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Comparative Analysis of Accuracy, Filter Performance, and Durability among Capnography Sampling Lines: Summary

Introduction

Hundreds of publications, representing data from patients around the world, support the effectiveness of capnography monitoring to help clinicians identify and mitigate respiratory compromise.[1,2] Accuracy of capnography readings and overall cost can be influenced by several features, including oxygen dilution, filter quality, and mechanical stability of the sampling line.[3,4] The purpose of this bench study was to evaluate performance between currently available sidestream capnography sampling lines claiming compatibility with Microstream™ enabled capnography.

Methods

A series of bench tests were performed on a selection of commercially available sampling lines to assess mechanical durability, filter perforamnce, and $EtCO_2$ accuracy. All sampling lines tested were designed for adult patients. Testing was not for verification or validation, but a limited evaluation.

Accuracy

Two tests were used to evaluate accuracy: rise time and $EtCO_2$. For each test type, three separate sampling lines were tested for five repetitions each (n = 15).

Accuracy - Rise Time

Rise time is the time taken for a measured $EtCO_2$ value to increase from 10% to 90% of the peak $EtCO_2$ value and indicates the systems ability to effectively differentiate breaths.[5] Longer rise times increase liklihood that multiple breaths will be pooled into one sample, negatively impacting accuracy. **Figure 1** illustrates the test method used to evaluate rise time.

Accuracy - $EtCO_2$

A lung simulator (**Figure 2**) was used to generate airflow patterns resembling natural breathing through nasal or oral cavity. Multiple breathing conditions were evaluated.

Normal breathing: Vt = 450ml, RR = 10 bpm

Shallow breathing: Vt = 300ml, RR = 20 bpm

1. Oral breathing without supplemental oxygen
2. Oral breathing with supplemntal oxygen†
3. Nasal breathing with nostril obstruction and no supplemental oxygen (cannula)
4. Nasal breathing (no obstruction) without supplmental oxygen
5. Nasal breathing (no obstruction) with supplemental oxygen†

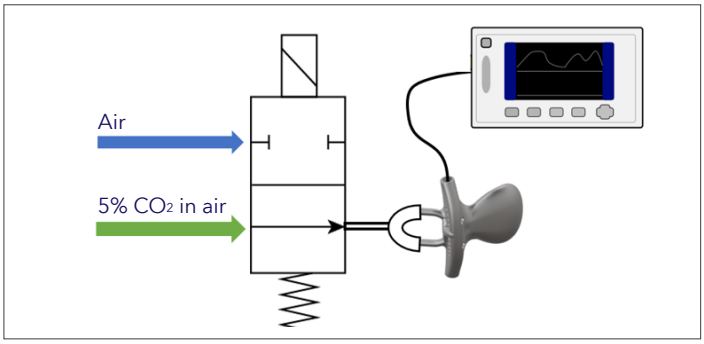

Figure 1: Solenoid-based breath simulator. Creates an alternating air and 5% CO_2 in air flow. Square waveform 0-5% CO_2. Accuracy was defined as the difference between $EtCO_2$ from the sampling line compared to expected $EtCO_2$ of 36mmHg (5% CO_2). Respiratory rates 10 - 80 bpm, at intervals of 10 bpm, were tested.

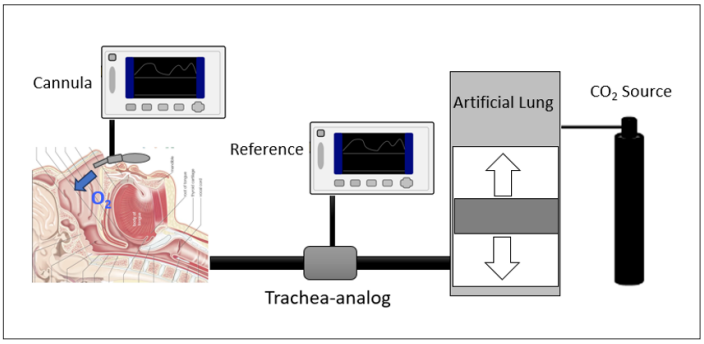

Figure 2: Anatomical airway model with artificial lung simulator to create a natural breathing cycle with variable exhaled CO_2 concentration. Accuracy was defined at the difference between measured $EtCO_2$ from the sampling line compared to reference $EtCO_2$, taken in the trachea.

† Data not presented in this document

Testing funded and conducted by Medtronic; bench results may not be indicative of clinical performance.

Mechnical Durability

Two seperate tests were completed to evaluate the durability of each sampling line. Three individual sampling lines were tested for each product and test type.

1. **Pull test:** Tests structural integrity by gradually stretching the sampling line with maximum speed of 300 mm/min and maximum force of 2kg.
2. **Leak Test:** Assess for leaks in capnography system through pressure measurement of closed system.

Filter Performance

Clog capacity, the point at which the filter clogs and the system was no longer able to pump, was assesed to evaluate filter performance. Water was introduced into the sampling line at a rate of 1 mL/min until clogged, up to 160µL (Microstream™ system specification). Three individual sampling lines were tested for each product.

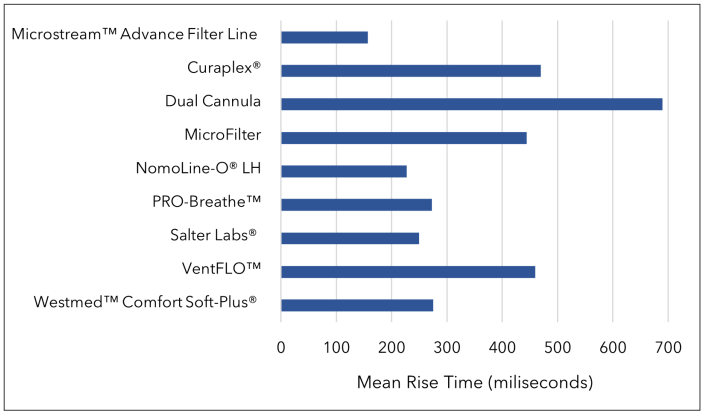

Figure 4: Mean rise time in milliseconds by sampling line. Microstream™ Advance was the only sampling line with a mean rise time average within the specification of 190 miliseconds. Sampling lines with rise times outside this parameter are considered incompatible with the system.

Results

Accuracy - Rise Time

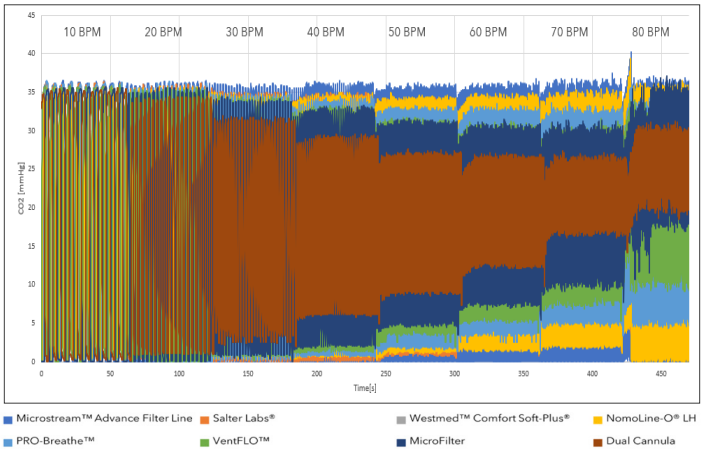

Figure 3: Sample solenoid-based waveforms of sampling lines. For this study, an expected single breath tracing would read 36 mmHg at the peak of the breath and 0 mmHg at the end of the breath, regardless of breathing rate. As shown in the graph, numerous tracings fall below the anticipated 36 mmHg at the onset of the breath and do not reach 0 mmHg at the end of the breath, starting at 20bpm. This illustrates how rise times outside the specifications of the capnography system can lead to inaccurate $EtCO_2$ measurements.

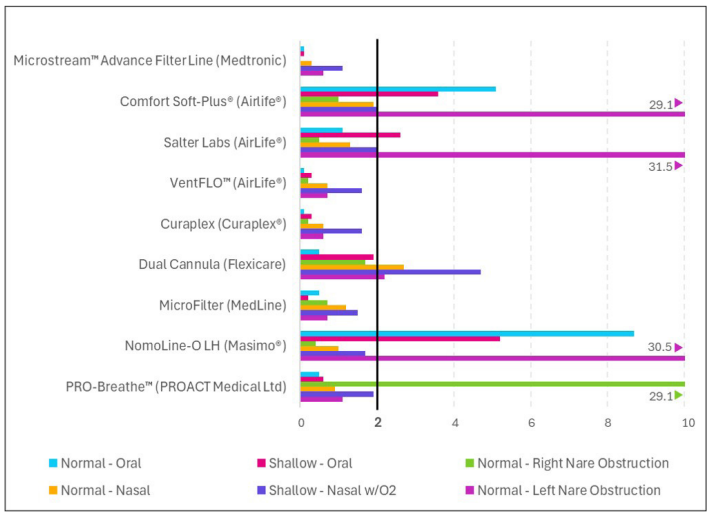

Figure 5: Accuracy of $EtCO_2$ by sampling line and breathing condition. Each bar represents average difference between measured and expected (36 mmHg) $EtCO_2$. The black line represents maximum difference allowed, as defined by system specifications. Many lines exceed specifications during oral breathing and with nasal obstructions. Shallow breathing also caused deviation for the specificaiton.

Sampling lines tested

Manufacturer	Product	Description	Ref#
MEDTRONIC	Microstream™ Advance Filter Line	Adult Oral-Nasal CO_2 sampling line	MVAO
SALTER LABS	Salter Labs	Adult O_2/$ETCO_2$ Filtered Oral/Nasal Divided Cannula	4MSF1-7-6
WESTMED	Comfort Soft-Plus®	Adult Oral/Nasal Cannula, 7' CO_2/CO_2 with reflective Luer	917
MASIMO	NomoLine-O LH	NomoLine-O LH Adult Nasal/Oral CO_2 Cannula with O_2 up to 5 lpm	4459
PROACT	PRO-Breathe™	Adult with O_2 delivery up to 5 lpm	PBMS04561
SUNMED®	VentFLO™	Adult Nasal $ETCO_2$/O_2 Nasal/Oral Cannula + Scoop	5707F-SE
CURAPLEX†	Curaplex	Adult Nasal $ETCO_2$/O_2 Nasal/Oral Cannula + Scoop	301-5707F-SE
MEDLINE	MicroFilter	Microfilter Oral/Nasal Adult CO_2 Cannula with O_2 delivery	HCS4607MO
FLEXICARE	Dual Cannula	Dual Adult Oral Nasal Cannula 7' O_2 delivery/CO_2 monitoring	032-10-180U

† Curaplex cannula appeared identical to the VentFlo cannula, including name on package, though the reference numbers differed.

Mechnical Durability

The Salter Labs® sampling line failed the pull test and PRO-Breathe™ sampling line failed the leak test. All other sampling lines passed both mechanical durability tests.

Filter Performance

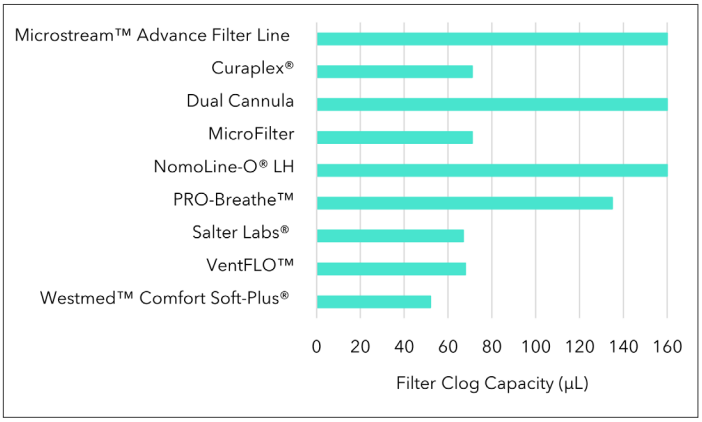

Figure 6: Filter performance. Measured by amount of liquid added to system before clogging of filter was detected, tested up to 160 µL. Flowrate was set to 1 milliliter per minute. Only 3 sampling lines met the Microstream™ clogging capacity performance specification. Sampling lines with a clog capacity less than 160µl were considered to have poor filter capacity, limiting their expected lifetime performance.

Conclusion

This study provides evidence of variation in the performance of currently available capnography sampling lines claiming compatibility with Microstream™ enabled capnography monitoring systems through evaluation of accuracy, mechanical durability, and filter performance. These findings highlight potential risks when using sampling lines from outside the Microstream™ product line in tandem with a Microstream™ enabled capnography monitor, which may compromise $EtCO_2$ accuracy in clinical applications. Further, lines that demonstrated reduced mechanical durability or filter capacity may require more frequent upkeep by the clinican, which may impact cost and workflow. Across all testing conditions, sampling lines outside the Microstream™ family were mixed in their performance, suggesting that these sampling lines may not provide reliable, consistent, or accurate measurements when used in tandem with Microstream™ capnography monitoring systems.

Explore the Microstream™ capnography monitoring system at **Medtronic.com/Microstream**

1. Waugh, J. B., Epps, C. A., & Khodneva, Y. A. (2011). Capnography enhances surveillance of respiratory events during procedural sedation: a meta-analysis. *Journal of clinical anesthesia,* 23(3), 189-196.2.
2. Wollner, E. A., Nourian, M. M., Bertille, K. K., Wake, P. B., Lipnick, M. S., & Whitaker, D. K. (2023). Capnography—an essential monitor, everywhere: a narrative review. *Anesthesia & Analgesia,* 137(5), 934-942.
3. Restrepo, R. D., Karpenkop, I., & Liu, K. E. (2020). Evaluation of Capnography Sampling Line Compatibility and Accuracy when Used with a Portable Capnography Monitor. *Journal of Visualized Experiments (JoVE)*, (163), e61670.
4. Jones T, Glozman D, Oglesby H, Mulier JP. Comparative analysis of accuracy, filter performance, and durability among capnography sampling lines: A bench study. Medtronic Manuscript. 2024.
5. Jaffe, M. B. (2018). Respiratory Gas Analysis—Technical Aspects. *Anesthesia & Analgesia, 126*(3), 839-845.

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