Low Flow Anesthesia & Patients Waking Up – Part 1

"Why would my patient wake up just because I reduced my oxygen flow rate?" At first, this question perplexes many of us who try low flow anesthesia. Later we realize that if our patients don't get lighter when we reduce our oxygen flow rate, we have likely been over-anesthetizing them in the past. In this four-part series we'll be taking a closer look at the advantages and disadvantages of low flow anesthesia, and dive deeply into how it all works.

"Quick and Dirty" Calculations

It's no secret that I am a fan of low flow anesthesia. When your patient is on a circle system, there are some distinct advantages to reducing the oxygen flow rate: patients have a tendency to stay warmer during anesthesia, it helps retain moisture, it's an efficient use of anesthetic gas, it costs about 90% less than using a non-rebreathing circuit, and it produces about 90% less pollution. Low flow anesthesia yields significant advantages to your patients, your practice, and your environment.

I am careful here to mention low flow anesthesia in the context of a circle system. Low flow techniques cannot be used with a non-rebreathing circuit. You'll find more information about circuits in my blog post Rebreathing or Non-Rebreathing. That post will help you decide when to use a circle system. It's more often than you may think. And to clarify further, here are some "quick and dirty" calculations for oxygen flow rates that are generally accepted as "low flow".

- 35 pounds and under? Set oxygen flow rate at 500ml / min
- Over 35 pounds? Calculate oxygen flow at 30ml / kg / min
- [Hint] You don't get to 1 Liter flow until you get to a 70 pound Labrador

There's more information about oxygen flow rates in my blog post Go With The Flow – How to decide the oxygen flow rate for small animal anesthesia.

OK. Let's do this!

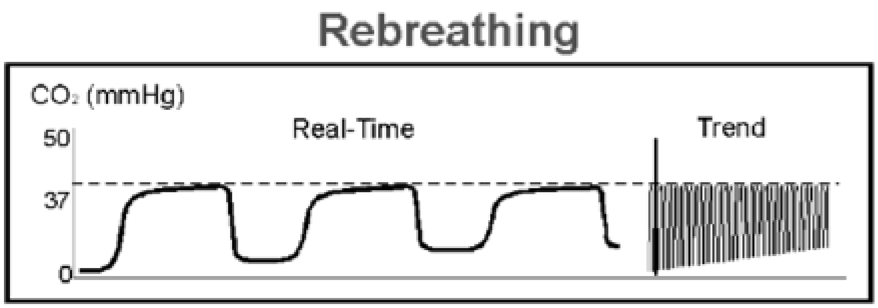
Now that you've decided to challenge a long standing *more-is-better* oxygen philosophy, and you're ready to try low flow anesthesia, this is a good time to ask about the downsides. In other words (as we've all asked all too often), "What could go wrong?"

When you change something as fundamental as the oxygen flow rate, you have to expect that other things may change as well. Here's a short list of challenges you may see.

1. You may scare your DVM.
2. Your patient may inspire CO_2.
3. Your patient may wake up.

Anything out of the ordinary related to anesthesia is going to capture your doctor's attention. So talk with them before you make changes to the way you normally do things. Explain the advantages and disadvantages of low flow oxygen delivery, and review your understanding of what to expect. Your doctor may also have experience to share with you. It's a great way to put everyone on the same page.

If you monitor CO_2 during anesthesia with a capnograph, you'll be able to easily detect inspired carbon dioxide by watching the baseline of the waveform during inspiration. Notice how the wave form depicted below does not return to "0" at inspiration, but rather continues to migrate upward. At each inspiration phase the wave form should return to zero. If it doesn't, the capnograph is detecting carbon dioxide in the inspired air.



There are a few reasons this may happen but for the sake of this conversation, number one on the list is insufficient oxygen flow. And it's easily resolved: turn up the oxygen flow rate. Since you may be trying low flow anesthesia for the first time, you may want to scrap the whole idea right now and go back to an oxygen flow rate you are more comfortable with. Resist that urge for a little longer. Turn the oxygen flow rate up just a little, and wait for a few breaths. Repeat until the wave form comes back to base line on inspiration. It won't take long.

If a capnograph is still on your wish list, all is not lost. Hypercapnia (elevated levels of carbon dioxide) has some pretty identifiable signs. If you are trying low flow anesthesia and your patient is experiencing rapid, shallow breathing (tachypnea) and/or red mucous membranes, hypercapnia is a pretty good guess as to the cause. Fortunately, the remedy is the same as if you had a capnograph: slowly turn up the oxygen flow rate until it resolves.

Going back to the first on the short list of challenges you may see (scaring your DVM), keep your doctor in the loop through all of this so everybody stays on the same page.

The third of the three challenges – Your Patient May Wake Up – is due simply to an insufficient amount of anesthetic gas. Over the next three posts in this series we will dive deeply into answering the question, "Why would my patient wake up just because I reduced my oxygen flow rate?" We'll approach the answer from three directions:

1. We'll look at the anesthetic gas itself
2. We'll look at how a vaporizer works
3. We'll look at the flow of oxygen through a vaporizer

Next up, understanding how to calculate an appropriate dose of a gas – a look at anesthetic gas as a drug.

Low Flow Anesthesia & Patients Waking Up – Part 2

"Why would my patient wake up just because I reduced my oxygen flow rate?"

The short answer is that your patient isn't getting enough anesthetic gas. We've established that even at a lower oxygen flow rate, the patient gets more than enough oxygen (see the post Go With The Flow). If the patient gets enough oxygen, and the anesthetic gas is mixed in the oxygen, why does it not get enough anesthetic gas?

Over the next three posts in this series we will dive deeply into answering that question. We'll approach the answers from three directions:

1. We'll look at the anesthetic gas itself
2. We'll look at how a vaporizer works
3. We'll look at the flow of oxygen through a vaporizer

In this post we'll explore how to calculate an appropriate dosage of an anesthetic gas. We'll look at anesthetic gas as a drug. Stay with me. This gets a little fussy.

A Brand New Gas

We all have our routines we follow when we're using an anesthetic gas we're familiar with. We set the vaporizer on a number that's comfortable. And whether your starting point is determined by careful calculation, habit, or doing what you're told, it usually works out just fine. They're all OK methods when we've had some experience with the gas we're using. However, it falls apart when we make changes to the any parts of our routine (like changing the oxygen flow rate) or when we use a gas for the first time.

For the sake of example, let's look at a gas that I just made up: C3PO. It's so new, it doesn't even have a name – just a bunch of letters and numbers. This revolutionary new anesthetic gas has countless advantages, no disadvantages, it's safe for all patients, and costs less than water. It's the kind of gas I would make up if I was making up an anesthetic gas (which I just did). The only drawback is that you will need a new vaporizer. Luckily, the distributor gave you the vaporizer.

What do you need to know about this gas before you are ready to use C3PO?

On your list will be how much to use. You are comfortable administering anesthetic gas through a vaporizer. And you're comfortable turning the dial up a little or down a little according to your patient's responses during a procedure, but you may have forgotten why your vaporizer dial settings start out higher with Sevoflurane than with Isoflurane, or why the settings for Isoflurane start out higher than for Halothane.

MAC – The Great Equalizer
To jog your memory, let's revisit the way relative potency is established for different anesthetic gasses. *Relative potency* is comparing the effectiveness of one gas to another. That's where MAC comes in. MAC stands for Minimum Alveolar Concentration, but that's only the first three words of the definition. The full definition is the "Minimum Alveolar Concentration required to prevent purposeful movement from a noxious stimulus."
I've always liked how concise that definition is; just a handful of important words. To start, it tells you that it wants to determine the least amount of gas needed at the smallest part of the lungs, the alveoli, where gas exchange occurs in the blood. Next it describes the response it's looking for. It doesn't look for subtle responses like an elevated heart rate or increased respiration rate, it defines the response as movement. And more specifically, purposeful movement. And finally it describes the stimulation as noxious. On a scale of degrees of stimulus, noxious ranks pretty low. More like annoying than painful. So, another way to write the definition of MAC might be "the least amount of gas required to keep a subject from pulling its foot back when you pinch its toe." As a matter of fact, that exactly describes a MAC study. The noxious stimulus is usually a toe pinch. The purposeful movement is usually the subject pulling its foot back.

It's a concise definition of a somewhat non-specific comparison. To make it even more non-specific, MAC is an ED50. That means that it establishes an *effective dose* (ED) for only 50% of patients – therefore ED50. And there are several things that can affect a patient's requirement for the MAC of anesthetic gas. Those things include the patient's physical status (a very sick animal won't need as much anesthetic gas as a bouncy, healthy one), sedatives and analgesics that the patient may have received, the degree of surgical stimulation, and of course the patient may just be in the other 50% group. Knowing the MAC of a gas is as useful as knowing what neighborhood your friend lives in: it might not get you to their front door, but it helps narrow the search.
To apply what we know about MAC to the operating room, we have to start with logic, then adjust to the individual patient and procedure. Once we know the MAC of an anesthetic gas, we know how much gas is required to prevent a patient from reacting to a toe pinch. Since the stimulation in surgery is likely to be greater than pinching a toe, logic dictates that the patient will need a higher dosage of anesthetic gas. In other words, the patient will need more than [1 X MAC] of the anesthetic gas you're using. But how much more?

From Theory to Practice
It is generally accepted that [1.25 to 1.5 X MAC] is required for surgery – also known as surgical MAC. The question may be asked like this: "What factor of MAC is required for surgery?" And the answer is 1.25 – 1.5 MAC.

The MAC of commonly used anesthetic gases are published. For reference in this example, the MAC of isoflurane is ~1.4%, and the MAC of sevoflurane is ~2.1%. The gas that I made up, C3PO, has a MAC of ~9%. So, if we are to calculate the surgical MAC of each of these three gases, it would look like this:

- Isoflurane = surgical MAC of about 1.75% to 2.1%

- Sevoflurane = surgical MAC of about 2.6% to 3.2%
- C3PO = surgical MAC of about 11.25% to 13.5%

Of course, we have to remember the limitations of MAC. The patient's physical status, the other drugs it has on board, the degree of surgical stimulus, or that it may just fall into the *other* 50% group who needs more or less anesthetic gas to achieve the same effect, all impact the actual amount of gas needed. Bearing all of those variables in mind, we know that isoflurane delivered at 1.75% should achieve the same effect as sevoflurane delivered at 2.6%. And if we are presented with a gas we've never used, and we know the MAC of that gas, we know the neighborhood where we can start looking for the dosage we need to achieve the effect we want.

In this post, we've broken down some of the mysteries behind administering an effective dosage of anesthetic gases. The big question we're answering in this series is why a patient might wake up simply because you turn down your oxygen flow rate. The short answer is that your patient wakes up because it doesn't get enough anesthetic gas. This section sheds light on how much anesthetic gas is enough, and how to calculate *enough* gas, regardless of the gas you're using. Part three of this four-part series looks at your vaporizer and how oxygen flow rate affects anesthetic gas delivery.

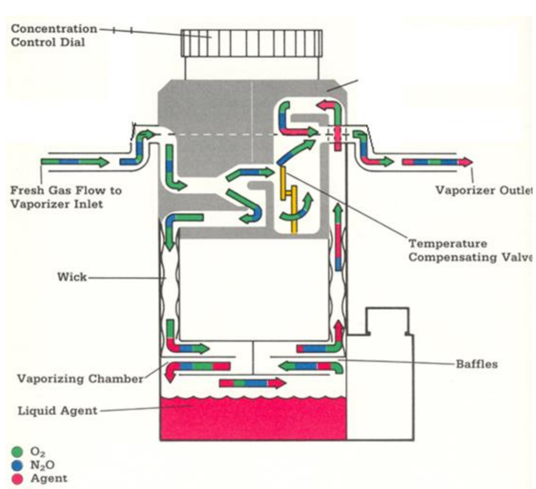
Low Flow Anesthesia & Patients Waking Up – Part 3

"Why would my patient wake up just because I reduced my oxygen flow rate?"

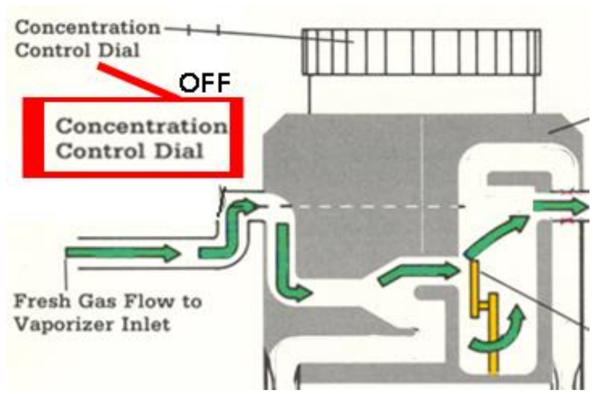
In this series we dive deeply into answering that question. We're approaching the answers from three directions:

1. We looked at the anesthetic gas itself in Part 2
2. We'll look at how a vaporizer works in this post
3. We'll look at the flow of oxygen through a vaporizer in Part 4

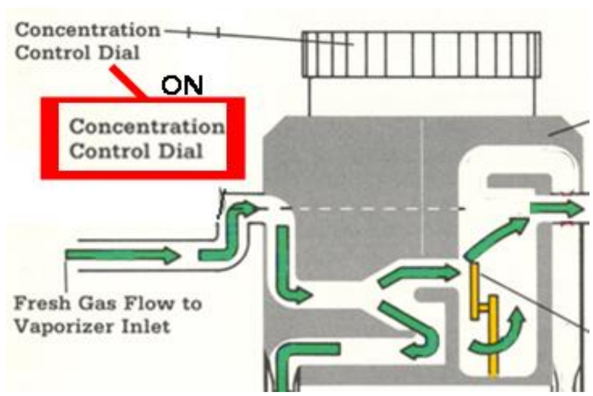
In this post we explore the role of the vaporizer, and how it turns a liquid into a precise concentration of gas. The big concepts of the process are pretty simple to understand if you don't get too tied up in the details. The picture below is used by one of our engineers to explain how vaporizers work. We'll use it to follow the flow of oxygen through a vaporizer and see how it picks up anesthetic.



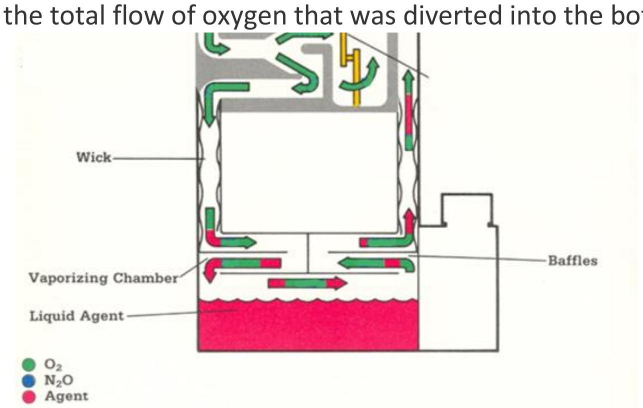
Wow. So many colored arrows going every which way. Let's break it down and follow just the oxygen. First we'll look at just the top half of the vaporizer.



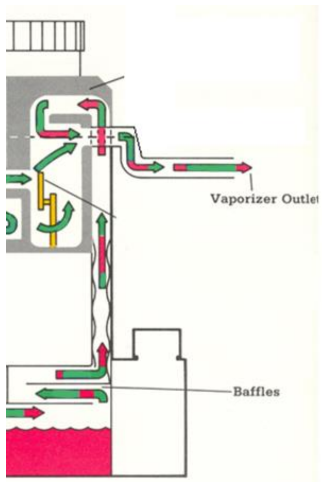
I've stripped away everything but the oxygen flow in this top-half view. I have highlighted the "Concentration Control Dial" label and showed what turning the setting to OFF will do to the oxygen flow. Notice the oxygen just flows straight through the vaporizer with no oxygen diverted into the lower half of the vaporizer.



In this view, everything is the same except the highlighted "Concentration Control Dial" is turned ON. Notice a percentage of the flow is diverted into the lower half of the vaporizer, while the majority of the flow still passes directly through and out of the vaporizer. Now let's slide the image a little lower and follow the percentage of the total flow of oxygen that was diverted into the bottom of the vaporizer.



The dial at the top of the vaporizer – the one we use to set our desired percentage of anesthetic gas – actually diverts a percentage of the oxygen flow downward, through the wick and into the sump holding the liquid anesthetic. There, it becomes saturated with volatilized anesthetic and travels through baffles and up the vaporizer to rejoin the main stream oxygen flow.



In this view we see the saturated oxygen moving through baffles and up through the wick to rejoin the main flow. Once it merges with the main flow of oxygen, the combined gases flow out of the vaporizer to the breathing circuit. The percentage of the flow of oxygen that was diverted from the mainstream and into the sump of the vaporizer has now been saturated with anesthetic gas. When it recombines with the main flow, that diverted percentage becomes the percent of anesthetic gas you set with the vaporizer dial. In other words, if you set the vaporizer dial at 2%, then 2% of the main oxygen flow is diverted down into the vaporizer, through the wick, into the sump where it's saturated with anesthetic gas, and back up to rejoin the main oxygen flow. As it mixes into the main flow, it changes the concentration of the gas out-flowing from the vaporizer. The mixed gas leaving the vaporizer is now 98% oxygen and 2% anesthetic gas.

It's interesting to learn the general principles of how a precision vaporizer works, but the question we're trying to answer is why a patient might wake up simply because you turn down your oxygen flow rate. The most important message to take from this section is that all of this concerns a *percentage* of the total oxygen flow. In the final part of this four-part series we'll look at the role that oxygen flow rate plays on anesthetic delivery, and how 2% of one oxygen flow rate does not equal the anesthetic delivery of 2% of another oxygen flow rate.

Low Flow Anesthesia & Patients Waking Up – Part 4

"Why would my patient wake up just because I reduced my oxygen flow rate?"

We originally posed the question in Part 1 of this series. It's a common challenge that often leads to abandoning the practice of low flow anesthesia. It's also a problem overlooked in the AAHA Anesthesia Guidelines for Dogs and Cats, when they talk about oxygen flow rates for circle systems and recommend, "During the maintenance phase, total O2 flow rate should typically be between 200 and

500 mL [per minute]." I agree with that recommendation, but there's more to the story. The short answer to the question is that the patient wakes up because it's not getting enough anesthetic gas.

In Part 2 and Part 3 of this four-part series, I filled in some of the background you need for rest of the story. In this final Part 4, we'll look at how the flow of oxygen through a vaporizer determines the actual dose of anesthetic the patient receives.

Again, stay with me. This gets a little fussy, but I guarantee it's worth it. And if you want to play along, grab a calculator - math is involved. But I promise it's no more complicated than calculating a tip at a restaurant. As a bonus, at the end of this post you'll find a link to the entire series compiled as one printable PDF.

The most important take-home message from Part 3 is that the anesthetic gas coming from a vaporizer is a *percentage* of the total oxygen flow. That percentage doesn't actually tell us the dose of inhalant we are presenting to the patient, it just tells us that a known portion of the gas flowing from the vaporizer is inhalant.

Grab your calculator and we'll break this down to its parts.

Let's say that you have your oxygen flow set at 1 liter per minute flow, and your vaporizer set at 1.5%. With those settings, how many milliliters of volatilized anesthetic are you presenting to the patient every minute? I'm pretty specific about the wording of that question. Administering anesthetic gas is not like administering any other drug. When you draw up a syringe of a drug and inject it into a patient, you know that the patient is getting all of the drug in the syringe. Therefore, you know how much drug is administered. When administering anesthetic gas, the patient uses significantly less than the total amount of the oxygen flow, and therefore oxygen and inhalant are being exhausted through the pop-off valve. So we can only calculate the amount of inhalant being *presented* to the patient each minute. To determine that actual dosage of inhalant administered to the patient, you'd need to use an agent monitor. Agent monitors, by the way, are great tools to understand how all of this works. If you have one anywhere near you, play with it. They're awesome.

Back to the question. You have your oxygen flow set at 1 liter per minute flow, and your vaporizer set at 1.5%. How many milliliters of volatilized anesthetic are you presenting to the patient every minute?

You're being asked what 1.5% of 1 liter is. The metric system is simple when you remember all of the rules. In this case, it's helpful to know that 1 liter = 1000 milliliters. Another useful hint when talking about numbers is whenever you hear the word "of", it means "times". So the numeric expression is 1.5% X 1000 milliliters. Or 0.015 X 1000 = ?

The answer is 15ml. The entire thought could be stated like this: With the oxygen flow set at 1 liter per minute, and the vaporizer set at 1.5%, you are presenting 15 milliliters of inhalant anesthetic to the patient each minute.

Is the patient using all of that 15ml of inhalant anesthetic presented each minute? No. And remember, we don't know how much of the 15ml it's using.

Now we decide to try low flow anesthesia. We turn the oxygen flow rate down from 1 liter per minute to 500ml per minute, and leave our vaporizer dial setting at 1.5%. How many milliliters of volatilized anesthetic are we presenting to the patient every minute now? The numeric expression is now 1.5% X 500 milliliters. Or 0.015 X 500 = ?

The answer is 7.5ml. With the oxygen flow set at 500ml per minute, and the vaporizer set at 1.5%, we are presenting 7.5 milliliters of inhalant anesthetic to the patient each minute. Even though the vaporizer dial setting is the same in each instance, the actual amount of anesthetic gas presented to the patient at 500ml oxygen flow is *half* of the amount presented at 1 liter flow. Half. It's not surprising the patient may become more lightly anesthetized.

When we challenge ourselves to step out of our comfort zone by reducing the oxygen flow rate during anesthesia, it's important that we see the broader picture and anticipate our response to changes in the patient. The patient will often become more lightly anesthetized and may even wake up. This often leads anesthetists to abandon the idea of low flow anesthesia. But now that we understand the relative potency of anesthetic gas, and how a vaporizer's delivery is tied to the oxygen flow rate, we can anticipate that the patient may get lighter, and we can be prepared to increase the vaporizer dial setting.

There are many great tools for today's veterinary anesthetist, but the most important monitoring tool is the person sitting at the head of the patient. AAHA summed up their Anesthesia Guidelines with this closing statement, calling out the key to success: "Successful anesthetic management requires trained, observant team members who understand the clinical pharmacology and physiologic adaptations of the patient undergoing anesthetic procedures, as well as the use of anesthetic and monitoring equipment."

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