

Resuscitation

Clinical application of high-frequency jet ventilation (HFJV) in transportation and cardio-pulmonary resuscitation

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The authors dedicate this publication to the memory of Ing. Ondrej Brychta, CSc.

Summary:

Clinical use of high-frequency jet ventilation during transport and CPR

The authors describe clinical use of high-frequency jet ventilation with PARAVENT PA (Elmet-Kalas-Medinvex) ventilator during transport of patients and for CPR in both pre-hospital period and in-hospital care.

The ventilator was used in 57 patients transported for different reasons or resuscitated after cardiac arrest. The most numerous subgroup of 44 patients was transported to CCU after surgical or diagnostic procedure performed in general anaesthesia. HFJV was realized in 11 patients during CPR. 5 patients were ventilated with a HFJV regimen during a long-term transport by ambulance for more than 30 minutes.

Vital functions and the parameters of ventilation and the acid base balance data were evaluated. No significant difference was noticed before and after transport.

Differences in acid base were observed in the group of resuscitated patients according to bag-mask ventilation or HFJV. Since the group was small the outcomes were not evaluated statistically.

Patients ventilated by HFJV tolerated the regimen relatively much better than bag-mask ventilation or ventilation by a conventional type of ventilator.

The incidence of complications was neglectable.

In conclusion the authors claim that high-frequency jet ventilation with PARAVENT PA ventilator is much safer and comfortable than ventilation with a conventional ventilator or with a bag-mask system.

Key words: high-frequency jet ventilation (HFJV), CPR, patient transport

High-frequency jet ventilation is nowadays primarily used in the clinical practice in resuscitation units (Sjöstrand et al. 1977, Klain and Smith 1977) but is fairly seldom used in pre-hospital or in in-hospital intensive care. Concerning this fact, we have started to use the transport HFJV ventilators of type PARAVENT PA (Medinvex-Kalas-Elmet) in pre-hospital and in-hospital intensive care, as well as for patients' transportation and in cardio-pulmonary resuscitation.

Technical appliance

For the needs of intensive care, high-frequency jet ventilators of type PARAVENT P, PA and PAT dedicated for in-hospital but also pre-hospital care are produced and in the time of drafting this publication already distributed to the medical market by the joint venture Medinvex-Kalas.

These are small transportable high-frequency jet ventilators with a simple use and operation, equipped with all necessary safety features, that can be used by

not only doctor, but also by well-trained emergency staff and paramedics.

For our purpose and in our conditions, HFJV ventilator PARAVENT PA seems to suit well to our requirements (Pic.1)

Technical parameters

Size: 165 x 110 x 220 mm

Weight: 3.5 kg

Sourcing: O₂ cylinder, 350-400 kPa

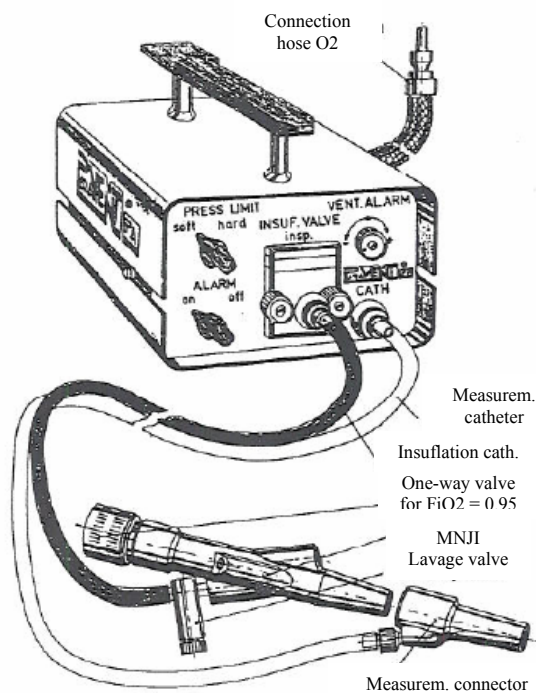
FiO₂ = cca 0.65 (or 0.95)

Vt = 10-250 ml according to the applied multi-nozzle jet injector (MNJI) and the nozzle used, frequency: 120 b/min

Time ratio Ti:Te = 1.25:1

Alarm of excessive pressure (soft) = 2.5 kPa, (hard) = 5 kPa with the limiter of ventilation energy and total stop of ventilator;

Alarm of non-ventilation (disconnection, fall-out of connector, disconnection of ventilation circuit, etc.).



Pic.1 Overview of HFJV ventilator PARAVENT PA with a display of connection of multi-nozzle jet injector (MNJI) and measurement connector.

Functional principle

The ventilator itself is constructed on the basis of pneumatic logic features and apart from the source of compressed O₂ gas it doesn't need any other source of energy. The functionality of alarms is also based on the pneumatic principle.

The ventilator consists of two basic components. It's the ventilator itself, that produces pneumatic pulses of stable pressure time-amplitudes (Ti, Te) and frequency. Alarm and safety system is integrated inside the ventilator. The second, decisive part of the system is so called multi-nozzle jet injector (MNJI) that creates the gas mixture injected into lungs. The energy carrying the gas mixture into lungs is generated in this part. The insufflation pressure (Pin) (pneumatic impulses) are lead from the ventilator into the nozzles of MNJI. Multi-nozzle jet injectors are adapted to intubation cannulas that means that for ET cannula no.3 there is the corresponding MNJI no.3 to be used, up to ET cannula no.10 with corresponding MNJI no.10 [3].

In each unit of MNJI, there are three insufflation nozzles of different, but exactly defined, diameter, that serves the supply of O₂ from the ventilator and as a source of energy for transportation of breathing gases into lungs. The nozzles are marked with the numbers I, II and III. The nozzle no. I is the smallest one and thus after the connection of insufflation pressure the generator is the softest and the power the smallest. The nozzle no. II has the bigger diameter and the ventilation energy higher by cca. 100%. The nozzle no. III has the biggest diameter and the ventilation energy is the highest – cca. 150% in compare to the nozzle no. I. With the adaptation of individual nozzles to the ventilator one can change the ventilation energy in

the range of ca. 150%. In the MNJI unit, there is also another nozzle that is oriented in the opposite direction. It's a nozzle of expiration support that is used in PARAVENT PAT ventilators for expulsion mode. The connection of alarm section of ventilator is performed through the connection of tube ending into the measurement cone, or onto the measurement catheter of endotracheal cannula. [1, 2]

The ventilation ratios of individual MNJIs and their nozzles are designed in such a way that with the use of same insufflation pressure (Pin) is the ventilation of 1900 g premature newborn baby comparable to the ventilation of 100 kg weighting adult. Newborn is intubated with 2.5 mm ET cannula and connected to MNJI no. 3 and adult is intubated with 9 mm ET cannula with MNJI no.9, whereas the ventilation is comparable concerning the needs of both ventilated subjects.

The advantage of such a solution is that it's not necessary to change insufflation pressure (Pin). The change of ventilation power can be achieved by the change of connected nozzle I, II or III.

Material and methods

High-frequency jet ventilation was used in 3 groups of patients in-hospital as well as pre-hospital care, i.e. for inter-departmental transport, for treatment of patients in emergency rescue services and for cardio-pulmonary resuscitation in the department. Considering the limited possibilities of monitoring during transport, we were trying to collect as many objective parameters, even though it wasn't always possible. For the application of HFJV, we used HFJV ventilator PARAVENT PA from the prototype series. EKG was normally monitored by cardiomonitor of defibrillator BDP13 or MRL360 SLX.

Sample taking in transported patients for the purpose of examination of blood gases (ABL 330 Radiometer) was done from arterialized capillary blood. In resuscitated patients in the department, from arterial cannula or through puncture from arteria femoralis. Patients treated during emergency rescue transport had blood sample offtake taken only after admitted to CCU (A-R) unit. In chosen group of patients, we monitored ventilatory parameters and parameters of mechanical properties of lungs with a PC monitor DYNAVENT 888 (Medinex). This system is unusable in urgent situations. In some patients, we monitored ventilatory parameters using capnoventil and adapted gasmeter G1,6 (Prema). Pressure was monitored by the electronic pressuremeter LKM220 (Tesla). The statistical evaluation was performed in PC ACCES 386. During transport we monitored SpO₂ with pulzeoxymeter (Pace-Tech).

Patients can be divided into 3 groups

The first group is comprised of patients that were primarily transported post-operative from surgery department to CCU.

The second group is comprised of patients, that were transported to CCU in clinical death or exited in CCU

and were successfully resuscitated already in ERS ambulance vehicle or directly at CCU department.

The third group is comprised of patients, that were for acute arrest or injury treated in ERS ambulance vehicle or were transported by ERS ambulance vehicle over distance more than 25 km.

The basic characteristics of the groups is in **Tab. I**.

Tab.I Group of all patients

	Patients transp. after anesthesia	Patients resuscitated	Long-term transport	Transport	Total
No.	41	11	3	2	57
Avg. Weight [kg]	84 ±9	79±8.6	80.6±8.8 *	1300±100 **[g]	

** - newborns (premature born babies)

* - adult patients

Results

The basic and also the reference group is comprised of patients that were transported to CCU from other department, resp. from surgery rooms after anesthesia. In most cases, these were patients with accompanying complicating disorder, mostly of cardiac origin. In three patients, there was an asthma in anemnesis.

The results of basic measurements are in **Tab.II**.

The results of further two groups of patients are in **Tab.III** (there are also individually measured values).

The results that we gained from relatively small and mainly non-homogeneous group of patients were not statistically evaluated. Considerably more data was gained in the group of patients, however to show and prove the effectivity of HFJV in resuscitation and in transport, its publication is not considerably more important.

Tab.II Group of patients transported after anesthesia to CCU and ventilated by HFJV (n = 41)

Weight [kg]	No. [I]	MV (1) [l]	MV (2) [l]	MV (3) [l]	pCO ₂ (1) [kPa]	pCO ₂ (2) [kPa]	pCO ₂ (3) [kPa]	pO ₂ (1) [kPa]	pO ₂ (2) [kPa]	pO ₂ (3) [kPa]	MNJI [mm]	Nozzle no.
55 ±10	6	6 ±1	17 ±2.2	17 ±1.8	4.4 ±1.2	4.2 ±0.8	4.1 ±0.4	17 ±4.3	29 ±5.3	31 ±5.8	7	I-II
75 ±10	24	7.5 ±1	19 ±2.1	20 ±3	4.2 ±1.2	3.8 ±1.1	3.7 ±1.0	16 ±5.0	27 ±5.1	29 ±5.2	8	II
95 ±10	11	8.4 ±1.3	21 ±3.2	21 ±3.3	4.1 ±1.1	3.6 ±1.6	3.6 ±1.2	15 ±5.0	29 ±5.2	28 ±5.3	9	II
total	41											

Average duration of HFJV = 22 ±5 minutes, Pin = 160 kPa, Ti:Te = 1.25:1, Pmax = 2.8 kPa, Pmin = 0.3 kPa
Comparing pCO₂ before and after the connection to HFJV, no statistical significant difference was found.

Index (1) – measurement before the termination of anesthesia FiO₂ = 0.33

Index (2) – measurement after 5 minutes after connected to HFJV FiO₂ = 0.6

Index (3) – measurement after transport, before disconnection from HFJV FiO₂ = 0.6

MV – minute ventilation

pCO₂ – arterial pCO₂

pO₂ – arterial pO₂

MNJI – size of MNJI in mm = size of ET cannula

Nozzle – number of nozzle on MNJI (I – the smallest, III – the biggest), Pin – insufflation pressure

Tab.III Group of patients that were resuscitated for circulation failure and were successfully resuscitated as the group of patients transported over distance of more than 25 km (n = 11), patients resuscitated in CCU (n = 8) and in ERS ambulance vehicle (n = 3).

Weight [kg]	No. [I]	MV (1) [l]	MV (2) [l]	MV (3) [l]	pCO ₂ (1) [kPa]	pCO ₂ (2) [kPa]	pCO ₂ (3) [kPa]	pO ₂ (1) [kPa]	pO ₂ (2) [kPa]	pO ₂ (3) [kPa]	MNJI [mm]	Nozzle no.
50-70	4	0	18 ±3.4	19 ±4	8.3 ±2.2	7.8 ±2.0	4.4 ±2.0	4.8 ±2.1	6.1 ±2.2	21 ±4	7	II
71-90	3	0	22 ±4.4	23 ±5	9.1 ±3.1	8.5 ±3.0	3.9 ±1.1	4.9 ±2.0	5.9 ±2.3	22 ±4.6	8	III
> 90	4	0	25 ±5	26 ±5.1	8.5 ±3.0	7.6 ±2.3	4.1 ±1.6	3.9 ±2.0	6.0 ±2.3	19 ±4.3	9	III
(n = 5) patients transported												
85	1	8.8	20.5	21.7	5.2	4.8	N	11.6	22.5	N	9	II
77	1	7.9	19.3	18.3	4.8	4.1	N	10.8	21.8	N	8	II
80	1	9.2	22.4	N	5.6	5.1	N	9.8	16.4	N	9	II
1400 g	1	N	N	N	5.9	5.5	4.9	6.6	8.9	9.2	3	III
1200 g	1	N	N	N	6.6	6.3	4.1	6.3	9.9	13.8	3	II

Size of MNJI in mm = size of ET cannula, the size of ET cannula used for children was 2.5 mm

Pin = 160 kPa, Pmax = 3.1 kPa, Pmin = 0.4 kPa, Ti:Te = 1.25:1

Number of resuscitated patients was from total of 23 resuscitated. Effectivity of CPR was 47.8%.

Index (1) – before connection to HFJV, FiO₂ = 0.21, in children ventilated conventionally FiO₂ = 0.4

Index (2) – after connection to HFJV cca within 5 min. from the start, FiO₂ = 0.6, in six patients FiO₂ = 0.98

Index (3) – before disconnection from HFJV, FiO₂ = 0.6

N – parameter wasn't measured

For small group, the parameters were not statistically evaluated

All other abbreviation as in Tab.I

Tab. IV. Comparison of speed of connection of patient to ALV after resuscitation (n = 6)

	AMBU FiO ₂ = 0.21	AMBU FiO ₂ > 0.6	Chiralog 1	PARAV ENT
Time [s] Trained team	10-20	25-60	120-180	<45
Untrained team	20-50	>120	>240	120-180

Tab.V Technical and clinical complications in all 3 groups

Type of complication	Number
through-up	1
aspiration	0
irritation by ET cannula	9
biting into cannula	1
activation of „total stop“ in Pw>5 kPa	1
induction of caughing reflexes	1
disconnection of insufflation O ₂	1
disconnect. of system during transport	2
failure of ventilator	0
TOTAL	16

The majority of patients were ventilated with FiO₂ = 0.6 that is the gas mixture flowing through MNJI after mixing of insufflation O₂ with torn-down air. In the cases when we wanted to apply 100% O₂ (FiO₂ = 1.0), we ventilated patients through the nozzle no. III and the entry of torn-down atmospheric air was closed by one-way valve that prevents tearing down air from atmosphere. In this case, gas supplied from MNJI has FiO₂ close to 1.0. We didn't find any considerable changes in PO₂ in ventilation with FiO₂ = 0.6 or 1.0. Patients were intubated either in general anesthesia or in urgent cases in unconsciousness, only in topical anesthesia, that was performed in each patient. Endotracheal cannula wasn't cuffed (was unsealed). In HFJV, it is not suitable to seal ET cannula, cuff should be deflated. Objective tolerance of HFJV was good, patients that regained consciousness or woke up from anesthesia tolerated worse endotracheal cannula than the ventilation itself. The topical anesthesia of larynx and trachea is always necessary.

We didn't discover statistical significant differences in blood pressure or pulse frequency during transport. During transport we monitored by standard the SpO₂ by pulseoxymeter.

Tab. VI. Some monitored parameters by Dynavent 888 (n = 4)

Patient number	Weight [kg]	Age [years]	MV (1) [l]	MV (2) [l]	C (1) [ml/kPa]	C (2) [ml/kPa]	Raw (1) [kPa/l/s]	Raw (2) [kPa/l/s]	Note
1	77	46	19	21	567	643	0.5	0.3	x
2	57	76	16	18	467	533	0.4	0.4	xx
3	96	52	23	23.8	677	701	0.2	0.3	xxx
4	65	49	18	19	710	720	0.5	0.5	xxxx

All patients were ventilated ($f = 120$ b/min, $Ti:Te = 1.25:1$, $P_{in} = 160$ kPa, $FiO_2 = 0.6$)

Endotracheal cannula no. 7, 8, 9 with corresponding MNJI, nozzle no. II, C = compliance, Raw = resistance

x – post-operative after transport, anemnesis negative

xx – post-operative after transport, in anemnesis bronchitis

xxx – post-operative after transport, anemnesis negative

xxxx – after CPR accident by electric current, in anemnesis spast. bronchitis

index (1) – cca. 20-30 min. after initiation of HFJV

index (2) – after disconnection from HFJV

Through progressive training, we have measured the time necessary for resuscitation team to initiate effective ALV after intubation. We were comparing application speed of ventilation with AMBU-bag, Chiralog ventilator and HFJV ventilator PARAVENT, including the unwrapping of sterile components.

The results are presented in **Tab. IV**.

The results listed in Tab. IV clearly document that a well-trained team is able to initiate HFJV ventilation with PARAVENT ventilator within 45 seconds from the initiation of CPR.

In ERS ambulance vehicle, it's possible to initiate the ventilation even faster as individual connections can already be pre-prepared. It's enough to open O₂ from cylinder, choose MNJI and connect to ET cannula. The start-up of ventilation with PARAVENT PA and AMBU-bag with O₂ connection was in our conditions time-comparable. Space accessibility of all components is within 7-15 meters. Average training time for individual resuscitation teams is cca. 60 minutes.

Concerning any kind of complications, we can divide these into clinical and technical.

In clinical practice, we didn't note down more relevant complications. Problems occurred primarily in the group of transported patients that had insufficient topical anesthesia and to whom ET cannula caused the irritation of airways after the wake-up from anesthesia. Deflexive reflex was observed only seldom. Concerning the physical safety of MNJI as well as the equipment of ventilator with safety and alarm system, we didn't encounter barotrauma. Technical and clinical complications are listed in **Tab. V**.

The results of some measured parameters of 4 patients that had its ventilation monitored by monitor Dynavent 888 are mentioned in **Tab. VI**.

Discussion

The application of high-frequency jet ventilation in pre-hospital care as well as in cardio-pulmonary resuscitation and in transport of patient is fairly new solution of problematics. The requirement that determines these possibilities is accessibility to small and reliable ventilator that fulfils all safety requirements and has simple use and operations [2].

We were testing application possibilities of HFJV ventilator PARAVENT PA (Medinvex – Kalas – Elmet), that is nowadays accessible on our market. The applicability of HFJV in clinical conditions was described in various publications, however only rarely in CPR. Firstly we were testing practical possibility of ventilation during transport in post-operative statuses with minimally disordered lung functions. We have discovered that during HFJV occurs a modest decrease of pCO₂, whereas oxygenation was sufficient in all patients. Considerable deviation of pulse and blood pressure were not detected. If following the application recommendations according to the user's manual of PARAVENT PA, the critical hypocapnia doesn't occur, even through mild hypocapnia is present.

If we used the corresponding MNJI for the given ET cannula and applied Pin through nozzle no. I and II, retention of CO₂ or hypoxia wasn't discovered in any case. For the safe application of HFJV during transport, we consider the presence of doctor for necessary. After certain experience of rescue personell will likely be possible to drop from this condition.

In the group of resuscitated patients, the oxygenation as well as the elimination of CO₂ in compare to ALV applied by AMBU-bag has improved. After the renewal of circulation, fairly quickly within few tens of minutes, hypocapnia emerged. During the resuscitation, we have principally used nozzle no. III due to our apprehension of relative hypoventilation in cardio-pulmonary arrest. It seems that after the resuscitation of patient, if lung functions were not extremely disordered (lung edema, trauma, ARDS), it

is suitable after the initial use of nozzle no.III to swap patient to nozzle no.II and after the control of blood gases alternatively perform further remedies. Considering the small group of patients it is not possible to draw definite conclusions.

The use of concept of safe ventilator has manifested itself on a minimum of complications that emerged. However, they weren't of severe character. In the cases of airways irritation by ET cannula, we treated such cases in easy way by applying an aerosol 2% Mesocain (Spofa) in dosage of 5 ml into the lavage valve of ventilator. This dosage was enough to perform the topical anesthesia of airways which prevented further irritation of airways by ET cannula [7].

Conclusion

According to the preliminary clinical results, we have concluded that HFJV applied by safe ventilator, i.e. by ventilator that is equipped by all safety features, is a suitable alternative to conventional ventilation during longer-term transportation. In cardio-pulmonary resuscitation, with HFJV it is further possible to ensure basal oxygenation and elimination of CO₂ and it can be done faster and more effective than with AMBU-bag. In our study we didn't evaluate the effect of 'inadvertent PEEP'. It seems to us that we got into our hands a new, effective and simple appliance for short-term HFJV that can ensure a higher comfort and effectiveness as well as safety for both patient and medical personnel.

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