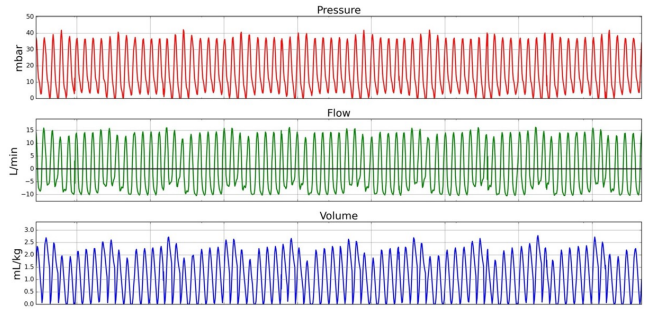
High frequency oscillatory ventilation with volume guarantee What is the evidence and how to use it?



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18th Hot Topics in Neonatal Medicine, Jeddah, 14/02/2024

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Short Bio and Declarations

- Consultant Neonatologist in Cambridge (UK) since 2010
- Interest and active research in neonatal ventilation
- Downloaded data from neonatal ventilators
- Developed computational methods to analyse and interpret ventilator “Big Data”
- Consultant for Vyaire Medical and Dräger Medical
- In this talk I am presenting my own knowledge, experience and research findings as a clinician

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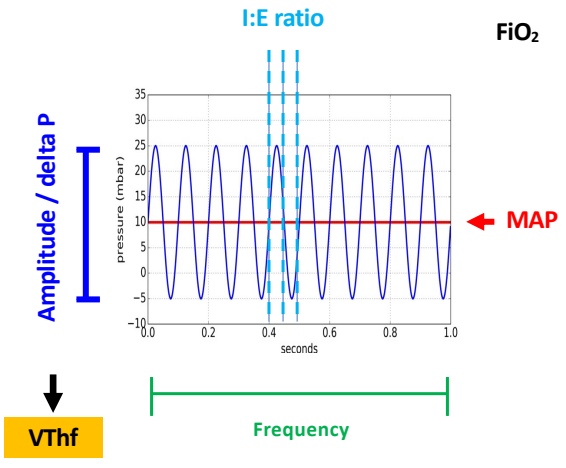
Summary of the talk

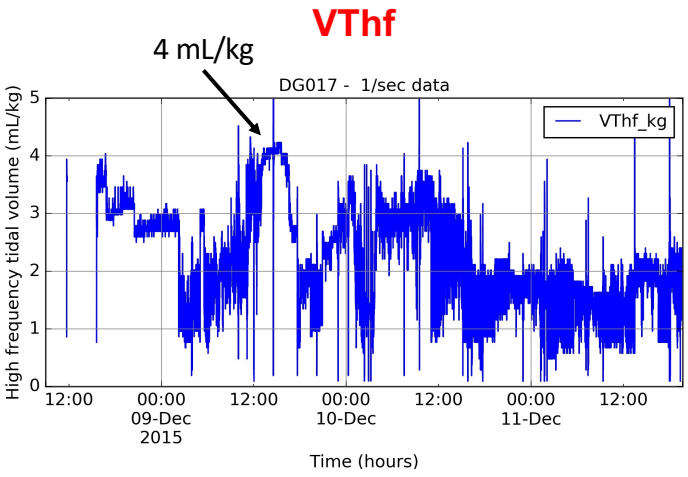
- Basic features of HFOV-VG
- What is the evidence for its use
- Practical points and advice

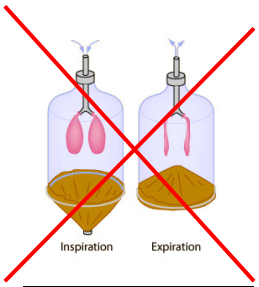
HFOV

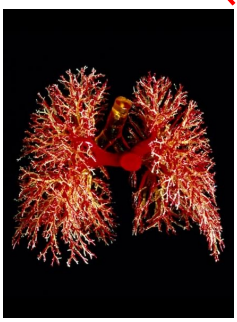
- Both negative and positive pulses are applied around the **MAP** level
- Inspiration & expiration both active, dynamic processes, driven by **deltaP**
- Pressure oscillations result in gas movement "high frequency tidal volume" (**VThf**)
- **Frequency** ranges 5-20 Hz = 300 - 1200/min
- **I:E ratio**: 1:1; 1:2; 1:3



The “tidal volumes” and gas exchange mechanisms of HFOV are different from those of conventional ventilation (?)







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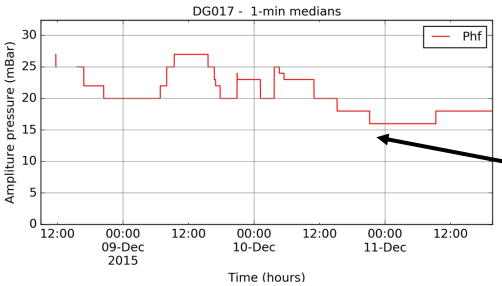
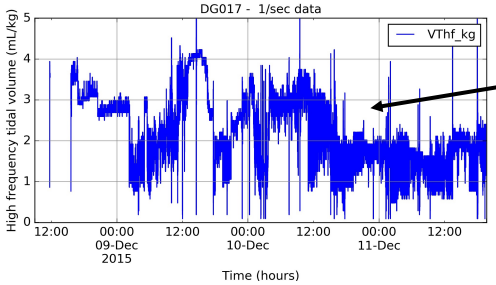
“Traditional” HFOV (without VG)



Amplitude / deltaP

Changes in amplitude made by clinicians



Oscillation volume changes with every oscillation

VThf

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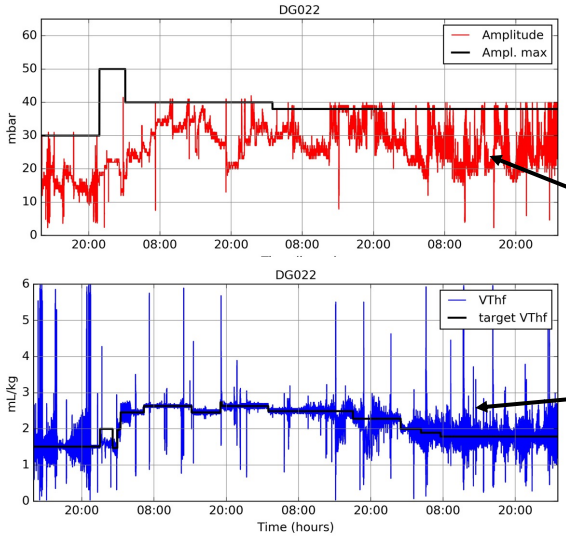
Volume targeted HFOV (HFOV-VG)

- Setting the tidal volume (**VThf**) directly
- **Amphf$_{max}$** is set as the maximum allowed amplitude (similar to P_{max} during conventional ventilation)



Amplitude / deltaP

Pressure amplitude changes every second…

… To maintain oscillation volume close to its target

VThf

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Introducing HFOV-VG into clinical practice

- Data about HFOV-VG were very limited
- Very small studies
  - Iscan et al, *Neonatology*, 2015
  - Gonzalez-Pacheco *et al*, *J Perinatology*, 2016
  - Enomoto *et al*, *Am J Perinatology*, 2017
- VThf used was usually 1.5-2.5 mL/kg
- Less variability of VThf and CO_2
- No clinical outcomes were tested

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Introducing HFOV-VG into clinical practice

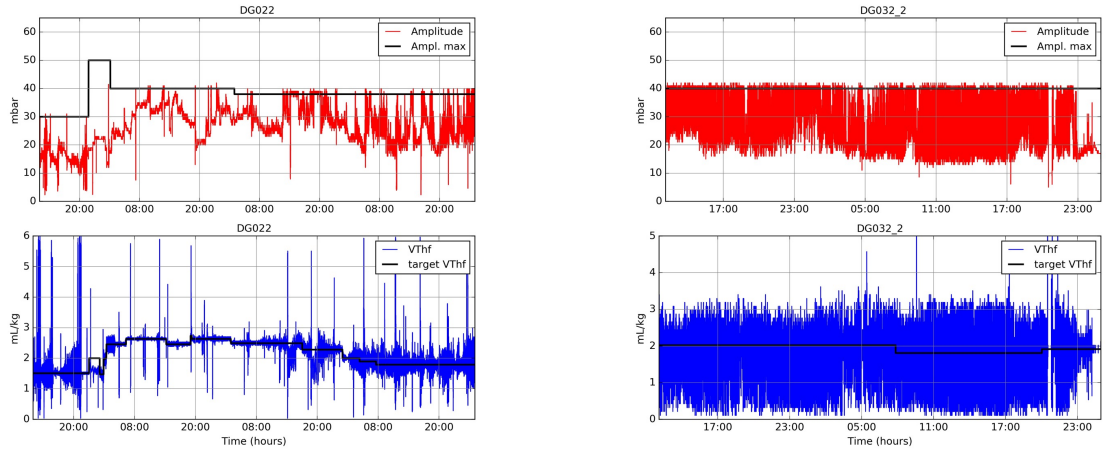
- Started to use it in Cambridge in 2015 using Dräger VN500 ventilators
- Set the parameters of HFOV as usual
- Monitored ventilation with $tcpCO_2$ and pCO_2
- When CO_2 was in target range enabled **VG**
- Downloaded all ventilator data over many days
- Analyzed these large data sets computationally

Belteki G et al., *Arch Dis Child Fetal Neonatal Ed*. 2019.

Amplitude and VThf – data obtained every second

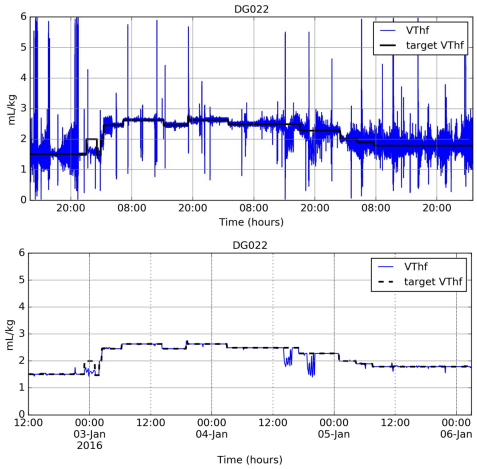
- Sedation & muscle relaxation
- No spontaneous breathing

- Sedation only
- Spontaneous breathing effort

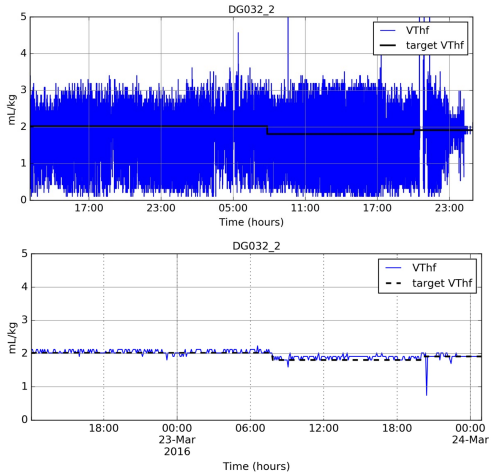


VThf - averaged over 5-minute periods

- Sedation & muscle relaxation
- No spontaneous breathing



- Sedation only
- Spontaneous breathing effort



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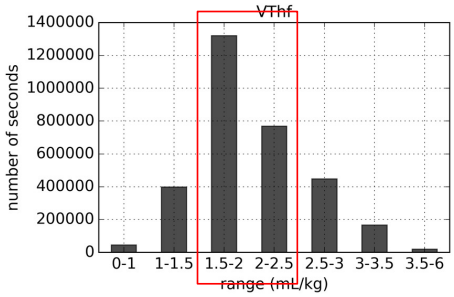
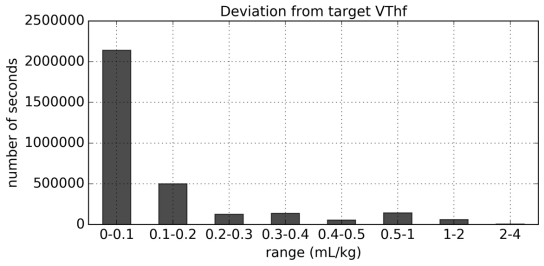
Maintenance of oscillation volumes during HFOV-VG

- 17 infants
- 3.1 million seconds (~37 days)
- median VThf: **1.93 mL/kg** (IQR: **1.64-2.45 mL/kg**)



- Deviation of VThf from set target was <0.2 mL/kg in 83% of time



Belteki G et al., *Arch Dis Child Fetal Neonatal Ed*. 2019

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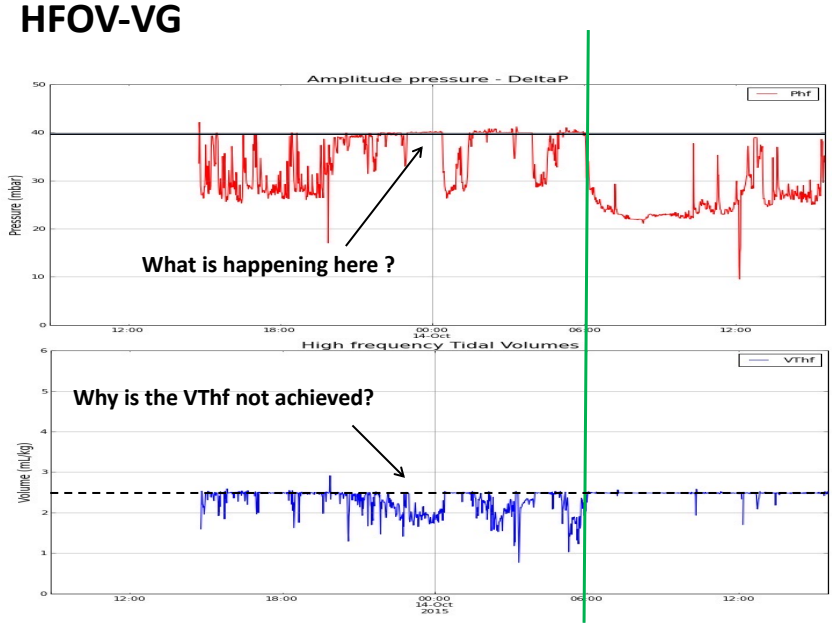
HFOV-VG



DeltaP / Amplitude

VThf

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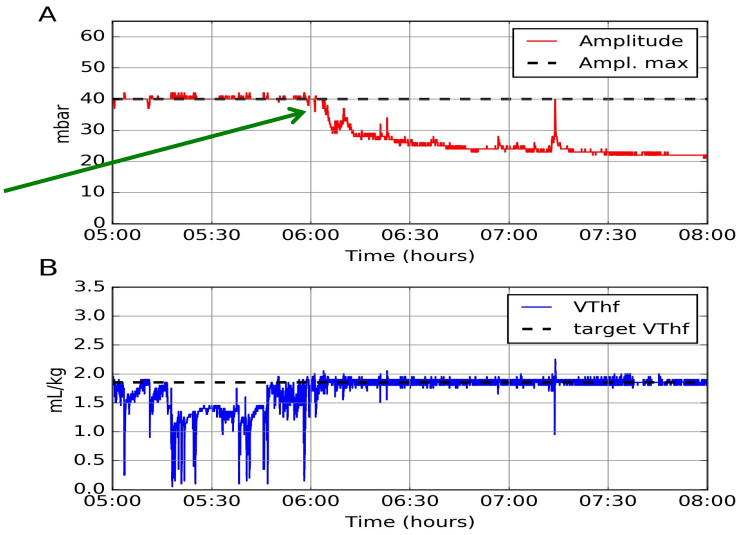
When amplitude is reaching Amp_{max} oscillation volumes (VThf) will be limited

Muscle relaxant



DeltaP / Amplitude

VThf

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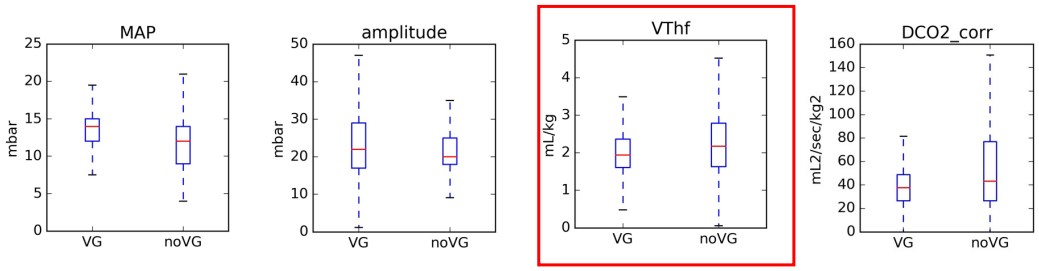
During HFOV-VG VThf is less variable



	Median			IQR		
	VG	No VG	p	VG	No VG	p
MAP	14	14	0.236	1	1	0.172
VThf	2.02	2.26	0.061	0.29	0.66	0.028
amplitude	23	24	0.269	9	0	<0.001
DCO2_corr	41.32	45.3	0.099	9.09	29.76	0.010

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Comparison of HFOV and HFOV-VG

- HFOV-VG maintains pCO_2 levels within target range and reduces VThf delivered variations more consistently than HFOV alone after surfactant administration.
  (Tana M et al, *Front Pediatr,* 2022)
- Compared with HFOV alone, HFOV-VG decreases the fluctuation of VThf and the incidence of hypercapnia and hypocapnia in infants with acute hypoxic respiratory failure after congenital heart surgery. (Zheng TR et al, *Pediatr Pulmonol*, 2021)
- Compared with HFOV alone, HFOV-VG decreases VThf levels and reduces the incidence of hypercapnia and hypocapnia in preterm infants with acute hypoxic respiratory failure after patent ductus arteriosus ligation (Lin HZ et al, *Heart Surg Forum,* 2022)
- Compared with HFOV alone, HFOV-VG reduced proinflammatory systemic reactions after congenital cardiac surgery, decreased the incidences of hypercapnia and hypocapnia, and shortened the postoperative mechanical ventilation duration
  (Zheng YR et al, *J Cardiothorac Vasc Anesth,* 2022)

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Clinical outcomes ??

- Use of HFOV-VG as part of a quality improvement program in extremely preterm infants
- Use of HFOV-VG with high frequency (15-20 Hz) and low VThf (<2 mL/kg)
- **Improved survival without BPD**
- **Fewer respiratory readmissions until 2 years of age**

HFOV parameters			p-value
VThf (ml/kg)	2.2 (1.8–2.6)	1.7 (1.5-1.9)	**<0.01**
Frequency, max (Hz)	9.0 (8.0–10.0)	16.0 (15.0-17.0)	**<0.01**
DCO2	31.0 (19.0–48.0)	28.2 (18.5-45.3)	0.84
MAP	13.0 (11.0–14.0)	12.0 (10.0-14.0)	0.40

Solís-García G, et al. *J Matern Fetal Neonatal Med*. 2022

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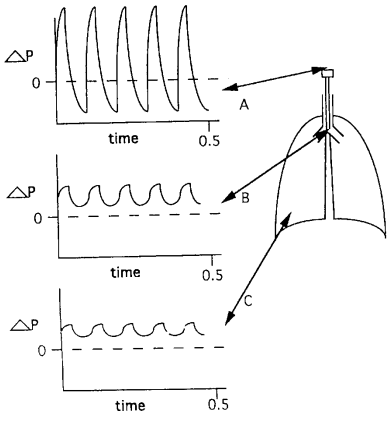
Pressure Effect with Oscillation

Pressure at the proximal end of the ETT

Pressure at the carina

Pressure in the distal airways



Higher frequencies attenuate better and cause less damage: always use the highest possible frequency

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Average VThf of different babies were very different

Recording	Weight (g)	VThf (median)	VThf (5th-95th centile)
DG005_1	1995	1.85	(1.30, 1.90)
DG006_1	650	2.77	(2.46, 3.08)
DG009	1080	2.69	(1.39, 3.43)
DG018_1	755	3.31	(3.05, 3.84)
DG020	2250	1.51	(1.29, 1.87)
DG022	2850	2.14	(1.47, 2.63)
DG025	515	1.94	(1.36, 2.331)
DG032_2	940	2.02	(0.74, 2.55)
DG038_1	1100	2.45	(1.45, 2.82)
DG040_1	570	1.75	(1.40, 2.63)
DG046_1	1180	1.44	(1.19, 1.86)
DG049	520	1.92	(1.73, 2.50)
DG050	1490	1.61	(1.28, 1.74)
DG053	3476	2.5	(2.01, 2.70)
DG056	1950	1.54	(1.18, 1.85)
DG069_1	830	1.69	(1.20, 2.17)
DG077	1660	1.99	(1.81, 2.35)

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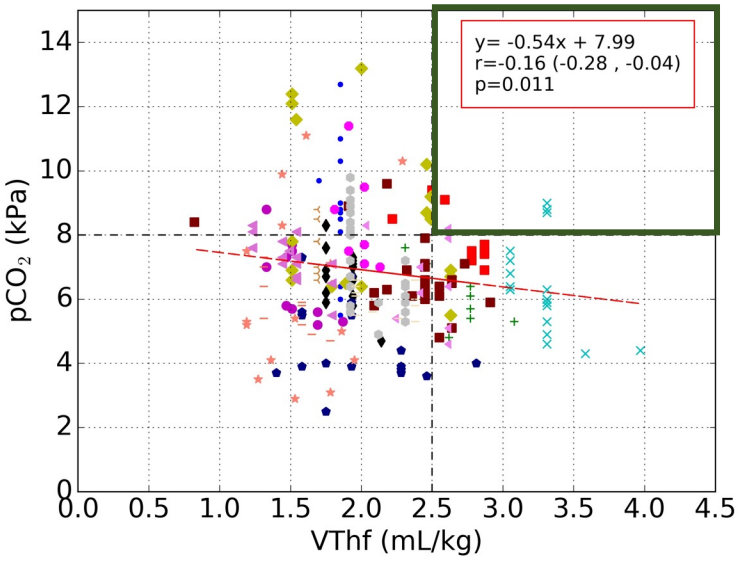
Relationship between VThf and pCO_2



Poor correlation between **VThf** and **pCO_2** when data from multiple patients are considered

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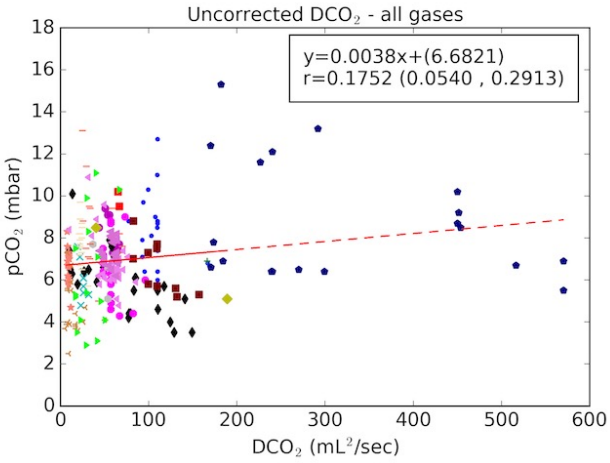
Relationship between DCO_2 and pCO_2



DCO_2 ~ Frequency x VThf ^{2}

- DCO_2 can be used to monitor HFOV in the same baby
- DCO_2 values obtained from different babies cannot be compared

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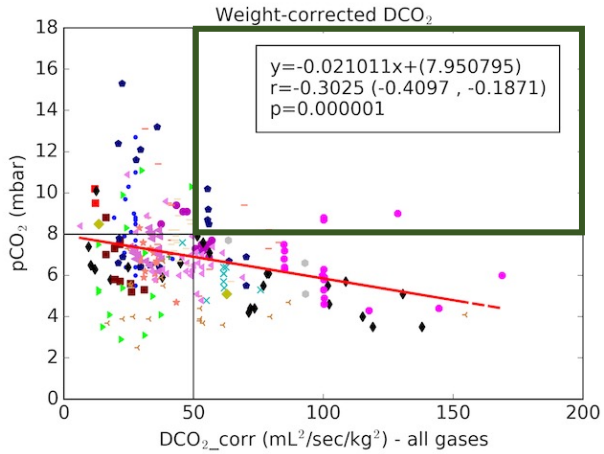
Weigh-corrected DCO_2 can used in different babies



DCO_2 ~ Frequency x VThf ^{2}

- $DCO_{2corr} = DCO_2 / BW^2$
- More than **50 mL/s/kg^2** is rarely required to achieve normocapnia

Belteki et al., *Pediatric Pulmonology*, 2017

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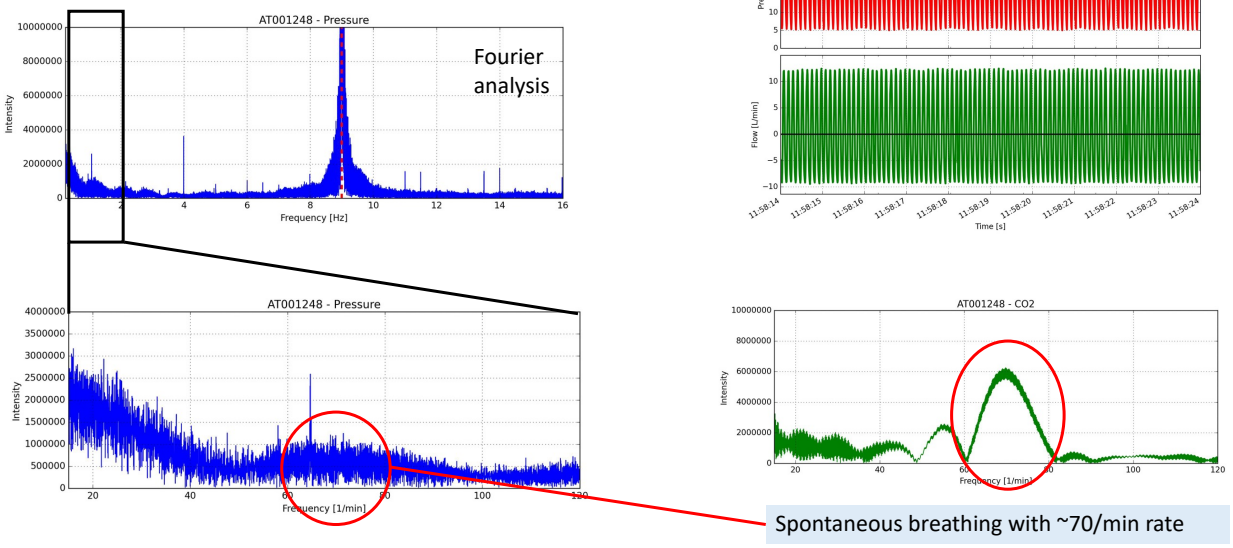
Spontaneous breathing during HFOV



Spontaneous breathing with ~70/min rate

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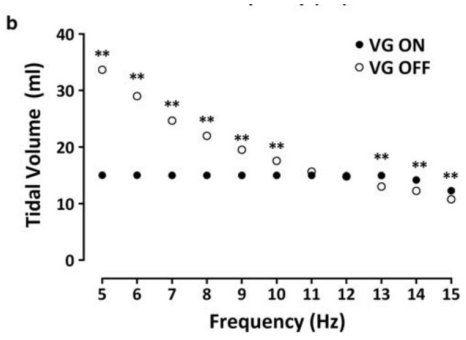
CO_2 elimination during HFOV without VG

DCO_2 ~ Frequency x VThf ^{2}



Mukerji et al, Journal of Perinatology (2014)

- Frequency and VThf are not independent:
  VThf ~ 1 / Frequency
- **DCO_2 ~ Fr / Fr^2 = 1 / Fr**
- **Reducing the frequency improves CO_2 elimination**

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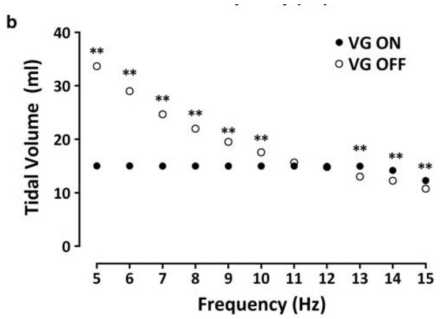
CO_2 elimination during HFOV-VG

DCO_2 ~ Frequency x VThf ^{2}



Mukerji et al, Journal of Perinatology (2014)

- There is no inverse relationship between frequency and CO_2 elimination on HFOV-VG: ***increasing the frequency improves CO_2 elimination***
- Volumes >2.5 ml/kg in large babies may only work with frequency <10 Hz on some oscillators
- DCO_2 becomes a setting not a measurement

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Conclusions

- Overall, tidal volume (**VThf**) is well maintained but there is significant short-term variability probably due to spontaneous breathing
- **$AmpIhf_{max}$** has the same role and issues as P_{max} during conventional VG ventilation
- **VThf** to achieve normocapnia is variable and one cannot use a single value for all patients
- Only few babies need more than 2.5 mL/kg VThf to avoid hypercapnia
- Continuous monitoring of CO_2 levels remains important ($tcpCO_2$)

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Recommendations for HFOV-VG

- Start HFOV-VG with **2 mL/kg** (may vary on different ventilators)
- Set $Amplhf_{max}$ at **5 - 10 mbar / cmH_2O** above the actual amplitude
- Change VThf based on $tcpCO_2$ and blood gases
- The required VThf is almost always between **1.5 – 3 mL/kg**
- During weaning reduce VThf only by **0.1 – 0.2 mL/kg** at a time

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Acknowledgements

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- All doctors and nurses of NICU in Cambridge

www.github.com/belteki

https://www.researchgate.net/profile/Gusztav-Belteki

https://www.cambridgeperinatalgroup.org

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Thank you for your attention !