Non-Invasive Airway Cleansing with Application of Expulsion Effect of HFJV (High Frequency Jet Ventilation)

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***The aim* of this study was to demonstrate the effectiveness of the use of expulsion and impulsion nozzle high frequency ventilation (VFDV) for cleansing respiratory system during long-term mechanical ventilation. *Material and methods*. Retrospective study. In the group of 198 patients presenting its own procedures and the application of inpulsive and expulsive effect of the nozzle frequency ventilation (VFDV) for cleansing and maintaining a patent airway. They used high frequency jet ventilation with the possibility of expulsion and epulsion programming and assessed a total of over 8000 expulsion procedures. Changes in lung mechanics, hemodynamics, effectiveness of expulsion and the need for suction beforeexpulsion and in regular application of VFDV were monitored. *Results*. We statistically compared and evaluated the effectiveness of expulsion in the VFDV group of 198 patients on long-term UVP, which was effective in average of 94.9% of patients. The impact of expulsion regime on circulatory, ventilation systems and gas exchange in the lungs, including lung mechanics, were analyzed. The authors found that the application of VFDV had a substantial and statistically significant effect on hemodynamics. Application of expulsion and lavage (a technique is described) statistically significantly reduced airway resistance Raw ($p<0.01$) and improved the levels of lung static compliance ($p<0.01$) compared with the prior expulsion. Changes in blood gases during the expulsion itself did not have a major impact on gas exchange in the lungs or on the pH in this group, but there was a statistically significant increase in PaO_2 ($p<0.05$). A key finding was that when comparing the number of manipulations in the airways (suction), a radical reduction in the number of pumping was observed, if expulsion was used regularly. A statistically significant difference in the application of expulsion was detected when compared to most groups of patients ($p<0.01$). The number of necessary manipulations on the airways was reduced by over 100%. Reducing the number of suctions decreased traumatization of mucosa and the risk of infectious complications. *Conclusion*. The expulsion and lung lavage was an effective and noninvasive method for airway cleansing. VFDV expulsion could contribute to substantial improvements in the care of the maintenance of airway patency in long-UVP. *Keywords:* respiratory cleansing, long-term UVP, high frequency ventilation, expulsion, inpulsion.**

Artificial lung ventilation (ALV) significantly developed especially in recent decades and became an integral part of intensive medicine. Like any vital support functions ALV, especially long-term, has adverse effects and risks that must be removed or at least minimized. Apart from well-known effects during long-ALV, one of the major problem is the so-called distortion of self-cleaning lung function.

Physiological observations.

Self-cleaning respiratory capacity can be schematically divided into physical (mechanical), immunological and biochemical. Now, in many ways we can affect all mechanisms but especially in the management of ALV we can effect mostly physical mechanisms, which the most important are mucociliar transport and cough.

Respiratory mucosa of the nasal cavity to terminal bronchioli is lined with cylindrical epithelium in which we distinguish mucociliar cells in the ratio of 5:1. Ciliar cells on the surface (200), each capable of movement — fast twitch in proximal direction with the slow return. Cilia are moving in a double layer of mucus produced by ciliated cells. The bottom layer is formed of a less dense mucus, the upper is a viscous elastic gel. For cilia correct function it is essential that mucus production is adequate in quantity and quality.

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Then the whole mechanism works by inspiration of particles which «stick» to mucous layer of cilia, and are moved from the lungs up to hypofarynx where they are swallowed or, if the stimulations of lungs are stronger, coughed out. Direction of movement of mucus in the nose and nasopharynx is the opposite — down to hypopharynx.

The upper airways have a special status — nasal cavity, mouth and pharynx. With mechanical and electrostatic filtration in upper airways (hair, nose, passages, tonsills) they scavenge particles larger than 10 nm. In addition, the air is heated to a body temperature and water vapor is saturated and after mixing in the alveolar dead space gas has a temperature of 37 degree Celsius and 100% relative humidity. Particles smaller than 10 nm are deposited on the tracheobronchial tree membrane, 0.5 to 1 nm — penetrate to alveoli, where macrophages eliminate them, below 0.5 mm — are breathed back. The speed of the movement of cilia is very variable, with a range of 1—20 mm/min [Paleček, 1987].

Cough is a defensive reflex, which has an important role in purifying airways from excessive mucus and dust particles. After a slow and deep inspiration, a strong contraction of abdominal muscles creates expiration and in closed glottal slot and narrowing trachea intrathoracic pressure can be increased up to 10—15 kPa. After the sudden opening of the glottis, a very fast stream of air is created at up to 120 m/s top flow 6—12 l/s, which carries entrained sputum and other irritants out.

The other purification mechanisms can be secretions solution, exhalation of volatile substances, alveolar and bronchial fluid transport, interstitial lymph drainage, phagocytosis with alveolar macrophages or hystiocytes, penetration of antigens into lymph nodes, cellular immune responses, immunoglobulin secretion, destruction of particles by enzyme systems [Trojan 1992].

Pathophysiological mechanisms for the application of ALV.

During the ALV there is a disruption of those defenses and by several factors.

1. Endotracheal or tracheostomic cannula discard activity of the upper airways, because the inhalation of air into the trachea without prior filtering and especially warming and humidification. Low temperature of the breathing mixture and its low relative humidity leads to a loss of clean water, energy loss and drying of mucous layer in which are ciliary cells, which impair their movement and hence the overall sputum transport. There is a thickening of sputum, bronchial narrowing or complete obturation, increase of the airway resistance, worsening of ventilation distribution, resulting of atelectasis. Heavy stagnant mucus or crusting are also suitable medium for the growth of microorganisms, which facilitates the formation of infection [Paleček, 1987].

2. Decrease of mucus production may be caused by hypovolaemia, dehydration, hypoxia, lack of energy substrates for mucociliar cells, action of some drugs.

Not only the amount of produced mucus is reduced, but also its physical nature changes, especially viscosity. The lack of mucus, and especially its high viscosity, significantly interferes with the work of the respiratory epithelium, lungs drainage capacity decreases, retention of secretions, creation of mucus bays with the consequences mentioned above develops. Since a high adhesion of mucus, it may gradually stick to the tracheal cannula and become the cause of mechanical obstruction.

3. Greater production of mucus or the presence of pathological content in airways (in hypervolemia), irritation of bronchial walls, during inflammatory processes associated with the production of large amounts of exudates, during aspiration (blood, stomach contents, cerebrospinal fluid, etc.), the transport mechanisms can be functional, but because of the increased amount of content their capacity is insufficient. Despite the escalation of activities there is an imbalance between the amount of mucus production and capacity of transport mechanisms.

4. A very significant factor deteriorating lung drainage during ALV is a partial or complete loss of ability to expectorate. In intubated patients with tracheostomy tubes there is no basic condition for an effective cough — hermiticity of airways. It is disturbed by the presence of tracheostomic or tracheal cannula. Other possible causes are patient's relaxation, a condition associated with muscle paralysis (myasthenia, poliomyelitis, polyradiculoneuritis), loss of cough reflex (central nervous system involvement, intoxication, drugs, for example opiates), energy insufficiency of expiratory muscle, atrophy, inadequate analgesia [Zilber, 1984; Jayr, 1993].

5. Intubation or tracheostomy cannulation represent a foreign body in trachea, which narrows and also mechanically interrupts the path for mucociliar transportation. Mucus is in the trachea under withheld sealing balloon of endotracheal cannula. From the immediate space to a few centimeters below the balloon mucus is not practically possible to evacuate.

6. Cause of failure of self-cleansing mechanisms may also be a primary bronchial wall damage, for example burns.

Clinical experience and long-term statistics show that the problem of maintaining clean airways during ALV is still of great significance. The most common and serious complications in these patients are respiratory infections, which prolong the duration of hospitalization and often lead to the death. Hence the importance of strict observance of certain principles and applications of several procedures to prevent and to manage these complications [Warner, 1999].

Some of the basic attributes on maintaining a good airway patency.

Heating and humidifying of respiratory gases.

As it was mentioned above, the alveolar gas should have a 100% relative humidity (RH) at the body temperature, (37 st.C.) It should be noted, however, that RV is always covered on the gas temperature [Török, 1994].

Patient nutrition.

Dehydration should be avoided. Hyperhydratation with overproduction of mucus and increased water content in the lungs has also negative effects. This factor should be taken into account especially during ALV early days, usually when there may be water retention. Energy — nutrition cover is essential for the maintenance of defense features, for respiratory muscles to work, for effective cough and in the transition to spontaneous ventilation and disconnecting the ventilator. Malnutrition leads to atrophy of respiratory muscles [Zilber, 1984; Warner and Weiskopf, 2000].

Mucolysis.

Liquefying mucus and reduction of its viscosity is often a prerequisite to its removal from airways by suction or other technique. The most effective method of application is the direct application of medication into the cannula, a suitable combination is a total parenteral administration generally [Warner and Weiskopf, 2000].

Physiotherapy

Includes breath rehabilitation and mobilization. They may only be auxiliary methods and do not lead to expulsion of sputum. In the complex with other measures they create the conditions to remove sputum, therefore underestimation isn't in place.

In non-cooperative patients (unconsciousness, relaxation) we do positional drainage when we change the patient's position: sides, back or other positions (abdomen), in which we always lavage low lying areas of the lungs. Efficiency increases together with mechanical action — the thoracic wall — massage, «hammering» chest, vibrations etc. [Drábková, 1982].

Removal of sputum is the most important but also most problematic part in the patient's airways care.

Suction

The most commonly used method of closed or open suctiont system. The advantage is its technical simplicity and modesty. Cons: during open suction system must be open breathing circuit and the interruption of ventilation, which can lead to a transient hypoxia, loss of PEEP, recruitment loss and the loss increases the risk of infection. In assessing the preferred closed-suction systems [Jongerden, 2007], the assumptions about the global efficiency versus open method were not confirmed. Suction is limited by the coil length and diameter so the suction can be exhausting just from the large airways (trachea and main bronchi). Frequent repetitions can cause traumatization and cause significant damage to the mucosa.

Bronchoscopic desobstruction

It is targeted extraction and removal of mucus plugs using bronchoscopy working channel under direct visual control. It can be combined with targeted application of mukolytics to affected parts, making extraction easier [Henke et al., 1994]. The disadvantage of the method: the need to interrupt ventilation, can be eliminated by simultaneous administration of high-frequency ventilation, which does not require sealing of airways.

In an already established atelectasis the desobstruction is almost always not enough, because the obstruction of lung tissue behind obstruction is collapsed and in hyperexpansis within chest physiotherapy the most wind capacity goes to normal tissue, not to atelectasis. In these cases, the success of using the modified bronchoscope in which end the bronchial balloon was added and allowing occlusion supplying atelectatic area and exhaust duct was connected to autoexpansion bag with a pressure regulator. After the secretions suction the bronchoscope was jammed into the bronchi, the pressure was increased to 3 kPa and 60 seconds. Slow flow rate was maintained. This procedure allows the local application of high pressures to the collapsed tissue, which increases efficiency and prevents barotrauma [Heerden et al., 1999].

Mechanic exsufflation.

These artificial supported expiration in which exhaled air in a split of second reaches top flow about 7 l/s, while there is an entrainment of sputum and its movement towards the outside of the lungs. This method is comparable to the consequences of cough and requires special machinery — mechanical exsufflator. In clinical practice it was introduced in 1950th and despite its effectiveness and canniness to tracheal mucosa did not find wider application [Bach, 1993].

Percussive fans

Operating on the principle of superposition of the oscillation frequency on the fan breath curve, and oscillatory vibration with frequency of 100—300 c/min vibrating sputum and facilitate its removal [Jelic, 2005].

High frequency compression of rib cage

They work on a mechanical frequency of pneumatic vest fitted on the patient's chest, which oscillates. In a spontaneously breathing patient it may improve removal of mucus from the respiratory tract [Jones, 1995].

Mechanical percussion.

Devices operating on mechanical, electrically powered mechanical principle simulating chest hammering with hand.

Pneumatic oscillators

Operating on the principle that during the expiration in spontaneously breathing patient to resistance they vibrate gas stream. The vibrations are transmitted to the airway and help remove the mucus [Jelic, 2005].

Expulsion by frequency ventilation.

One of the positive effects of the high frequency jet ventilation (HFJV) is that it can move with bodies (foreign body, mucus, aspiration, aerosol, drug) within the tracheobronchial tree and this movement can be programmed.

Theory of expulsion effect

Two forces operate on active obstruction: in so-called inspirium, inpulsion power (IN), which tends to move the body (distally) and expirium, expulsion strength (EX), which tends to move body proximally, i.e. out of the bronchial tree. The size of the force is directly proportional to the gas density, surface projection of obstruction and square time internal flow. Assuming that the density of inspired and expired gas is the same and area of obstruction does not change, the resulting force applied to the obstruction depends on the gas flow rate [Brychta et al., 1985].

Mathematically we can express simplified inspiration (IN) and expiration (EX) power:

$$IN = \int_{T0}^{Ti} Qi(t)^2\, dt \qquad EX = \int_{Ti}^{Te} Qe(t)^2\, dt$$

HFJV — there is programmed and actual gas flow as well as programmed time of inspirium and exspirium defined. On this basis, we can very simply say that impulsive and expulsive mode can be adjusted by changing the ratio of inspirium time and exspirium time.

If we use longer inspiratory than expiratory time, IN-strengh will be less than EX-strengh, expulsive effect will be created with gradual shift of obstruction towards the out of the lungs. Conversely, if the expiratory time is longer than inspiratory, IN-strength will be bigger than the EX-strengh, impulsion effect will be created, shifting the body distal. When inspiratory and expiratory time is the same, the same IN and EX strengh will arise and there will be neutral effect and the obstruction will oscillate in one place.

Briefly summarized: the application of HFJV, resulting in $Ti<Te$ expulsion for $Ti=Te$ is a neutral effect, for $Ti>Te$ impulsive effect [Brychta, Pokorny, 1986; Török, 1988] Fig. 1.

It should be noted that during application of high frequency ventilation with fan nozzle Paravent PAT-e (Kalas), nonhermetic technology is used, ie ET balloon cannula is not sealed. HFJV — there is always an auto (inadvertion) positive pressure after expiratory in alveolate area (PEEP), the value for Ti: Te = 1:1 is about 0.3 to 0.6 kPa (3—6 cm H_2O). Similarly, the pressure in the tracheal area throughout the respiratory cycle is positive compared to atmos-

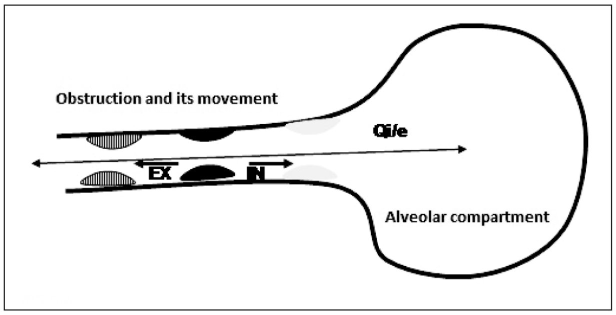

Fig. 1. Schematic representation of the movement of airway obstruction with a predominance of impulsion Force (IN) and expulsion Force (EX).

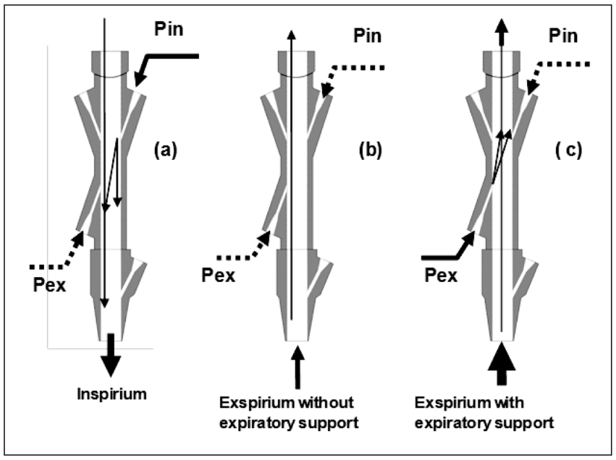

Fig. 2. Schematic representation of a pressure generator activity during HFJV at inspiration (INSPIRIUM) and expriration (EXPIRIUM) (*a*) without expiratory support (*b*) and with expiratory support (*c*).

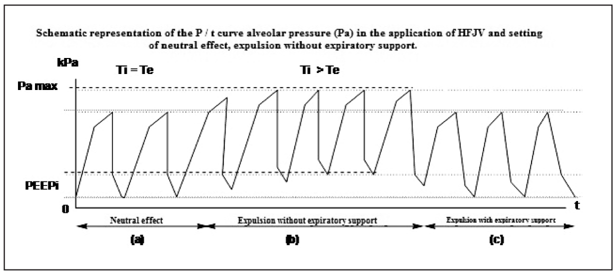

Fig. 3. Schematic representation of the P/t curve alveolar pressure (Pa) in the application of HFJV and setting of neutral effect (Ti:Te = 1:1) (*a*), expulsion (Ti:Te = 2:1) without expiratory support (*b*), which significantly increases auto — PEEP. Expiratory support reduces the PEEP values closer to the size of the neutral effect (*c*).
As PEEP are also changing high alveolar pressures Pa max.

Table 1

Age difference of patients

Age (years)	Number	%
0—5	11	5,56
6—15	7	3,54
16—39	25	12,63
40—59	77	38,89
60—69	52	26,26
70 and more	26	13,13
Total	198	100,00
Men	96	48,48
Women	102	51,52

phere. In case of ET leak there is a gas leakage (around the ET cannula) to hypofarynx which prevents leakage of saliva and mucus from the oral cavity into the trachea. In application of so-called expulsion regime with the ratio of Ti:Te = 2:1 the high PEEPi with value of 1 to 1.5 kPa (10—15 cm H_2O) will be areated, so the fan will automatically turn on support expiration, which will reduce PEEP to about 0.3—0.6 kPa (3—6 cm H_2O). The support accelerates expiratory gas flow and increases the efficiency expulsion effect in the bronchial tree. Expiratory support is set to a power that will not eliminate the pressure in the tracheal against the atmosphere (Fig. 2 and 3).

Clinical use

Expulsion effect is used for cleansing of the lungs during long-term ALV after the aspirations of any genesis in mucoviscidosis and so on. Impulse effect can be used for administration of certain drugs (eg CPR) mukolytics, local anesthetics, corticosteroids, NaHCO3, possibly surfactant [Török, 1988; Zábrodský, 1988].

Materials and methods

HFJV is used in our department since 1989. For the implementation of expulsion, impulsion and lavage high-frequency ventilator Paravent PAT-e (Kalas medical) was used. To monitor the pressure in the trachea, the flow of gas in the insprium and exspirium (Qi/Qe), lung compliane (Cst) and airway resistance (Raw), we used a computer monitor DYNAVENT (Medinvex), then monitor for mechanical properties of the lungs (MVP-Watch) for Fans GE (Mediconsult). Acid/base balance was measured with ABL630 (Radiometer). For the invasive measurement of hemodynamic we used CS-3 (DATEX-GE) monitor with a Swan- Ganz thermodilution catheter (Arrow). We monitored ECG, blood pressure (BP), temperature, heart rate (P), SpO_2 with CGCS monitor (DATEX-GE). We also investigated the frequency of required tracheal suction with and without the use of expulsion or lavage. As a lavage solution, in 95% we applied an aqua pro injectione.

In over 500 patients HFJV was applied. 198 patients were ventilated longer than 72 hours within 6.8±2.7 days. Their distribution by sex and age is in Table 1.

Patients were usually ventilated in the pressure mode (controled pressure ventilation), PS (ASB) (pressure support), Bilevel + PS (bilevel ventilation with pressusre support), or MLV (multilevel ventilation) / Török 2007/. Patients with severe asthma were usually ventilated for the first 12 hours under VC (volume control). Humidification was done with humidifiers MR 850 (Fischer Paykel) at 37±1°C. — relative humidity of 100%. Cleansing of the respiratory tract was done during the first 24 hours with classical vacuum. 24 hours later we started with the regular application of purifying respiratory expulsion by HFJV 5—12 x per 24 hours.

In a group of patients with aspiration (either during cardiopulmonary resuscitation, usually at home before the arrival of a medical emergency, or acid stomach contents in emergency anesthesia) we started from the beginning with application of lavage and expulsion of HFJV. In patients with asthma, we used expulsion always after the breathing stabilization when bronchospasm was released and retention mucus began to be a problem. HFJV is in acute asthma attack and in status astmaticus absolutely contraindicated.

Table 2

Splitting of patients into diagnostic groups, their mortality, duration and number of ALV (artifitial lung ventilation) expulsions *n*=198

Dg. Group	Number of patients	Mortality (more than 96 hours in connection on ALV)	% of deaths	ALV duration (days)	Total number of expulsions
Bronchiolitis	6	1	16,67	4,2±2	115
Pneumonia/COPD	28	3	10,71	5,1±2,25	690
Acute respiratory distress syndrome	18	6	33,33	8,9±3,1	1020
Craniocerebral trauma	51	12	23,53	6,4±2,5	1790
Aspiration during cardiopulmonary resuscitation	31	11	35,48	7,1±2,6	1270
Acid aspiration	6	1	16,67	4,5±2,1	120
Thoracic trauma/polytrauma	27	4	14,81	14,8±4,1	2814
Asthma/spastic bronchitis	7	1	14,29	4,1±2,2	117
Other causes	24	9	37,50	6,5±2,64	846
Total/average	∑198	∑48	AVG= 24,24	AVG = 6,8±2,8	∑8782

Notes. AVG — (average); ∑ (sum) together /total.

Table 3

Subjective evaluation of efficacy (improvement of austult. Hit, mucus in hypofarynx) *n*=198

Dg. Group	The total number of patients	Successful expulsion of patients (number)	% of successful patients
Bronchiolitis	6	5	83,3
Pneumonia/COPD	28	27	96,4
Acute respiratory distress syndrome	18	17	94,4
Craniocerebral trauma	51	51	100,0
Aspiration during cardiopulmonary resuscitation	31	29	93,5
Acid aspiration	6	6	100,0
Thoracic trauma/polytrauma	27	26	96,3
Asthma/spastic bronchitis	7	5	71,4
Other causes	24	22	91,7
Average	198	188	94,9

Distribution by diagnostic groups, as well as the number of patients which eventually died and the number of expulsions carried out in different groups and its effectiveness is given in Table No. 2 (Table 2). In some patients the parameters of lung mechanics were monitored — submissiveness (Cst), airway resistance (Raw) and invasive hemodynamics and Qs / Qt.

The effectiveness of expulsion and possible lavage was evaluated by subjective and objective criteria.

Subjective: improved auskultation findings, the presence of mucus in the hypopharynx during expulsion.

Objective: improvment of SpO_2 (SaO_2) or without change, improvement or non-deterioration of PaO_2/FiO_2 index, improvement of lung mechanics, improvment or non-deterioration of gas exchange in alveolocapillary membrane (Qs/Qt). We also compared the need for the classical suction from trachea without the use of expulsion by HFJV in the first 24—48 hours after the connection to ALV and use of expulsion at regular intervals: 5—12 times daily during the following days ALV until possible disconnection from the ventilator or death of the patient. Statistical evaluation was done by matched *t*-test.

Lavage procedure and expulsion.

If the mucus was not viscous, we applied the expulsion without any other preparation by switching patients from a classical fan to a high-frequency fan and, after HFJV start, we removed sealing cuff on ET cannula so that mucus could move freely into mouth and hypofaryngx. We started with neutral modes of Ti:Te = 1:1, frequency of 120/min and a drive pressure Pin=160±10 kPa. After about a minute we turned on the expolsion regime (Ti:Te = 2:1).

When the mucus was viscous, then 30—60 min. before the planned expulsion, patients were prepared by nebulisation mucolytics. After HFJV connection, we applied in inpulsion mode (Ti:Te = 1:2) lavage solution (in 95% aqua pro inj., Rare also Mistabron) of approximately 1.5 hours ml/kg/24 with a single dose not exceeding 10—15 ml.

In patients with aspiration (gastric acid content or even blood), we always started with expulsion so that aspiration was not transfered to deeper parts of the lungs, then we did lavage. In acid aspiration, we did lavage with 1.05% $NaHCO_3$ or water, while the volume was more than 1.5 ml/kg/24 hours and a single dose was only 20 ml. Before we ended the expulsion of acid aspiration we instilled in impulsion mode (Ti:Te = 1:2) hydrocortisone 100 mg in 5—10 ml of water. The usual lavage solution for blood aspiration was water.In case of analgesia of respiratory mucosa, we applied 1—3 ml 0.5% of Marcain (Astra) to cannula using lavage valve (before the end of expulsion).

Results

Average duration of expulsion (2—3 lavage cycles) using HFJV was 11±3 minutes with a maximum of 25 minutes. The effectiveness of expulsion was evaluated according to these criteria.

Table No. 3 is a subjective evaluation of the effectiveness of expulsion effect in different groups of patients. The highest efficiency was in the group of thoracic trauma, aspiration and in craniocerebral injuries, the lowest among cases with bronchial spasms and in a mixed group (Table 3).

Table 4 shows the change in parameters of lung mechanics. We can see statistically significant improvement in lungs compliance Cst and airway resistance (Raw)

Table 4

Comparison of changes in lung mechanics before and after application of 48-hours expulsion n=198

Dg. group	Number of patients	Raw (kPa.s.l-1) Before expulsion	Raw (kPa.s.l-1) After expulsion 48 hours	Raw (kPa.s.l-1) t-test	C (l.kPa-1) Before expulsion	C (l.kPa-1) After expulsion 48 hours	C (l.kPa-1) *t*-test
Bronchiolitis	6	1,2±0,12	0,8±0,12	p<0,05	0,4±0,1	0,44±0,1	NS
Pneumonia/COPD	28	0,85±,09	0,71±0,08	p<0,05	0,42±0,12	0,48±0,07	p<0,05
Acute respiratory distress syndrome	18	0,88±,08	0,80±0,06	p<0,05	0,29±0,5	0,41±0,6	p<0,01*
Craniocerebral trauma	51	0,67±,07	0,58±0,07	p<0,05	0,51±0,8	0,61±0,1	p<0,01
Aspiration during cardiopulmonary resuscitation	31	1,05±0,4	0,82±0,09	p<0,01	0,38±0,4	0,49±0,09	p<0,01
Acid aspiration	6	1,27±0,11	0,94±0,1	NS	0,34±0,11	0,47±0,06	p<0,01
Thoracic trauma/polytrauma	27	0,71±0,7	0,68±0,05	p<0,05	0,55±0,1	0,58±0,06	p<0,05
Asthma/spastic bronchitis	7	2,1±0,5	1,1±0,9	p<0,05	0,42±0,08	0,51±0,09	p<0,05
Other causes	24	0,63±0,6	0,60±0,05	NS	0,54±0,7	0,59±0,05	p<0,05
Total	**198**						

Notes. * — changes in Cst with ARDS were also influenced by the recruitment maneuver, which is not possible to evaluate solely as an effect of expulsion.

Table 5

Comparison of selected hemodynamic parameters in patients regardless of the reason for expulsion application. Average of five consecutive measurements n=28

Time	CI ($l \cdot min^{-1} \cdot m^{-2}$)	TPR ($dyn \cdot sec \cdot m^5$)	PVR ($dyn \cdot sec \cdot m^5$)	IVO_2 ($ml \cdot min^{-1} \cdot m^{-2}$)	Qs/Qt (%)
Before expulsion	3,2±0,4	1510±200	190±15	159±20	18±4
During expulsion	3,1±0,4	1495±170	185±18	163±21	16,3±4#
After expulsion to 30 minutes	3,1±0,5	1380±150*	177±14	169±19	14,2±3,5*

Notes. * — statistically significant differences in the level of p<0.05; # — not evaluated the outcome of the application, FiO_2 = 0.55 during VFDV.

Table 6

Changes in blood gases and pH n=127

Time	pH	$PaCO_2$ (kPa)	PaO_2 (kPa)	PaO_2/FiO_2 (kPa)
Before expulsion	7,33±0,04	4,98±0,57	9,8±3	25
During expulsion	7,36±0,03	4,35±0,4	16,3±4#	29
After expulsion 48 hour	7,35±0,03	4,85±0,3	11,6±3,5*	29*

Notes. * — statistically significant differences in the level of p<0.05, compared with the results measured before and after the expulsion of repeated expulsions 48 hours with stable FiO_2 = 0.41 ± 0.098; # — not evaluated the outcome of the application, FiO_2 = 0.55 for VFDV.

in the most of the results. We compared the results of Cst and Raw before periodical expulsions and after 48 hours of regularly applied expulsions possibly associated with lavage.

In a relatively small group of hemodynamically monitored patients changes in hemodynamics and O_2 delivery (VIO_2) before, during, and 24 hours after application of expulsion were monitored. The results are shown in Table 5. Statistically significant difference determined by the matched *t*-test was only a decrease in peripheral vascular resistance (TPR) and the improvement of Qs/Qt. Changes in cardiac index (CI) and pulmonary vascular resistance (PVR) were not significant. The above table shows, by the fact that HFJV and expulsion have a very minimal effect on hemodynamics.

Changes in blood gases are shown in Table 6, suggesting that after expulsion we noticed oxygenation improvement (PaO_2/FiO_2) and also PaO_2 at statistically significant levels, without any statistically significant changes in pH. In the table are averages of 10 consecutive measurements. The value of PaO_2 during the expulsion could not be assessed as an improvement, because during the conventional IPPV FiO_2 = 0.41±0.11 was applied and HFJV was FiO_2 = 0.55 to 0.6

Evaluation of manipulation in the trachea during 24 hours interval of application without the expulsion and after its application is shown in Table 7. From this point it is clear that the introduction of regular expulsions caused a statistically significant decrease in the need to use the suction of the tracheobronchial tree using the suction catheter in all groups of patients.

Because an open breathing system with nonhermetic cannula was used, mucus builded around the cannula went out to hypofarynx during the expulsion and was sucked out. It should be noted that in the groups of patients with aspiration, the expulsion was applied from the beginning of ALV and that these results are partly distorted.

Table 7

The average number of suctions within 24 hours in one patient

Dg. group	Number of pat.	Before expulsion conventional UVP 24 hod	After expulsions after 24 hours	After expulsions after 72 hours	*t*-test comparison after 72 hours of expulsion
Bronchiolitis	6	22±4	15±4	12±4	$p<0,05$
Pneumonia/COPD	28	24±5	17±4	13±4	$p<0,01$
Acute respiratory distress syndrome	18	20±4	14±4	11±3	$p<0,01$
Craniocerebral trauma	51	18±4	11±3	10±3	$p<0,01$
Aspiration during cardiopulmonary resuscitation	31	31±5	11±3	10±4	$p<0,01$
Acid aspiration	6	34±6	12±3	10±5	$p<0,05$
Thoracic trauma/polytrauma	27	25±5	13±4	9±6	$p<0,01$
Asthma/spastic bronchitis	7	22±4	10±3	9±7	$p<0,05$
Other causes	24	19±4	11±3	9±8	$p<0,01$
Average		19±4,5	12±3,5	10±3,28	

Discussion

The HFJV introduction into clinical practice and the use of programmable movement of foreign bodies in the airway, that is inmpulsion and expulsion effect, significantly changed the care for long-term ventilated patients. The presented retrospective study demonstrates a very good, more than 90% filtration efficiency of the method. Improvement of blood gas values and mechanical properties of the lungs with minimum cardiac output.

There are however some drawbacks and limitations. There are also some unsuitable patients with significant obstructive disease of airways (status asthmaticus) where HFJV is contraindicated. First, mucus must be liquefied, spasms elimination and after that we can try the expulsion. We underline the absolute necessity of adequate liquefaction of sputum in all patients. The dried and stucked secretions cause the total failure of expulsion. Sometimes it is necessary to work for several hours.

In terms of staff safety, we should keep in mind that during the expulsion, an infectious aerosol is created, which requires the use of protective equipment (mask, hat, gloves) and rigorous disinfection of the environment. For expulsion, it is necessary to use the original «expulsion set», which is removing this special aerosol to containers with disinfection solution or with a bacterial filter into the atmosphere (Fig. 4).

For wetting and heating the gases we use solely heated — molecular humidifiers, even if in the literature views appear on the appropriateness of the use of recuperation humidifiers (so-called artificial noses) and for long-ALV [Misset et al., 1991]. We strictly stick to a gas temperature of 35—38 st.C and it is considered necessary to include a bacterial filter to inspiration branch of the respiratory circuit. Cold aerosol generators are used only for the time necessary to nebulisate the drugs — 15—20 minutes to greatly reduce the risk of airwy's contamination.

Adequate hydration, as well as wetting and heating of gases, is often underestimated especially in departments with less experience with ALV.

Since the efficiency of mucolytic products is very close, their use in the workplace depends on experienced staff and availability. In our department, we particularly use mucolyticum Mistabron for its good tolerance, reliability and availability. However, N-acetylcysteine in combination with bronchodilatanciom [Henke et al., 1994] is popular abroad, at least according to available sources.

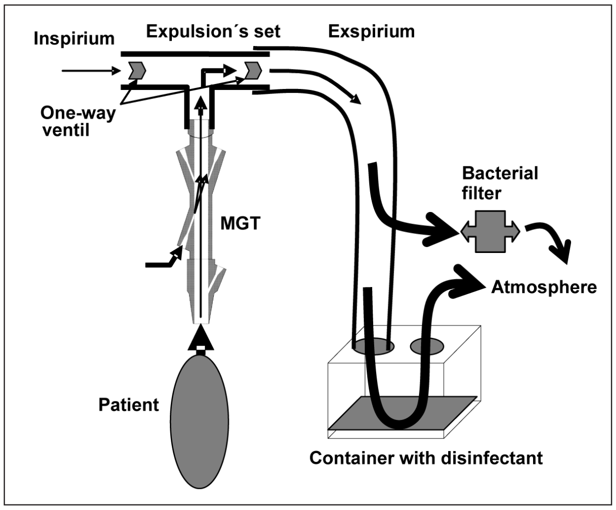

Fig. 4. Connection of expulsion set to MJI (multinozzle jet injector) and connection to a container with disinfectant or a bacterial filter.

Physiotherapy is considered an appropriate complement to expulsion. Positional drainage, hammering the chest and breathing against resistancewere were proved as the best.

Exhaustion was long and probably will still remain as an essential means to remove sputum. It is not different in our department, where it is used routinely in patients without complicating factors (aspiration, pulmonary contusion, atelectasis, focal pneumonia, overproduction of mucus). In stabilized, lege artis ventilated patients without complications listed above, in addition at least partially cooperating patient, seems to be sufficient. Its main disadvantage is that, as with any recurrence of instrumental intervention, the risk of disease introduction into the airways and the mucosa traumatization.

In our department, we have a flexible bronchoscope, so we can target desobstruction in cases where expulsion is ineffective, or in torpid atelectasis. Literary data indicates, in specific cases, their high efficiency.

Conclusion

Finally, it should be noted that HFJV is not a panacea and it itself doesn't solve the problem of how to maintain the viability of airways in patients during long-ALV. It's just one of the means which can help in this effort. In the study group was quite clearly demonstrated the improvement in parameters of lung mechanics and in particular, significant reduction in need for manipulation of the suction catheter in the airways, because after the expulsion, mucus was sucked out from hypofarynx. Minimizing respiratory mucosa traumatization is a very good prevention against respiratory inflammation during ALV. A prerequisite to a successful management of airways cleansing problem is in fact a comprehensive approach to the patient and use of all available means and procedures. Their underestimation or incorrect application is a serious mistake and often with lethal consequences for the patient.

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