Mainstream or Sidestream Capnography?

These generic guidelines illustrate the factors to consider when selecting between traditional mainstream and sidestream monitoring. The VM-2500-M and VM-2500-S have been designed to overcome many of these factors.

1.0 Diverting – v – Non-diverting

A capnometer, by definition is either diverting (i.e. sidestream) or non-diverting (i.e. mainstream).

Diverting (sidestream)

A diverting capnograph transports a portion of a patient's respired gases from the sampling site, through to a sampling tube, to the sensor. Before the gas reaches the sensor, the sample is often passed through a water trap and drying tubing prior to being analysed.

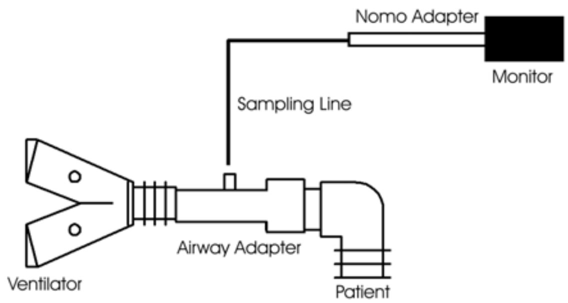


Illustration of the VM-2500-S (with internal ISA CO_2 Analyser)
NB. The VM-2500-S does not require a water trap.

Non-diverting (mainstream)

A non-diverting capnograph does not transport gas away from the sampling site.

The sensor, consisting of the sample cell and infrared bench, is placed at the airway. This location results in a "crisp" graphical representation of the time varying CO_2 value that reflects in real-time the partial pressure of carbon dioxide within the airway.

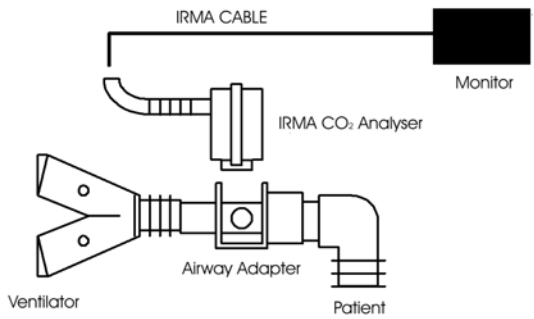


Illustration of the VM-2500-M (with external IRMA CO_2 Analyser)

2.0 The Use of CO_2 Monitoring in Neonatal Applications

Generally sidestream capnographs may not be accurate in neonatal and paediatric patients because the unit aspirates a significant proportion of the patient's total ventilation.

3.0 Factors to Consider when Selecting the Sidestream Measurement

1. Supplemental Oxygen

For accurate $EtCO_2$ monitoring, particularly with non-intubated patients receiving supplemental oxygen, sidestream sampling systems may not accurately reflect the capnogram because of the dilution effects of the supplemental flow of gases.

2. Damage to the sample line

The sampling tube typically hangs free between the breathing circuit and monitor where it is vulnerable to being crushed, kinked and may be damaged during machine movement.

Sources of leaks external to the monitor such as loose fittings, cracked or slit sampling tubes, cracked sample filters and cracked airway adapters along with sources of leaks to the monitor, such as partial disconnection have been reported as causes of significant artefact in the capnogram.

3. Response time

Using a remote location results in a delay time of up to several seconds and a rise time distortion of perhaps greater than 200 ms. This delay in total response time can be significant due to the need to provide the clinician an earliest warning as possible.

4. Use during surgery

If used during surgery the sampled gas that is withdrawn from the patient may contain anaesthetic gases and as such should be routed back to a gas scavenging system or returned to the patient breathing system to avoid "pollution" of the operating room environment.

5. Condensation

Condensation from the humidified sample gas in combination with patient secretions can block and contaminate the sampling line requiring frequent replacement.

6. Difference between the gas flow rate below the sample flow rate

At the sample-tubing airway interface, expired gas may be diluted with entrained ambient air whenever the gas flow rate falls below the "constant" sample flow rate.

7. Set-up

The use of sidestream monitoring requires that careful attention be paid both to the physical setup external and internal to the monitor, as well as careful interpretation of the capnogram waveform.

8. Temperature

In sidestream systems the temperature of the sampled gases decreases toward room temperature during its transit from the patient connection to the monitor. This can result in condensation forming on the walls of the tubing and a resulting decrease in the partial pressure of water vapour. This decrease in water vapour pressure can cause an apparent increase in CO_2. Sidestream devices compensate with software for water vapour removal and as a result may introduce errors since assumed conditions may be very different form the actual and physical conditions may change over time.

9. Water or water-vapour effects

Condensed water or water-like mixtures have other very serious effects such as obstruction of the sampling line or airway adapter. If droplets appear within the cuvette optical path, sever scattering and absorption occur.

10. Extubation

Endotracheal tube positioning is commonly verified by observing expired CO_2 during a series of manual short breaths. It has been noted that the long transport delays often associated with sidestream sampling may result in an excessive delay in observing the presence of expired CO_2 and possible false diagnosis of oesophageal intubation.

4.0 Factors to Consider when Selecting the Mainstream Measurement

1. Use on non-intubated patients

While mainstream devices may also be used on non-intubated patients, either as a sidestream sensor using an appropriate adapter or as a mainstream sensor with a facemask, the use of a low deadspace good sealing facemask combined with a mainstream airway adapter allows for superior CO_2 monitoring and volumetric capnography. This is especially useful for emergency medical service applications and during non-intubated conscious sedation.

2. Partial Pressure

Partial pressure dilution effects are of a concern. This has been effectively minimised in mainstream systems by heating the airway adapter and its windows above body temperature or by using coatings. How close the exact water vapour pressure is to Body Temperature and Pressure, Saturated conditions (BTPS) depends on factors including the presence and type of humidification, fresh gas flow, length of time in use and ambient temperature.

Mainstream devices correctly read the partial pressure of CO_2 at the conditions in the breathing circuit typically at or near BTPS and do not require software compensation for water vapour.

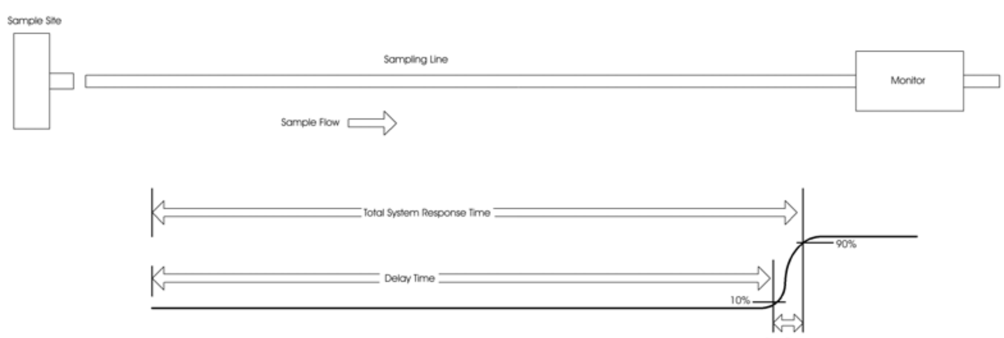
3. Extubation

Historically, the primary concerns of mainstream based systems are related to size and weight. However, the reduction in both size and weight has alleviated these concerns to the point that with correct attention to the breathing circuit, the risks of extubation are minimal.

4. Heating of the sample cell

Since the windows of the mainstream sample cell are heated slightly above body temperature, burn issues have been raised by some. However, the temperature during normal operation of a heated mainstream sensor will not reach a temperature high enough to cause even redness of the skin.

5. Total System Response Time



Delay Time – Time from a step function change in gas level at the sampling site to the achievement of 10% of the final gas reading of the capnograph (i.e. the time taken to move from the point of sampling to the point of measurement). Longer delay times can lead to an underestimation of CO_2 due to the dispersion of gases.

Rise Time – Time required to achieve an increase from 10% to 90% of final value when step function change in concentration occurs at the sampling site (i.e. the time taken for the monitor to respond to a step change in CO_2). Longer rise times can lead to an abnormal waveform; a reduced slope of phase II.

Total System Response Time – Time from a step function change in gas level at the sampling site to the achievement of 90% of the final gas reading of the Capnograph.

Total System Response Time = Delay Time + Rise Time

NB. Mainstream systems do not suffer from delay time.

6.0 Specific Detail Regarding the VM-2500-M and VM2500-S

Feature	VM-2500-M (IRMA CO_2 Analyser)	VM-2500-S (ISA CO_2 Analyser)
Airway Connections		
Location of infrared analysis unit (sensor)	IRMA CO_2 Analyser is located at the airway connector	ISA CO_2 Analyser is located in the monitor
Required components to "sample" gas	Airway Adapter IRMA CO_2 Analyser	Airway Adapter Nomo Adapter Sampling Line
Weight of airway connector	Adult/Paediatric Airway Adapter: 6g IRMA CO_2 Analyser: 30g	Adult/Paediatric Airway Adapter: 8g Nomo Adapter: 5g Sampling Line: 5g
Location of airway connection	End of endotracheal tube (typically)	End of endotracheal tube
Use on non-intubated patients	Yes, with a facemask or mouthpiece	Yes, with a nasal/oral cannula
Components: disposable or reusable?	Airway Adapter: Disposable IRMA CO_2 Analyser: Reusable	Airway Adapter: Disposable Nomo Adapter: Reusable (approx. 2 weeks) Sampling Line: Disposable
Durability of airway connector	Airway adapter inexpensive to replace IRMA CO_2 Analyser: Meets relevant shock and vibration requirements for transport.	Airway adapter inexpensive to replace ISA CO_2 Analyser: Meets relevant shock and vibration requirements for transport.
Can be used in collaboration with simultaneous oxygen administration?	Yes with facemask	Yes with nasal cannula
Easy to use when patient is in unusual positions such as in prone position.	Yes	Yes
Sample gas value drawn	None	50 ml/min
Deadspace added to airway connector	Adult/Paediatric: 6ml Infant: 1ml	Adult/Paediatric: 6ml Infant: Varies depending on the outside diameter.
Warm-up		
Warm-up time	10 s to full specification	10 s to full specification
User tasks during warm-up	No action required	Automatic zeroing takes place
Zeroing		
Zeroing	Manual, if required.	Automatic – performed at start up and after every 24 hours. Manual zeroing is also possible.

Zeroing during use	No. A successful zeroing requires the presence of ambient air in the IRMA Airway Adapter.	Yes. The reference gas is taken from a separate valve to the sampling line.
Calibration		
Calibration	Not required due to internal reference components + software compensation and very stable light souring.	Not required due to internal reference components + software compensation and very stable light souring.
Calibration to reference gas cylinder	Not frequently required. User attaches sensor to reference cell.	Not frequently required. User attaches sensor to reference cell.
Response and Signal Fidelity		
Total Response Time	< 1 second	< 3 seconds
Delay Time between sampling and waveform display	None	< 2.8 seconds
Rise Time (from 10 to 90% of final value)	≤ 90ms (at 10 l/min)	≤ 200ms (at 50 l/min sample flow and 2m sample line)
Waveform display	Crisp. No deformity of capnogram due to non-dispersion of gases.	Smooth appearance because the gas is filtered by the sample line artefact and slower response time.
Numeric display	Displayed after one breath and then a continually updated breath average.	Displayed after one breath and then a continually updated breath average.
Moisture and Contaminations		
Changes in water vapour pressure	Not affected	Nomo Adapter removes water and vapour from the sampled gas.
Moisture handling	IRMA CO_2 Analyser is heated to prevent condensation. The XTP non-condensing light transmission window prevents a decrease in performance when vapour is present.	The membrane-like surface of the sampling line allows water to evaporate into the surrounding air.
Potential of cross-contamination between patients	None – disposable airway adapter is used to reduce risk of contamination.	None – disposable airway adapter is used to reduce risk of contamination.
Zeroing and Calibration		
Gas scavenging	Not required	The gas outlet is not designed to return the exhaust gases to the patient circuit or a scavenging system.
Use in true closed circuit anaesthesia	Yes	No
Compensation		
Compensation for nitrous oxide concentration	Manual	Manual
Compensation for oxygen concentrations	Manual	Manual
Barometric pressure compensation	Automatic	Automatic
Airway pressure compensation	Automatic	Automatic
Neonatal Use		
Suitable for Neonatal use	Yes, low deadspace airway adapters are available	Not advisable due to the aspiration of gas.