for both patients and ventilators. Specifically:

OXYGENATION:

The salient advantage of a B-V-M with a bag-style reservoir and high-flow (15-20 L/min) oxygen is that it can, as recommended, deliver 90-100% oxygen.[1,6-12]

A pocket mask, used to ventilate every three seconds with supplemental oxygen at 15 L/min, has been estimated to deliver roughly a 40-50% concentration of oxygen.[8-11,13,14] With the pocket mask it is evident that, during the expiratory phase (i.e. between ventilations), the continuous flow of oxygen from the tank simply reflects off the patient's face and escapes to the atmosphere through the one-way valve.

VENTILATION VOLUME:

With B-V-Ms the difficulty of providing patients with even the minimum recommended tidal volumes is frequently cited.[1,6,7,10,13,15-27] This is attributed to the difficulty of maintaining both an adequate face seal and an open airway with one hand while squeezing the bag with the other, even while using an oropharyngeal airway, a difficulty that is compounded[28] by hand fatigue. Over half of the nurses and medical students,[ibid] 18 of 21 senior student nurses,[26] and from one third[23] to roughly half[6,19] of the Emergency Medical Technicians tested have been unable to provide the minimum recommended tidal volume with a B-V-M, even with normal lung compliance. Over 80% of the ventilations have been found to be inadequate.[26] As a result, the B-V-M "may be a major hazard to successful resuscitation."[16]

Ventilatory volumes have also been shown to change with lung compliance.[29] Testing with paramedics found that ventilatory "tidal volume rapidly fell as lung compliance decreased,"[30] attributed to increasing difficulty with the mask seal and diversion of ventilatory flows to the stomach.[26] Lung compliance has been found[2,31-33] to be "markedly reduced within a short time after cardiac arrest," a trend which continues even after a return of spontaneous circulation,[34] due to "commonly-found" edema,[4] aspiration[35] and reduced thoracic compliance.[36,37] Changes in patients' airway resistance are also "likely to be a significant factor in the apparent decreased compliance."[2,11] And gastric inflation "may also elevate the diaphragm and restrict lung movements,"[25,26,33-35,38] further decreasing respiratory system compliance.

Using two hands to squeeze the bag with (i.e. intubated, or with two operators) has been found to give "a clinically important increase in delivered tidal volume."[27,29,39] As a result, it has been recommended that the bag-valve apparatus always be squeezed with two hands, and used only on intubated patients[13,16,29,39] to avoid mask leak problems. Because of the difficulty of using a B-V-M, it is the policy of the Workers' Compensation Board in British Columbia that the pocket mask "is preferred for those who don't use a bag-valve mask frequently," and that "if there is any difficulty using the bag-valve mask, the Attendant should immediately switch to the pocket mask."[83]

Even when there is a good face seal and lung compliance, the inadequacy of the tidal volume provided by a B-V-M can be confirmed simply by having a colleague apply one to you and ventilate every three seconds. If this equates to a patient's experience, then perceived tidal insufficiency (i.e. acute discomfort caused by inadequate removal of carbon dioxide) would appear to be behind complaints from conscious patients about the use of B-V-Ms to assist their breathing. Patients who need ventilation at accident scenes are generally in shock; those still conscious tend to be excited (if not panicky) in their struggle to breathe, and in pain. All of this will greatly increase their need for "air." The author has seen a patient trapped in wreckage, struggling to breathe and with three broken limbs, use their remaining unbroken limb to push away the B-V-M being wielded by a skilled operator.

And even if a B-V-M-with-(bag)reservoir collects and delivers all of the oxygen from a unit to the patient's lungs, the tidal flush provided by a 15 L/min flow is uncomfortably small. This can be verified simply by inhaling oxygen at 15 L/min directly from the line from an oxygen unit, an experiment which will soon have even a relaxed experimenter sucking for "extra." This indicates that the ventilatory tidal volume from a 15 L/min oxygen flow, even if delivered by a B-V-M-with-reservoir without any leakage (two operators), will be inadequate to relieve a patient's respiratory discomfort and would be better augmented.

On the other hand, when ventilating with exhaled gas (i.e. mouth-to-mouth or by pocket mask), both the research[1,6,10,15-17,20,22,24,40] and the author's experience of being ventilated in practice sessions indicate that there is no such problem in providing adequate tidal volumes. This is not surprising because the vital capacity of most people is so far above the minimum required that a ventilator can compensate for some mask leakage,[32] which is also reduced or eliminated because they use both hands to maintain a face seal and patent airway.

GASTRIC INFLATION, REGURGITATION AND ASPIRATION:

Reduced lung and thoracic compliances, gastric inflation and increased airway resistance inhibit ventilatory flows into the lungs (above). At the same time, relaxation ("rapid and severe"[38]) of the lower esophageal sphincter and obtundation of the protective laryngeal reflexes decrease resistance to air flow into the stomach.[26,41-43] Steady ventilations with just enough pressure to overcome respiratory resistance may eliminate, or will at least minimize, gastric inflation of unintubated patients. Slow (1.5-2 sec.), even (pressure) breaths have been recommended,[1,30,44,45] to reduce gastric inflation and the likelihood of subsequent aspiration.

Because of the smaller-than-vital capacity of B-V-Ms and leakage from around the face seal, ventilators tend to "puff" air into a patient to generate chest wall movements which indicate successful ventilation. Studies have shown a lack of fine control when squeezing the bag, resulting in "dangerously high" peak airway pressures and flow rates.[25,42,46-48] Extremes of both hypo- and hyperventilation of intubated patients have been found ("a common problem"[49]), attributed to "vigorous but uncontrolled" bag-valve ventilation (two-handed) by skilled hospital staff.[ibid] These ventilatory variations are wide enough to cause pH and PCO2 changes in the blood gases resulting in "life-threatening complications" (e.g. arrhythmias, systemic hypotension, coronary vasospasm).[49-52] These uneven ventilations combine with the physiological changes to divert ventilatory flows from the lungs to the stomach.

Inflating the stomachs of cadavers with air has been found to be "an almost certain way of producing regurgitation of water instilled into the stomach."[53] Autopsies after resuscitation attempts found gastric dilation in 29.1% of patients.[54] "It is now clear that regurgitation and aspiration must be considered as major hazards"[55] ("the major problem"[56]) during resuscitation. Vomiting has been found in 30.6%[54] (33%[57]) of cases of cardiac arrest and CPR, and autopsies show pulmonary aspiration in 31% of out-of-hospital CPR patients and in 10% of (more rapidly intubated) in-hospital patients.[58] Aspiration pneumonia has been found to be "significantly related to mortality" of patients following cardiac arrest,[59] or "the direct cause of death" of patients requiring resuscitation.[53] In-hospital aspiration has resulted in mortality rates of 62%[60] (or 63%[61]).

A B-V-M has been found to put almost three times as much air into a patient's stomach as a pocket mask.[62] With normal lung compliance, gastric insufflation of 1.3 litres has been found after one minute of B-V-M ventilation, increasing to 3.0 litres[26] (3.7 litres[63]) when lung compliance is reduced. Forty percent of the total volume from a B-V-M has been found to inflate the stomach when lung compliance is low.[26] B-V-M ventilations have been found to be "associated with a high risk of gastric inflation and subsequent increased risk of regurgitation" in hospital studies of patients undergoing CPR.[41,64] In evaluations of hospital[65] and prehospital[66] techniques for treatment of cardiopulmonary arrest and fibrillation, aspiration with the use of B-V-Ms was noted to be "a significant problem" (21% and 33% of patients respectively), and was found to have "clearly contributed to the deaths of a number of patients who (had) survived to be hospitalized."[ibid] Researchers have suggested[67] that spirometers be used with bag-valves, and that ventilation devices be developed with microprocessors to make breath-by-breath adjustments in response to changes in patients' respiratory compliance.

With a pocket mask, on the other hand, the two-handed face seal and the operator's larger vital capacity make it easier for a ventilator to generate chest wall movement with a steady, slow breath. And anyone singing or whistling a tune is demonstrating considerably more control over air flow rates and pressures than can be achieved, even with two hands, by crumpling a self-inflating bag. This would appear to explain the greatly reduced gastric inflation observed with pocket masks,[62] despite the greater ventilation volumes being delivered (above).

HYPERCARBIA:

Tissue studies of heart muscle have shown that carbon dioxide, "even in modest concentrations" has a "rapid and profound" inhibiting effect on contractility, independent of pH or PO2.[68-70] Similarly, studies of resuscitation after induced ventricular fibrillation in animals have found decreased cardiac resuscitability and a raised threshold for electrical defibrillation with increasing carbon dioxide levels,[71-73] again independent of metabolic (lactic) acidosis and despite high levels of oxygen. The recovery rate (i.e. return of spontaneous circulation) fell from 75% to 13% when 5% carbon dioxide (similar to exhaled air[74]) was added to the ventilating gas (i.e. 95% oxygen).[71] This adverse ("cardioplegic"[75]) cardiovascular effect is also associated with post-resuscitation ventricular arrhythmias.[73] Serial blood gas analyses during hospital resuscitation attempts found that patients who died in the emergency department had had significantly higher CO2 levels than patients who were successfully resuscitated, though "all other parameters showed no significant difference."[76] Carbon dioxide in the ventilating gas has been suggested[77] as part of the explanation for studies indicating that resuscitation attempts using cardiac massage (i.e. without ventilations) are just as effective as CPR for the first few minutes.

Room air contains a negligible amount of carbon dioxide (.03%). A B-V-M delivers this or, with increasing supplemental oxygen flows and a bag-style reservoir, will progressively reduce the concentration of carbon dioxide in the ventilating gas mix until it is effectively zero (i.e. 100% oxygen).

A ventilator with a pocket mask delivers exhaled air with 4% +- 0.6% carbon dioxide, even while performing one-operator CPR.[74] With high-flow supplemental oxygen this concentration will be cut proportionately (by from 1/4 to 1/3) as the oxygen in the ventilating gas increases from 16.4% +- 0.7% (exhaled air) to 40-50% at a 15 L/min flow. The cardiac effect of carbon dioxide at the resulting concentration (roughly 2-3%) hasn't been established in the literature surveyed. Arterial blood gas studies do show that there is a "striking fall" in PaCO2 levels when a patient is intubated after being ventilated either by mouth-to-mouth[4] or with a B-V-M.[76]

SYNTHESIS:

It is proposed that an oxygen reservoir attached to a pocket mask will relieve the shortcomings of both the pocket mask and the B-V-M, combining their best effects (i.e. the former's tidal volume with the latter's high oxygen content) to meet A.H.A. standards for adequate ventilation.

The reservoir (picture) consists simply of a section of standard flex hose 3 feet long (enclosing a volume of about 300 ml.), with a mouthpiece at one end and an oxygen delivery port which fits onto the one-way valve of a pocket mask at the other. This reservoir-valve-mask (R-V-M) might be described as a B-V-M-with-reservoir *without the bag*, or more simply as a B-V-M you blow through instead of squeezing. Oxygen, which escapes from the system between ventilations if fed directly into a pocket mask, is instead collected in the flex hose above the one-way-valve. The operator holding the mouthpiece in their teeth will distinctly feel the back-flow between ventilations as oxygen feeds into the reservoir. The collected oxygen is delivered to the patient with subsequent ventilations. Dead air (and possibly some alveolar gases) from the operator's respiratory tree can be expected to enter the (reservoir and) patient's airways more or less in sequence after the bolus of oxygen from the reservoir, supplementing the ventilatory volume of the oxygen. These gases will be mixed with the continuous flow of oxygen from the tank, as is usual during ventilations with a pocket mask. So expired air from the operator's respiratory tree powers and then supplements the ventilatory volume of the oxygen.

Ventilating every three seconds using the reservoir (R-V-M) with supplementary oxygen at 15 L/min delivers oxygen to a patient at concentrations consistently above 85%.[10,78,79] At 20 L/min the oxygen concentration delivered is 100%.[78] For spontaneously ventilating patients the device acts as a non-rebreathing mask, delivering the same oxygen concentrations.[79] By the author's calculation, ** these results are consistent with delivering to a patient 100% of the oxygen from a 15 L/min flow if the ventilations are given slowly (roughly 1.5 sec.). R-V-M ventilations also compare favourably with the "inhalation technique" in which a ventilator inhales the oxygen, effectively using their own lungs and airways as a reservoir. That method delivers 71% O2 to the patient when oxygen is supplied to the ventilator at 15 L/min.[40] The difference may be simply because ventilators using this technique will inhale some room air for their own comfort, thereby mixing and diluting the oxygen.

As well as increasing the oxygen concentration delivered by a pocket mask, the reservoir will enhance both a ventilator's capacity to deliver adequate tidal volumes, and their control over the ventilatory flows. Any singer or wind instrument player can confirm that straightening up takes pressure off the diaphragm and allows better breath control, making it easier to deliver slow, even breaths to (hold a note or) reduce gastric inflation. So a patient's demand for generous tidal volumes, best met by expired air ventilations, can be more easily and safely met when a reservoir is added to the pocket mask.

To summarize the most important advantages of the R-V-M: first, an operator can provide adequate tidal volumes powered by expiratory air, as with a pocket mask. The ventilator uses both hands to maintain a patent airway and a mask seal, difficult for even experienced operators to accomplish one-handed with a B-V-M. Second, the R-V-M appears to match the O_2 delivery of a B-V-M-with-(bag)-reservoir, or at the very least to deliver oxygen at far higher concentrations than can be achieved with a pocket mask alone, in the process reducing potentially dangerous levels of carbon dioxide in the ventilatory gas. Third, the inadequate airway maintenance and the high peak pressures and flow rates characteristic of the use of B-V-Ms, which result in gastric inflation and the consequent increased risk of aspiration, can be greatly reduced if not eliminated.

The R-V-M has other advantages over a pocket mask in rescue situations. A ventilator can look around, communicate, organize people and react to changes in the situation far more easily if they don't have to keep bending down and losing sight of the scene every two seconds. Using the R-V-M will be safer for the operator than exposing the back of their head and neck to a crowd every time they bend down to ventilate. And the ventilator can keep more distance (full arm's length; better than with a B-V-M) from a convulsing or potentially combative patient. And in rough conditions, as when moving a patient on a stretcher, in a boat or on a toboggan going down a ski slope, sudden jolts won't cost the ventilator their teeth.

Added to a pocket mask, the reservoir may also give superior protection from airborne diseases by distancing the operator from the one-way valve through which the patient is exhaling (let's not get near hepatitis or TB). Studies have found reluctance on the part of both the public[80] and health-care professionals[13,79,81] to use either mouth-to-mouth or pocket masks to ventilate, especially those patients (59%[57]) considered "dirty" (i.e. presence of vomitus, blood, secretions, infection) or otherwise unpleasant. Though there is no backleak through the one-way valves of the most commonly used masks,[82] the addition of other "distancing" devices (i.e. a mouthpiece or a bacterial filter) has helped to overcome the reluctance of professionals to use pocket masks.[13] My conversations with rescue personnel indicate that a reservoir 3 (or 4) feet long makes the idea of using a pocket mask more comfortable.

With a reservoir on the pocket mask the ventilator doesn't have to keep interposing their head to within two inches of a patient's face, obstructing others' attempts to assess levels of consciousness or eye reactions, apply hard collars or deal with head/facial/neck injuries. The ventilator's view of the patient's chest or abdominal movements to assess the effectiveness of the ventilations actually improves. To stabilize C-spine, the operator has the option of holding the patient's head between their knees. In fact the operator gains considerable freedom of position, making it easier to ventilate, for instance, a patient positioned on their side for drainage, or in awkward circumstances during extrication (e.g. ventilating a driver from the back seat of a car, or reaching to a patient trapped in an enclosed space). This can help considerably if the alternative is to lean in a car window with a pocket mask or a B-V-M, getting in the way of the firefighters who are trying to cut away the door and roof.

The operator's "feel" of ventilations with a pocket mask is the same with or without the reservoir. Blowing through three feet of flex-hose will confirm that the resistance offered by the reservoir is imperceptible, and the operator gains considerable freedom to adopt a more comfortable position (e.g. upright) in which they can breathe more easily (some operators do have degrees of difficulty inhaling while bending over a patient). And it seems intuitive that the better sensitivity or "feel" of the ventilations compared to a B-V-M will confer another advantage: an operator will quickly notice, and compensate for, changes in the patient's resistance to ventilation, as from a partially blocked airway, loss of thoracic compliance or developing atalectasis, because their tendency is to deliver "a breath" (in volume, with a two-handed seal), as opposed to "squeezing down" the (leaky) bag. The author has observed the tendency of first aid students to adjust their ventilation pressures to match the various models of Resusci-Anne doll (and blow harder when someone has poked a piece of gauze down a doll's throat). When ventilating with a pocket mask I've noted my own reflex adjustment, immediate and without thinking, to match changes in a patient's respiratory resistance.

Finally, the current protocols of the Workers' Compensation Board in British Columbia call for an Occupational First Aid attendant, while ventilating, to teach a bystander to use a pocket mask if there is no one already trained available to help. This frees the attendant to deal with the transport priority, but precludes giving the patient high-concentration oxygen (with a B-V-M-with-reservoir, which we are not about to try teaching to a passer-by) until the first aid attendant can take over ventilations again after they have packaged the patient on a spine board, begun or at least organized transport, and fully assessed the patient. Adding the reservoir will enable anyone who can use a pocket mask to deliver high-concentration oxygen as soon as the first aid attendant can crack the tank, and to keep it up until the patient can be intubated.

So far, studies of prehospital ventilation techniques have employed a variety of in-vitro models, human and animal in vivo models, ventilation rates, O_2 flow rates and operator positions. Not only should these variables be compared in future testing, but they all should be evaluated by their effects on patients' blood gases. That effect is, after all, the reason we ventilate people. Apparently we don't know much about whether increasing the O_2 concentration in the ventilating gas by increasing the O_2 flow rate from 12 to 15 or even 20 L/min makes a practical difference to the patient. Studies in humans “are lacking.”[1]

In future studies it might also be useful to attempt to simulate the relevant effects of rescue situations on ventilators, especially the considerable influence of adrenaline on both their vital capacity and the steadiness of their hands. The effect on the former will tend to increase the effectiveness of expiratory air ventilations (as when the delivered minute volume during 5 minutes of CPR increases by from 50% to 130%[74]). The latter effect may be expected to reduce the effectiveness of attempted one-handed face seals, and therefore the percentage of operators considered able to ventilate adequately with a B-V-M. Such tests might, for instance, be set up on the third floor of a building and have the operators walk up a half-dozen or so floors, take the elevator down to the main floor and then run back up to the test room. Tests after one minute of rest might then reveal differences in the usefulness of expiratory air-powered vs. hand-powered (i.e. B-V-M) ventilations even more marked than those which have been found in the testing to date.

The good news is that a reservoir to fit the one-way valve on a pocket mask can be put together from standard parts (i.e. mouthpiece, flex hose and oxygen port) for less than $10.00. If you store a reservoir and mask with each oxygen unit (it’s smaller than a B-V-M, easily sterilized after use and mashable into various spaces), you can buy a cheaper pocket mask (i.e. without an oxygen port) and save more than enough money to pay for the reservoir.

An assembly problem has cropped up with the Laerdal mask because the company has added a flange to the top of their one-way valve, making it impossible to attach anything until the flange is sanded down. It is possible to fit an oxygen port to the one-way valve of any other pocket mask (in some cases using an adapter), or to manufacture one-way valves with a oxygen ports built-in (or added on) proximal to the valve.

*** Based on the estimated tidal flow generated by a 15 L/min O2 flow at this ventilation rate, and on comparisons with the results obtained[1,6-12] with a B-V-M-with-reservoir at high O2 flows delivering, almost certainly, smaller tidal volumes.*

I hope this idea will do some good.

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