Journal of Perinatology www.nature.com/jp

ARTICLE

High-frequency oscillatory ventilation with or without volume guarantee during neonatal transport

Vera Balog[1,2], Gabor Liszkay[1,3], Lajos Lantos[1], Agnes Jermendy[2] and Gusztav Belteki[1,4]✉

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OBJECTIVES: To analyse deviation of ventilator parameters from their set targets during high-frequency oscillatory ventilation (HFOV) with or without volume guarantee (VG) and compare the two modes during emergency neonatal transport.
STUDY DESIGN: Retrospective observational study using the fabian™ HFOi ventilator.
RESULTS: Median deviation of mean airway pressure from the set value was <1 cmH_2O. During HFOV the pressure amplitude differed from the set value by <1 cmH_2O. During HFOV-VG median deviation of the oscillation volume (VThf) from the targeted value was −0.07 mL/kg, but in some cases VThf was by >0.38 mL/kg below target. Setting maximum allowed amplitude 10 cmH_2O above the usually required amplitude improved maintenance of VThf. HFOV and HFOV-VG parameters were similar, except the lower amplitude during HFOV without VG. VThf <2.5 mL/kg avoided hypercapnia in most cases.
CONCLUSIONS: HFOV and HFOV-VG maintain ventilator parameters close to their targets and are promising modalities during neonatal transport.

Journal of Perinatology; https://doi.org/10.1038/s41372-024-02109-9

INTRODUCTION

Effective and safe emergency transfer of critically ill infants is an essential component of the neonatal services provided for a geographical region [1, 2]. Infants born in district hospitals may require transfer to tertiary neonatal intensive care units (NICUs) due to prematurity or congenital malformations if an in-utero transfer was not feasible, or if a significant malformation was not recognized antenatally. In addition, term infants without congenital malformations may require intensive care due to early-onset infection, meconium aspiration syndrome or hypoxic-ischaemic encephalopathy. Intensive care of critically ill infants must start in the hospital they have been born in and it needs to continue during their transfer to the NICU.

Most critically ill infants require respiratory support, frequently mechanical ventilation via an endotracheal tube. Over the last two decades, neonatal ventilators have been developed considerably, including the availability of volume-targeted ventilation, also known as volume guarantee (VG), and the option to use high-frequency oscillatory ventilation (HFOV), which previously had been limited only to dedicated ventilator models [3, 4]. More recently, the use of VG has become available during HFOV as well [5].

VG ventilation and HFOV are routinely used in many NICUs and conventional ventilation with VG is now the predominant mode of ventilating infants in Europe and in Canada [6, 7]. However, the adoption of these modes by neonatal transport services has been lagging, and many of them still use controlled mandatory ventilation (CMV), despite the increasing availability of these modes on their ventilators and the evidence to support their use. The use of VG ventilation during transport was first reported only in 2019 and it is currently becoming more widespread [8, 9]. There is only one report about the use of HFOV during neonatal transport, which assessed its safety in nine patients by comparing physiologic and ventilator parameters before and after the transfer [10]. Currently, there are no reports analysing ventilator parameters of HFOV used during transport.

The delay in the use of these advanced ventilation modes during transport has been due to lack of experience, beliefs that the choice of a ventilation mode is not important due to the relatively short duration of transfer, and concerns about physical forces during the transfer potentially interfering with complex adaptive ventilation modes or with high-frequency oscillations. However, these ventilation modes may have already been started in the referring hospitals, and changing ventilation to CMV for the duration of transport takes time and may destabilise the infant. Concerns that physical forces impair these ventilation modes remain speculative; in fact, in a recent study, we showed that acceleration and vibration of the ambulance does not interfere with volume-targeted conventional ventilation [11].

In this paper, we present the analysis of ventilator data from critically ill infants who were ventilated during their emergency transfer using HFOV with or without volume guarantee. We were interested in how closely to the set target values ventilator parameters were maintained during transport. We were also interested in how clinicians set the mean airway pressure (MAP) and, during HFOV-VG, the maximum allowed amplitude pressure and how babies responded to them. Finally, we wanted to compare ventilator parameters during HFOV with or without VG. We hypothesized that the use of HFOV-VG will be associated with

[1]Neonatal Emergency & Transport Services of the Peter Cerny Foundation, Budapest, Hungary. [2]Division of Neonatology, Pediatric Center, MTA Center of Excellence, Semmelweis University, Budapest, Hungary. [3]Bethesda Children's Hospital, Budapest, Hungary. [4]Neonatal Intensive Care Unit, The Rosie Hospital, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK. ✉email: gbelteki@aol.com

Received: 4 June 2024 Revised: 29 August 2024 Accepted: 30 August 2024

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lower and less variable oscillation volumes than using HFOV without VG.

METHODS

Patients and clinical care

Clinical and ventilator data were collected from infants transferred by the Neonatal Emergency and Transport Service of the Peter Cerny Foundation (NETS-PCA, Budapest, Hungary) over a 3-year period (between October 2020 and September 2023) who received invasive or noninvasive respiratory support during inter-hospital transport using a fabian™ HFOi neonatal ventilator (Vyaire Medical, Mettawa, IL, US).

NETS-PCA is a dedicated neonatal transport service operating since 1989 that covers a geographical area in central Hungary which includes Budapest and has a total population of ~4.5 million. The transport team includes a fully trained neonatologist with experience in neonatal transport, an experienced neonatal transport nurse, and a professional driver with experience in driving neonatal ambulances. All emergency transfers are completed using blue lights, sirens, and ambulance priority. Respiratory management including the choice of respiratory support and ventilation settings is generally at the discretion of the transport team without an explicit guideline. In December 2021 a formal case review meeting was performed when the problem of setting the maximum allowed amplitude (Ampl_max) too low was identified and a recommendation was made to set it by 10 cmH_2O above the usual "working" amplitude seen during HFOV-VG for each baby.

For this study, infants were considered if they were ventilated using HFOV with or without VG during part or all of their emergency transport. Transfers when HFOV was used for less than 10 min or only during multiple short HFOV trials, even if they were together longer than 10 min, were excluded. We also excluded infants if their postmenstrual age during the transfer was >46 weeks or if important clinical details were missing. Recordings were considered as HFOV-VG or HFOV without VG if volume guarantee was on or off for >90% of the HFOV ventilation in the recording, respectively.

The study was approved by the Scientific and Medical Research Council Ethics Committee of Hungary (reference number: 40158/2018/EKU). Due to the observational nature of the study, the need for parental consent has been waived by the Ethics Committee.

Data retrieval

Ventilator data were recorded prospectively by a data logger developed by Vyaire for research purposes. All ventilator parameters were downloaded with a 0.5 Hz sampling rate including fraction of inspired oxygen (FiO_2), mean airway pressure (MAP), pressure amplitude (Amp), oscillation frequency (expressed in Hz), oscillation volume (VThf) and diffusion coefficient of carbon dioxide (DCO_2, calculated as frequency multiplied by the square of VThf). Obtained values correspond to averages over 1 s periods just before the time stamp and are the same as the values displayed by the ventilator to clinicians. Ventilator settings, their changes, and ventilator alarms were also recorded. Data were retrieved with millisecond time stamps and exported as text files.

Clinical data were collected retrospectively from electronic healthcare records. Blood gases were obtained via capillary sampling using heel pricks in all cases, as babies did not have arterial catheters.

Data processing and analysis

Data were analyzed using Python (version 3.11.7, https://www.python.org) and its data science packages. Programming was done using Jupyter Notebook (version 8.15.0, http://ipython.org/notebook.html). Data were processed and analyzed using NumPy (version 1.26.3, http://www.numpy.org) and pandas (version 2.1.4, http://pandas.pydata.org). Statistical analysis was performed using SciPy (version 1.11.4, www.scipy.org). Visualization was done using matplotlib (version 3.8.0, http://matplotlib.org). All software is open source and freely available. The Jupyter notebooks containing and explaining all steps of data processing and analysis can be viewed on GitHub code repository at https://github.com/belteki/transport_HFOV.

For recordings which had both conventional ventilation and HFOV, only HFOV parts were included in the analysis, except when comparing FiO_2 and MAP during conventional ventilation and HFOV. When comparing HFOV with or without VG, recordings were only considered if >90% of their HFOV part was either with or without VG, and only this part was included in the analysis.

For ventilator parameters showing normal distribution within the recordings (MAP, amplitude, and VThf), mean and standard deviation (SD) were calculated for each recording, for parameters with non-parametric distribution (FiO_2, leak, and DCO_2), median and interquartile range (IQR) were determined for each patient. As these aggregate values themselves are not normally distributed, groups were compared using non-parametric Mann–Whitney *U*-tests and Wilcoxon signed rank tests for unpaired and paired analyses, respectively. P values < 0.05 were considered statistically significant.

To assess how ventilator parameters deviated from the set targets, the difference between the parameters (FiO_2, MAP, frequency, amplitude, and, in case of HFOV-VG, VThf) and their targets was determined for each data point. The median was then calculated for these deviations for each recording. Since both positive and negative alterations from the set target can occur and they can cancel each other out when medians are calculated, we also calculated absolute deviation for each parameter, where positive and negative alterations are summed. Absolute deviation represents the difference between deviation and zero (the deviation without sign). Data presented in the paper are group statistics (median and IQR) of these aggregate values.

To analyse the relationship between VThf or DCO_2 and blood carbon dioxide levels, the mean VThf and the median DCO_2 were determined during the last 10 min of each recording and correlated with the pCO_2 values in blood gases obtained at the end of transport.

RESULTS

987 infants received respiratory support with a fabian™ HFOi ventilator over the study period. Of them, 451 received mechanical ventilation via endotracheal tube, and among them, HFOV was used in 69 cases (15%). Of them, we excluded 7 cases when the duration of HFOV was <10 min, and further two cases which contained only short trials of HFOV in long recordings (even though cumulatively they were longer than 10 min). Clinical data were insufficient or could not be linked to ventilator data in 5 cases. Three cases included infants with >46 weeks of postmenstrual age and another recording was excluded as it corresponded to a second transfer of the same infant. Therefore, the final dataset included 51 infants (Supplementary Fig. 1). 38 received only HFOV with or without VG during transport, while 13 also had another mode of respiratory support, 8 of them for >10 min, which was synchronized conventional ventilation (SIPPV or SIMV) changed to HFOV later as rescue treatment. VG was used for >90% of the HFOV time in 26 cases and VG was off for >90% of the HFOV time in 22 cases. In 3 cases both HFOV-VG and HFOV without VG were used for >10% of the time. Basic demographic details, primary diagnosis, and medications of the infants are shown in Table 1. Five infants had pneumothorax requiring chest drain prior to transfer and no additional infant developed pneumothorax during transport.

Maintenance of ventilator parameters compared to the targeted values during HFOV with or without VG

During HFOV, with or without VG, the FiO_2 and the MAP deviated very little from their set targets: the median difference between the actual and target values was <1% and <1 cmH_2O, respectively (Table 2). Frequency of the oscillations did not differ from its target either. During HFOV without VG, the pressure amplitude differed from the target by <1 cmH_2O in most cases. During HFOV-VG, the median deviation of VThf from its target was −0.07 mL/kg in the group, but in a quarter of the cases, VThf was by more than 0.38 mL/kg below its target. However, the maximum allowed pressure amplitude (Ampl_max) was set too close to the actual required pressure amplitude and it limited the delivery of the set target oscillation volume in several cases, particularly during the first part of the study period (Fig. 1). Following a case review meeting and implementing the explicit guideline to keep Ampl_max 10 cmH_2O above the usually required amplitude,

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Table 1. Basic demographic and clinical details of the patients included in the study.

	All HFOV ($n = 51$)	HFOV-VG ($n = 26$)	HFOV without VG ($n = 22$)	p value[f]
Demographic details				
Gestational age, completed weeks, median (range)	38 (23–41)	38 (24–40)	37.5 (23–41)	0.59
Postmenstrual age, completed weeks, median (range)	38 (23–41.2)	38 (24–40.4)	37.5 (23–41.2)	0.63
Birth weight, grams, median (range)	3000 (460–4640)	3135 (630–4000)	2735 (460–4640)	0.29
Weight during transfer, grams, median (range)	3000 (490–4640)	3100 (665–4000)	2735 (490–4640)	0.27
Duration of transfer, minutes, median (range)	67 (20–193)	88 (25–193)	52 (20–182)	
Clinical details				
Primary diagnosis				
Meconium aspiration syndrome	15	10	5	
Sepsis/Pneumonia	4	2	2	
Congenital diaphragmatic hernia	8	3	4	
Other congenital malformation[a]	7	2	3	
Perinatal hypoxia	7	4	3	
PPHN[b]	5	1	4	
Hydrops[b]	2	2	0	
RDS	1	1	0	
Other/unknown	2	1	1	
Medications:				
Surfactant treatment (Curosurf)	14	5	9	
Inhaled nitric oxide	18	8	8	
Inotropic medication[c]	20	11	7	
Sedative medication[d]	45	22	20	
Muscle relaxant[e]	3	2	1	

Three infants received both HFOV-VG and HFOV without VG for >10% of the duration of HFOV and are not included in either group
HFOV high frequency oscillatory ventilation, *VG* volume guarantee, *PPHN* persistent pulmonary hypertension of the neonate, *RDS* respiratory distress syndrome, *CCAM* congenital cystic adenomatous malformation
[a]Includes CCAM, lung hypoplasia of unknown cause, urogenital malformations, and omphalocele
[b]Does not include cases secondary to conditions listed above
[c]Inotropic drugs included Dopamine, Dobutamine, Adrenaline, Noradrenaline, and Milrinone
[d]Sedative medication included opioids, benzodiazepines, and thiopental
[e]Muscle relaxant: atracurium
[f]Comparing HFOV-VG and HFOV without VG, Mann–Whitney *U*-test

maintenance oscillation volume close to its target during HFOV-VG was significantly better (Table 2).

Comparison of ventilator parameters during HFOV-VG and without VG

There was no significant difference between gestational age, postmenstrual age, birth weight, and weight during transfer between the groups (Table 1). The pressure amplitude was lower during HFOV without VG but there was no significant difference in oscillation volumes, mean airway pressure, and oxygen requirements between the groups (Table 3). Variability of VThf (expressed as the standard deviation of VThf readings for each patient) was also not significantly different between HFOV-VG and HFOV without VG. There was no difference in blood gases at the end of the transport between HFOV with or without VG.

Changes in FiO_2 and MAP during rescue HFOV

In recordings containing >10 min of both conventional ventilation and HFOV ($n = 8$), HFOV was always used as rescue ventilation mode. In these cases, MAP during HFOV was significantly ($p < 0.01$) higher than during conventional ventilation (Fig. 2A). However, there was no significant change in FiO_2 (Fig. 2B). In the whole cohort, 24 out of 51 infants received close to 100% oxygen during HFOV throughout the transfer (Supplementary Fig. 2).

Relationship between ventilator parameters and blood carbon dioxide during HFOV(-VG)

Blood gases showed improvement during transport: blood gases taken at the end of transfer were significantly less acidotic and the hypercapnia also improved significantly (Fig. 2 C & D).

Blood carbon dioxide levels showed no correlation with weight-corrected VThf or DCO_2. A VThf below 2.5 mL/kg and a weight-corrected $DCO_2 < 50$ $mL^2/s/kg^2$ were sufficient to avoid hypercapnia (defined as $pCO_2 > 60$ mmHg) in all but 2 cases (Fig. 3). Moreover, median VThf of >3 mL/kg and median DCO_2 of >100 $mL^2/s/kg^2$ occurred only in 3 and 2 cases, respectively, and all of them used HFOV without VG.

DISCUSSION

In this study, we analysed performance of the fabian™ HFOi neonatal ventilator in HFOV mode with or without volume guarantee during neonatal transport. It is the first paper analysing ventilator parameters during HFOV used in neonatal transport. It is also the first report using this ventilator model for neonatal HFOV-VG, as all previous human studies used the Dräger Babylog™ VN500 ventilator [5]. A further strength of our study is that data were downloaded with 0.5 Hz sampling rate, allowing us a detailed analysis based on hundreds or thousands of data points in each case.

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Table 2. Maintenance of ventilator parameters during HFOV.

Ventilator parameter	Group median (IQR)			*p* value[a]
	All data	Recordings before quality improvement meeting	Recordings after quality improvement meeting	
Deviation from target value				
All HFOV				
FiO_2 (=FiO_2–FiO_2 set), %	−0.5 (−1.7–0)			
MAP (=MAP–MAP set), cmH_2O	−0.3 (−0.4 to −0.2)			
Frequency (=Frequency–Frequency set), Hz	0 (0–0)			
HFOV without VG				
Amplitude (=Amplitude–Amplitude set), cmH_2O	0.1 (−0.3–0.7)			
HFOV-VG				
Amplitude (=Amplitude–Amplitude max), cmH_2O [b]	−4 (−14.5 to −0.35)	−0.2 (−0.50 to −0.05)	−6.6 (−17.5–1.6)	0.01
VThf (=VThf–VThf set), mL/kg	−0.07 (−0.38 to −0.06)	−0.5 (−0.65 to −0.25)	−0.07 (−0.11 to −0.03)	0.03
Absolute deviation from target value				
All HFOV				
FiO_2 (= |FiO_2–FiO_2 set|), %	0.7 (0.4–1.7)			
MAP (= |MAP–MAP set|), cmH_2O	0.3 (0.2–0.45)			
Frequency (=|Frequency–Frequency set|), Hz	0 (0–0)			
HFOV without VG				
Amplitude (=|Amplitude–Amplitude set|), cmH_2O	0.45 (0.3–0.7)			
HFOV-VG				
Amplitude (=|Amplitude–Amplitude max|), cmH_2O [b]	4.7 (0.7–14.5)	0.4 (0.35–0.70)	6.7 (1.7–17.5)	0.002
VThf (=|VThf–VThf set|), mL/kg	0.09 (0.07–0.38)	0.5 (0.25–0.65)	0.09 (0.06–0.11)	0.07

For each data point the difference between the parameter and its target was determined and their median value was calculated for each parameter in each recording. Data shown are group medians and interquartile ranges of these aggregate values. Since both positive and negative alterations from the set target can occur and they can cancel each other out when medians are calculated, we also show absolute deviations, where positive and negative alterations are summed. "Absolute deviation" refers to the difference between the deviation and zero, that is, the deviation without sign, also determined for each data point, marked as | |. See main text for more details

FiO_2 fraction of inspired oxygen, *MAP* mean airway pressure, *VThf* oscillation volume during HFOV, *VG* volume guarantee, *IQR* interquartile range, *Hz* hertz

[a]Mann-Whitney U-test, comparing recordings before and after quality improvement meeting

[b]During HFOV-VG Amplitude max is a maximum allowed amplitude rather than a target

Our results show that HFOV with the fabian™ HFOi ventilator requires similar oscillation volumes and DCO_2 to ensure normocapnia as another neonatal ventilator (Dräger Babylog™ VN500) from which such data have been reported [12, 13]. We also demonstrated that during HFOV-VG oscillation volumes are maintained close to the targeted value during transport, particularly when their delivery is not limited by the Ampl_max setting being too low. The deviation of VThf from its target was similar to values obtained during HFOV-VG use in the NICU, albeit with a different ventilator model (Dräger Babylog™ VN500) [12]. Our data suggest that HFOV and HFOV-VG can be safely used during emergency neonatal transport.

Ventilator parameters and blood gases during HFOV-VG and HFOV without VG were not significantly different, except for the amplitude, which was lower during HFOV without VG. Variability of VThf was also not lower during HFOV-VG, unlike the findings of others [14, 15]. This may be related to the characteristics of our patient population and possibly to the impact of physical forces.

The study period began at the same time as the transport team started to use the fabian™ HFOi ventilator and using HFOV and HFOV-VG during transport had become available. Therefore, our findings also reflect the learning curve of the team, particularly regarding HFOV-VG. In the initial recordings, Ampl_max was set too low, presumably due to the uncertainty about its role during HFOV-VG. The significant improvement seen after a case review and an explicit guideline demonstrates the effectiveness of regularly reviewing cases together with downloaded ventilator data. Based on our data we suggest that clinicians try to keep the Ampl_max 10 cmH_2O above the usually required "working" amplitude, although the safety of using a particular Amp_max has not yet been formally tested by us or others.

The transport team used HFOV as rescue mode in babies for whom conventional ventilation did not provide sufficient gas exchange or who required high ventilator parameters (i.e., FiO_2 and peak inflating pressure). Although the MAP was significantly higher during HFOV than during conventional ventilation, FiO_2 remained high during the HFOV in most babies. This suggests that hypoxia and the need for high FiO_2 in these infants may have been largely due to cardiovascular problems (e.g., persistent pulmonary hypertension, PPHN), rather than alveolar collapse or consolidation. This highlights the importance of formal recruitment manoeuvres at the start of HFOV, even in a transport setting [16]. An alternative is to use the forced oscillation techniques

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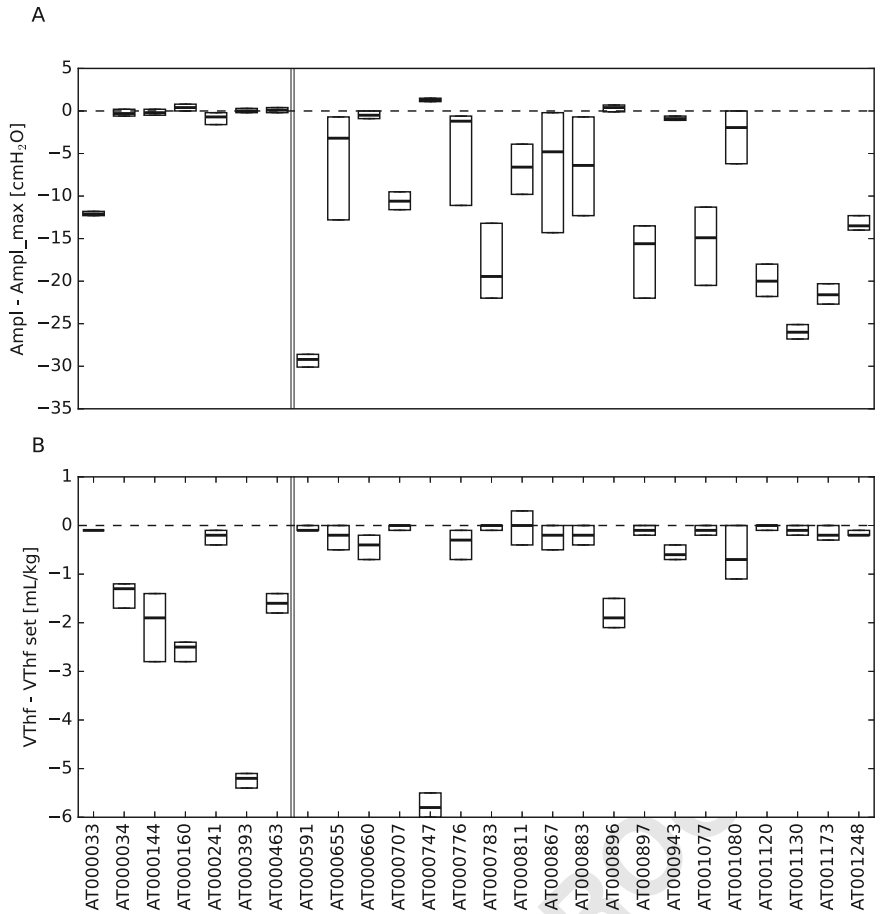

Fig. 1 Boxplots showing the difference between (**A**) the actual amplitude pressure (Ampl) and the set maximum allowed amplitude (Ampl_max), and (**B**) between the oscillation volume (VThf) and its target (VThf set) for each recording using HFOV-VG ($n = 26$). Boxes represent interquartile ranges; medians are shown as thick lines. In 6 out of the first 7 recordings, Ampl reached Ampl_max almost constantly because Ampl_max was set too low, resulting in a failure to deliver the set target oscillation volume. After a clinical case review and making an explicit guideline to set Ampl_max 10 cmH_2O above the working amplitude (double vertical line), the delivery of oscillation volume improved significantly.

Table 3. Comparison of ventilator parameters during HFOV-VG and HFOV without VG.

	Group median (IQR)		*p*-value[b]
	HFOV-VG[a] ($n = 26$)	**HFOV without VG[a] ($n = 22$)**	
Ventilator parameters			
FiO_2, median (%)	85 (65–98)	96 (73–98)	NS
MAP, mean (cmH_2O)	14.2 (12.1–15.5)	13.7 (12.6–15.6)	NS
Leak, median (%)	0 (0–0)	0 (0–0)	NS
Amplitude, mean (cmH_2O)	41 (32–48)	37 (25–40)	0.04
VThf, mean (mL/kg)	2.0 (1.8–2.3)	1.9 (1.5–2.2)	NS
VThf, standard deviation (mL/kg)	0.18 (0.13–0.26)	0.28 (0.14–0.44)	NS
DCO_2, median ($mL^2/s/kg^2$)	34 (29–52)	37 (23–48)	NS
Blood gases			
pH	7.24 (7.14–7.35)	7.21 (7.16–7.33)	NS
pCO_2 (mmHg)	54.3 (42.1–69.0)	58.5 (46.0–66.0)	NS
BE (mmol/L)	−2.7 (−6.0 to −0.65)	−2.6 (−7.2 to −51.5)	NS

For data with normal distribution within the recordings (MAP, deltaP, VThf), mean was calculated for each recording; for VThf, standard deviation was also calculated to reflect its variability within the recordings. For data with non-parametric distribution (FiO_2, DCO_2, leak), median and interquartile range (IQR) were calculated in each recording. Data shown in the table are group medians and interquartile ranges of these aggregate values

FiO_2 fraction of inspired oxygen, *MAP* mean airway pressure, *VThf* oscillation volume, *DCO_2* diffusion coefficient of carbon dioxide, *VG* volume guarantee, *IQR* interquartile range, *Hz* hertz, *NS* not significant

[a]Patients who received both HFOV-VG and HFOV without VG for >10% of time were not included in either group ($n = 3$).

[b]Mann–Whitney *U*-test

PEER REVIEW

(FOT) for identifying the optimal recruitment and MAP, which is also available on the fabian™ HFOi ventilator [17].

We found that pCO_2 in blood gases done at the end of transport showed no correlation with the VThf or DCO_2 during the last 10 min of the transport, even when those were corrected for body weight, similar to previous reports [12, 13, 18]. Several factors may have contributed to this. First, our analysis is based on capillary gases which may not have reflected the arterial CO_2 values in all cases, particularly in babies with coexistent circulatory problems. However, correlation between DCO_2 and pCO_2 was previously found to be poor even when only arterial gases were considered [13]. Second, different infants had different lung conditions and changes in their respiratory mechanics, requiring different VThf and DCO_2 to achieve the same level of gas exchange. Finally, some babies may have had spontaneous breathing during HFOV which could have contributed to their gas exchange.

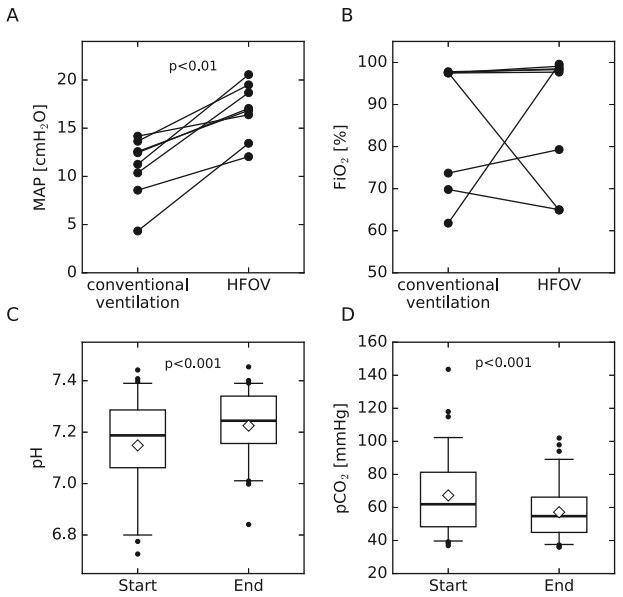

Fig. 2 Dot plots of mean airway pressure, MAP (**A**) and (**B**) fraction of inspired oxygen, FiO_2 in infants who received initial conventional ventilation followed by rescue HFOV during transport ($n = 8$). Each dot represents a patient. FiO_2 remained high during HFOV in most cases, despite the significantly higher MAP used (Wilcoxon signed rank test). Boxplots of pH (**C**) and in pCO_2 (**D**) in blood gases at the beginning and at the end of transport. Boxes represent interquartile ranges, medians are shown as thick lines, means as empty diamonds. Whiskers represent 5th and 95th centiles, outliers are shown as black dots. Both pH and pCO_2 showed significant improvement during transport (Mann–Whitney U-test).

Although babies received a wide range of average VThf and DCO_2, only very few of them required >2.5 mL/kg VThf or >50 $mL^2/s/kg^2$ DCO_2 to provide sufficient CO_2 elimination, what we also found in a different study using the Dräger Babylog™ VN500 ventilator [12]. We argue that clinicians should not routinely set higher values unless blood gases consistently show hypercapnia and technical issues such as poor perfusion have been ruled out. VThf >3 mL/kg only occurred during HFOV without VG, highlighting the need to carefully monitor oscillation volumes on the ventilator display when volume guarantee is not used.

There is only limited evidence so far that HFOV-VG has other benefits than maintaining VThf and pCO_2 in a tighter range than HFOV without VG and the short duration of transport makes it unlikely that the use of HFOV-VG would affect clinical outcomes [19]. Nonetheless, HFOV-VG has become widely available on modern ventilator models and has been increasingly used during neonatal clinical care (GB, unpublished observation). We think our findings are generalisable to other clinical situations and possibly to other oscillators.

Our study has several limitations. First, comparison of HFOV and HFOV-VG was done retrospectively, with the clinical decision whether to use VG left at the discretion of the clinicians. Even though the two groups did not differ in basic demographic and clinical characteristics, there may have been differences between them. Second, when assessing deviation of ventilator parameters from their set targets, we used data obtained by the ventilator's sensors, rather than measured by an independent device. Third, there was no continuous carbon dioxide monitoring during transport and blood gases were capillary samples. Finally, we present no data on the clinical outcome of the cases.

In summary, ventilator parameters are maintained close to their set targets during HFOV and HFOV-VG used in emergency neonatal transport. Oscillation volumes over 2.5 mL/kg are rarely required to achieve normocapnia.

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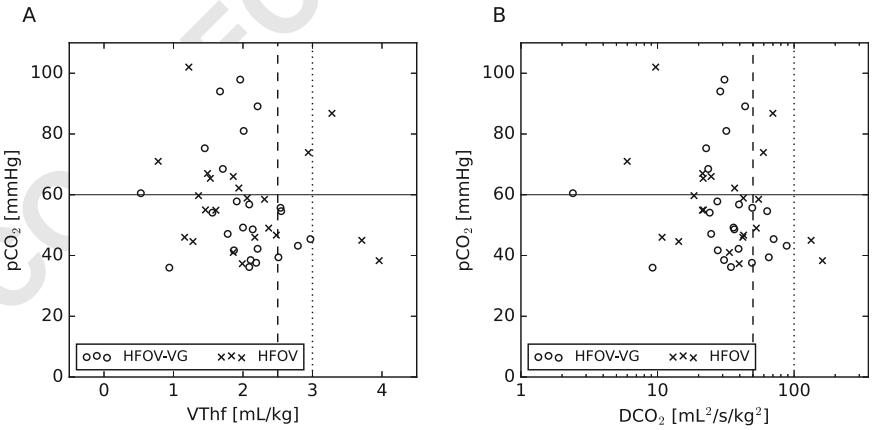

Fig. 3 Relationship between (**A**) the oscillation volume, VThf, or (**B**) the diffusion coefficient of carbon dioxide, DCO_2 during the last 10 min of transfer and blood CO_2 levels at the end of transfer (pCO_2). HFOV-VG recordings are marked by circles, HFOV recordings without VG are marked by crosses. Note the logarithmic x-axis on (**B**). There is no significant correlation between pCO_2 and either VThf or DCO_2. However, hypercapnia ($pCO_2 > 60$ mmHg, horizontal lines) occurred only rarely with VThf >2.5 mL/kg or $DCO_2 > 50$ $mL^2/s/kg^2$ (dashed lines). VThf >3 mL/kg or $DCO_2 > 100$ $mL^2/s/kg^2$ (dotted lines) occurred only in some cases of HFOV without volume guarantee.

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DATA AVAILABILITY

Notebooks containing the Python code and explaining all steps of data processing and analysis have been uploaded to a GitHub code repository and are available at https://github.com/belteki/transport_HFOV. Ventilator data are available from the corresponding author upon reasonable request and subject to research ethics committee approval.

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ACKNOWLEDGEMENTS

We thank to Rainer Kühner (Vyaire) for help with exporting data from the fabian™ HFOi ventilator.

AUTHOR CONTRIBUTIONS

VB participated in the conception of the study, collected clinical information, participated in the interpretation of results, and edited the manuscript. GL participated in the interpretation of results and edited the manuscript. LL participated in the acquisition and interpretation of clinical data and revising the article. AJ participated in the interpretation of clinical data and revising the article. GB was responsible for the conception of the study, statistical analysis, and interpretation of data, and wrote the manuscript. All authors read and approved the final manuscript.

COMPETING INTERESTS

Gusztav Belteki is a consultant to Vyaire Medical (Mettawa, IL, US) and Dräger Medical (Lübeck, Germany). Vyaire Medical did not ask the authors to perform the study or participate in it and did not provide any payment for it.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study was approved by the Scientific and Medical Research Council Ethics Committee of Hungary (reference40158-2/2018:/EKU). All procedures were in accordance with the ethical standards of the responsible committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 1983.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41372-024-02109-9.

Correspondence and requests for materials should be addressed to Gusztav Belteki.

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