WHITE PAPER

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Respironics LoFlo™ and Oridion Microstream® Technologies Contrasted

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ABSTRACT

Technical aspects of sidestream capnography are described and aspects of the Respironics LoFlo and Oridion Microstream technologies are contrasted. Components such as the pneumatic system and signal processing and contamination issues are discussed. The implications of these two different approaches to sidestream measurements are reviewed and the benefits of LoFlo sidestream capnography are highlighted.

SIDESTREAM DEFINED

A capnometer, by definition is either diverting (i.e., sidestream) or non-diverting (i.e., mainstream). A diverting capnometer transports a portion of the respired gases from the sampling site, through a sampling tube, to the sensor, whereas a non-diverting capnometer does not transport gas away from the sampling site [1,2]. In other words, one can view the difference between mainstream (non-diverting) capnography and sidestream (diverting) capnography as clinically measuring carbon dioxide at the sample site versus measuring carbon dioxide remotely in the monitor distant from the sampling site. Both the Respironics LoFlo and the Oridion Microstream devices are sidestream or diverting capnometers.

SIDESTREAM GAS SAMPLING – THE GAS PATH

Sidestream gas analyzers utilize either a long sampling plastic tube connected to an adapter in the breathing circuit (such as a T-piece at the endotracheal tube or mask connector) or a nasal cannula. The sample gas is continuously aspirated from the breathing circuit through the sampling tube and into the sample cell/measurement chamber within the monitor at sample flow rates ranging from 50 to 250 ml/min. The sampling tube length may vary but is typically between 6 and 8 feet in length and between 1mm and several mm in inner diameter. The distal end of the sampling tube of conventional sidestream systems terminates with a Luer fitting which is mated to a Luer fitting on the front of the monitor or module of a multi-parameter system. This sample is then often passed through a water trap and drying tubing prior to being analyzed. Sidestream sampling results in a delay time of up to several seconds and a rise time of perhaps greater than 200 ms. Also, the sampled gas withdrawn from the patient may contain anesthetic gases, and should be routed to a gas scavenging system or returned to the patient breathing system.

Leaks, as well as obstructions, can occur at any of the numerous connection points and along the tubing within the sidestream sampling system. The resulting distorted waveforms and the end-tidal values can be significantly different from actual, may not be detectable by normal calibration procedures [3], and pose a potential hazard. Additionally, sources of leaks external to the monitor, such as loose fittings, cracked or slit sampling tubes, cracked sample filters and cracked on-airway adapters, along with sources of leaks internal to the monitor such as partial disconnection of tubing, have been reported as causes of significant artifact in the capnogram.

The location of the sampling port varies and may range anywhere from an elbow connected to an endotracheal tube to the wye. For example, the sampling port may be placed on the ventilator-side of an in-line filter or HME. This results in a drier sampling tube with the inherent risk of distortion of the capnographic waveform and lower end-tidal values [4,5]. It may be also placed on the patient-side of the filter for more representative end-tidal values and capnographic waveforms, however there may be an accumulation of condensate and patient secretions in the sampling system.

The design of the sampling tube and its positioning within the breathing circuit or nares (if a nasal cannula is used) can affect the quantity of surrounding air that is entrained along with the expired gas. Additionally, the sample flow rate may vary significantly for a number of reasons including the sample tube length [6], and airway pressure. 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 capnographic waveform.

RESPIRONICS LOFLO SIDESTREAM SAMPLING SYSTEM

To address the problems associated with conventional sidestream sampling systems, the LoFlo Sidestream sample set provides the complete sampling path from the patient's airway to the sample cell. The sample set includes a removable and disposable sample cell which effectively obviates the need for preventive maintenance of the sample cell associated with sidestream systems (i.e., Oridion VitalCap® and MicroCap® capnometers). The sample cell is inserted into a receptacle to which the measurement optics is mounted. The measurement optics consists of detector and source assemblies (Figure 1). The sample cell windows are configured and oriented to be properly aligned with the measurement optics when inserted into the sample cell receptacle. The detector assembly comprises a window of infrared radiation-transmitting material, a beam splitter, two filters, and data and reference detectors.

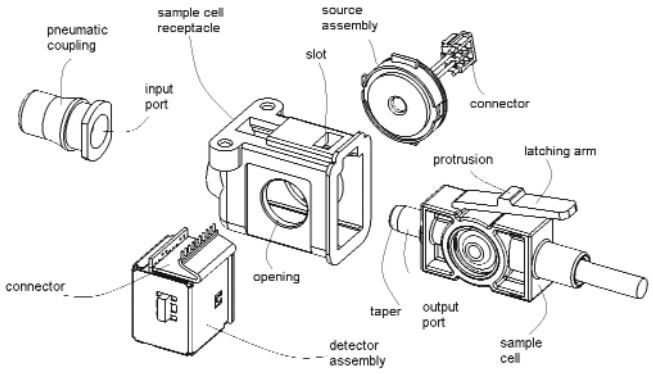

Figure 1 – Exploded view of the sample cell receptacle assembly from the detector assembly side.

The source assembly comprises an infrared emitter, a mounting and a window of an infrared radiation-transmitting material. Connectors on the source and detector assemblies provide the electrical interface to external electronics.

The sample set consists of a sample cell, filter, sampling tubing, dehumidification tubing (in some kits) and an interface to the patient or the breathing circuit. The sample cell portion of the sample set is designed to permit easy connection and disconnection. A latching arm of the sample cell mates with the sample cell receptacle to permit proper alignment of the measurement optics with the optical apertures in the sample cell, as well as proper seating of the sample cell output port with the pneumatic input. To remove the sample cell from the receptacle, the latching arm is depressed and pivots downward for release. The sample cell can then be removed from the receptacle. This device is simple to use and provides both familiar and intuitive operations for insertion and removal of the sample cell. The receptacle also contains a photo detector that detects when a sample cell is present and serves as a signal to turn on the sampling pump.

After exiting the sample cell through the output port, the gas enters the pneumatic system and travels into a pump of the sidestream module before exiting through the exhaust or scavenging port. The system is optimized for low flow using an integrated sample pump under active flow control.

LOFLO AND MICROSTREAM CONTRASTED

The LoFlo and Microstream technologies are compared in terms of the pneumatic configurations, the effects of contamination and signal processing.

Pneumatic Systems – The pneumatics of the LoFlo system are deceptively simple. The inclusion of a sample cell with the sample set permits the IR bench to be located earlier in the sample path. Downstream from the sample cell, a pressure transducer measures the circuit pressure so that the proper pressure compensations can be made to the CO_2 values. The remaining portion of the circuit consists of a flowmeter and brushless diaphragm pump. The output of the flowmeter is used to adjust the pump to maintain a constant flow rate under a variety of load conditions.

The Microstream technology, as implemented in the Oridion VitalCap and MicroCap capnometers, consist of a number of components. After entering the monitor, the gas passes through several inches of Nafion® tubing to reduce the water vapor content of the sample. The gas then passes through a valve (i.e. restriction) that is used to switch the input of the IR bench between the gas from the inlet port and the dried and filtered gas from the atmosphere inside the monitor. A pressure transducer is located distal to the IR bench to most likely compensate for the pressure drops associated with the sample set, valve, tubing and IR bench. Following the pressure transducer, the gas passes through a DC brush diaphragm pump before exiting through the exhaust port.

All sidestream capnometers use a mechanical pump with moving parts to draw a sample through the system. Of the various pump technologies available, both the LoFlo and Microstream systems use a motor driven diaphragm-type pump. Diaphragm pumps do not require a sliding seal between moving parts.

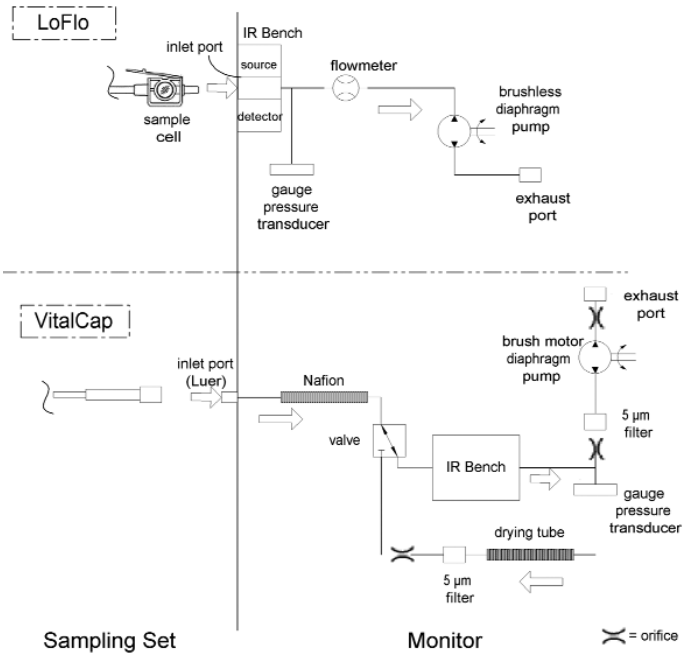

Figure 2 – Pneumatic schematics of LoFlo technology and Oridion VitalCap* handheld monitor (*manufacturing date of 2001)

The action of a diaphragm flexing back and forth within a closed chamber compresses the air. However, this is where the similarities end. The limiting factor on diaphragm pumps is the motor. Conventional brush-type DC pumps, as used in Oridion systems such as the VitalCap system, wears out long before brushless DC motors, as used in the LoFlo system. (see table 1) All sidestream systems must include methods of reducing the noise associated with operation including external vibration dampeners, acoustic baffles, and mufflers. Respironics LoFlo pumps are isolated from the gas bench and optical sensor, and suspended within a rubber envelope to further reduce noise and vibration, whereas the VitalCap pump is mounted on the main circuit board of the unit.

CONTAMINATION

Condensation from humidified sample gas in combination with patient secretions, can block and contaminate the sampling line requiring frequent replacement. Additionally, contaminants may partially obstruct the sampling tubes of all side-stream capnometers and increase resistance to flow in these tubes, thus affecting the response time and accuracy of the CO_2 measurement.

Recent designs of on-airway sidestream adapters, from both Respironics and Oridion for use with intubated patients, reduce the likelihood of aspirating secretions by using sampling ports that extend to the center of the adapter, rather than at the wall of the adapter. While Respironics uses a single robust port design to sample gas from the center of the airway adapter and Oridion uses a multi-port design, both types are still not totally immune to the problems outlined above.

Contaminants cannot be eliminated from the breathing circuit without degrading performance. Eventually water and other contaminants will accumulate within the sidestream sampling set. The use of water permeable materials such as Nafion® and filters within the sampling path can prolong the life of the sampling set. However, many users will use their single-patient-use sample tube until the tube clogs or a problem arises. Unfortunately, if the sample tube is used for too long, contaminants will breakthrough the filter and pass into the sample cell. No filter is immune to eventual clogging and distortion of the capnogram, particularly if preventive maintenance is inadequate. If droplets appear within the optical path in the optical bench, severe scattering and absorption of the IR beam can occur. However, true single beam ratiometric optical systems can successfully compensate for the contamination if scattering/absorption effects are not spectrum dependent. Therefore, to avoid the consequences associated with contaminants in the sample cell and possible damage to the optical bench that would require the monitor to be returned to the factory for an overhaul, a sampling tube set with a disposable sample cell is advised.

Unlike other currently available disposables, the LoFlo sample set provides a complete sampling path from the patient's airway to the sample cell. Therefore, contamination may be more easily observed, leaks are less likely and such problems are easily remedied by replacement of the disposable. Any problems internal to the device downstream from the sample cell can be automatically detected and will not affect the fidelity of the measurement.

SIGNAL PROCESSING

Conventional sidestream capnographs may not be accurate in infant and pediatric patients because they aspirate a significant portion of the patients total ventilation [6]. Additionally, the high respiratory rates that infants breathe require an adequate bandwidth and sampling rate. To compare the performance of the LoFlo and Oridion Microstream technologies under these conditions the following test was performed. A low deadspace valve was switched at respiratory rates from 10 to 150 b/min in steps of 10 b/min between a calibration gas of 5% CO_2 balance nitrogen and room air. The measured end-tidal value reported on each instrument was recorded. At 110 b/min the VitalCap unit (in normal mode) stopped reporting end-tidal CO_2 values. For the Vitalcap unit, the test was restarted in Neonatal mode at 60 b/min and run to 150 b/min. The VitalCap unit performed within specifications over the entire range provided that the neonatal mode was enabled for the higher respiratory rates. The LoFlo unit performed within specifications over the entire tested range. The VitalCap unit's values rose as respiratory rate increased whereas the LoFlo unit's values slightly decreased. As the rate increases it can be reasonably expected that the system would report slightly lower values due to the inherent low pass filtering effect of the pneumatics.

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Table 1 – Comparison of Specifications of LoFlo and Microstream based Sidestream IR Capnometers

	Sidestream System		Comment
	Respironics/Novametrix	Oridion	
Model	**LoFlo**	**VitalCap****	
Optical Bench			
Sensor IR source	Low voltage pulsed source solid-state	Pulsed RF gas discharge lamp using high voltage	Use of high voltage requires careful design to prevent potential hazards.
Location	At connection to sample, easily accessed	Within monitor, not easily accessed	Optical bench should be accessible for maintenance and observation.
CO_2 bench subject to contamination	No, sample cell part of disposable	Yes, sample cell within monitor and unprotected if contaminants breach filter	IR bench should be protected from contaminants.
Accuracy			
CO_2 accuracy ranges (mm Hg)	0-40 ±2 mm Hg 41-70 ±5% of rdg 71-100 ±8% of rdg 101-150 Unspecified	0-38 ±2 mm Hg 39-76 ±5% of rdg 77-99 ±8% of rdg	Accuracy should be within ±2 mm Hg at normocapnia and should permit display of values over 100 mm Hg so that hypercapnic levels associated with permissive hypercapnia can be distinguished from very high levels of hypercapnia.
Pump			
Sampling flow (ml/min)	50±10	50 ±7.5	Low sampling rate permits measurements to be made in infants.
Pump life (continuous use) (operating hrs) (operating days)	24,000 hrs 1000 days	7,000 hrs (replacement)*** 292 days 14,000 hrs (return to factory for overhaul) 583 days	The pump is a major cost component of a sidestream sampling system. Therefore, a longer pump life means lower operating costs over the life of the monitor. Pump life should be rated in years of continuous operation not months.
Automatic operation	Yes	Yes	For ease of use, it is preferable that the pump only turn on once the sample kit is connected to the monitor.
Signal Processing			
Data sample rate (Hz)	87 or 100 (depending on model)	40	Higher data sampling rate needed to adequately reproduce capnographic waveform in infants at high respiratory rates.
Interference comp. N_2O O_2	 Yes Yes	 "Included in CO_2 accuracy specs" Yes	Design should be robust to minimally affected by spectral overlap and correct for pressure broadening effects.
Calibration method	No routine cal required, adapter ZeroCal <20sec	Self Cal, Check 1x year with calibration gas	Calibration checks should be simple and fast.
Response time (ms) Delay time (ms) Rise time (ms)10-90	2000 typ, < 3000 max Approx 1800 < 200	2450 typ; 2900 max Approx 2000 190 neo / 250 adult	Delay between sampling site and measurement cell should be understood. Response time should < 200 ms to better reflect waveform at sampling site.
Sample set			
Airway adapters	Infant/ped low deadspace Ped/Adult	Neonatal low deadspace Adult	Airway adapters with appropriate resistance and deadspace should be available for the range of patients to be monitored.
Airway adapter "resistant" to contaminants	Yes	Yes	Design of sampling port within airway adapter should sample gas from the interior of the adapter rather than the wall.
Sampling cannulas offered	Nasal; oral/nasal; nasal w O_2; oral/nasal w O_2;	Nasal; oral/nasal; nasal w O_2; oral/nasal w O_2	Offerings should include both nasal and nasal/oral with and without supplemental O_2
Sampling tube ID (mm)	1	1	Sampling tube inner diameter should be as small practically possible.
Filter	Yes	Yes	Filter should minimally affect response time.
Sample cell part of disposable	Yes, contaminants cannot damage optics	No, within the monitor-optics susceptible to contamination	Sample cell optics should be protected from contamination.

(**Data from product literature, manuals, and other publications)
Note – CO_2 Accuracy LoFlo – all specs are ±12% for resp rates > 80 bpm; VitalCap (per manual) – "$EtCO_2$ accuracy is maintained up to 80 breaths/min. From 81 to 150 bpm accuracy is ±12%, if the $EtCO_2$ is higher than 18.8 mmHg in neonatal mode."
***Per VitalCap manual p. 53 – "Pump and flow system should be replaced every 7,000 operating hours." And "Monitor should be returned to the manufacturer for periodic maintenance every 14,000 operating hours."

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