„Past, Present and Future of Jet Ventilation”

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35 Jahre nach der Erstbeschreibung der Jetventilation am Patienten soll das internationale Symposium „Past, Present and Future of the Jet Ventilation” den gegenwärtigen Stellenwert und die Grenzen dieses alternativen Beatmungsverfahrens aufzeigen.
Ziel dieses Symposiums ist es, die Jetventilation einem größeren Kreis der Ärzteschaft in der Klinik zugänglich zu machen und die Akzeptanz dieser Methode zu verbessern. Wesentlich erscheint hierbei eine enge Verknüpfung von Wissenschaftlichkeit und klinischer Praxis.
Zahlreiche experimentelle und vor allem klinische Untersuchungen sowie technische Innovationen, insbesondere zur hochfrequenten Form der Jetventilation, förderten in den letzten Jahren das Verständnis dieser Beatmungsform. Die praktische Anwendung der Jetventilation ist heute sicherer als zuvor. Neben der Entwicklung der Jetventilation werden in den folgenden Abstracts die derzeit empfohlenen Indikationen am Patienten vorgestellt. Darüber hinaus werden aber auch künftige Einsatzmöglichkeiten dieses Verfahrens dargestellt. Insbesondere die Poster-Abstracts befassen sich mit Forschungsansätzen zum Thema Jetventilation, wobei die Erhöhung der Sicherheit dieses Beatmungsverfahrens eine besondere Rolle spielt.

R. Gottschall, Jena

VORTRÄGE

Jet ventilation: Personal recollection

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The ability to deliver normal tidal volumes by a jet through a small cannula or nozzle offers an advantage especially in ENT surgery, where the surgeon and anesthesiologist have to share the same space in the airway. Already in 1967 *Sanders* (1) described jet ventilation for bronchoscopy via a special adapter attached to the bronchoscope. *Spoerel* (2) in 1971 applied jet ventilation through a transtracheal 16g needle. *Jacobs* (3) used in 1972 transtracheal ventilation through 14g intravenous catheter inserted by cricothyroid membrane puncture for immediate restoration of adequate airway in a series of 12 patients. Our group described the use of the method in ENT anesthesia (4) in 1974 and published in 1976 our experience with 80 patients with a hand-held manually operated jet (5). To avoid the cumbersome manual ventilation we built an automatic fluidic ventilator, which we then used in over 800 patients (6).
One of the main concerns in jet ventilation was the possibility of barotraumas (7) due to high driving pressure needed to overcome the resistance of the narrow tubing. To decrease the tidal volumes and stimulated by the observation of *Jonzon* & al. (8) of a stable homeostasis at higher respiratory rates we decided to combine jet ventilation with high frequency. We started to experiment with our automatic jet ventilator and were able to increase ventilatory frequency up to 600 breaths per minute with good gas exchange (9). These results induced us to systematically study the physiology of high frequency jet ventilation and continue to develop new ventilators. Our best partner was the Swiss company Acutronic Medical that was over the years responsible for more than half of all jet ventilators in clinical use around the world. The utility of jet ventilation was shown in endoscopies (10, 11), upper airway obstruction (12), bronchopleural fistula (13) and independent lung ventilation (14). One promising application, as an assist to failing circulation (15), was unfortunately not followed.
At peak of its popularity in mid-eighties, high frequency jet ventilation was considered a solution to most of our problems even in ARDS. As with any new method, when it fell short of expectations to improve results in respiratory failure, the interest in its use declined. But in recent years, thanks mostly to our European colleagues, its merits are being recognized again.
In our own experience with over 3,000 patients we have shown that it can be used in any patient requiring respiratory support (16). But it is especially useful in situation where its unique advantages can be fully realized: open airways, endoscopies, and emergency airway management. High frequency jet ventilation (HFJV) by utilizing small tidal volumes produces lower airway pressures and less movement in surgical field adding a degree of safety. It also prevents aspiration and can be easily superimposed on spontaneous breathing.

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Supraglottic and infraglottic jet ventilation in ENT

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Sanders introduced jet pumping in the airway for ventilation during rigid bronchoscopy in 1967. *Spoerel* and *Greenway*, in 1971, published the first time on infraglottic and *Oulton* et al. in the same year on supraglottic jet ventilation for endolaryngeal procedures. The possibility to ventilate without interruption eased the anaesthetists and the better working conditions pleased the ENT-surgeons so much that the method was and is widely accepted, despite the lack of controlled prospective studies (RCS). No RCS exist comparing ventilation through intubation tubes to any form of jet ventilation for ENT-procedures. No RCS exist either on differences of working conditions, complications, and efficiency of ventilation between different modes of jet ventilation (1). The later addition of high frequency to further improve working conditions by *Klain & Smith* in 1979 and superimposed (*Aloy* et al. 1990) and double frequency (*Kull* et al. 1993) to improve gas exchange does not change the conditions of jet technology (2).

Jet ventilation is pressure-limited. The airway pressure (AP) created by a jet pump depends on pressure, flow, and velocity of the jet gas; if the latter are kept constant, AP increases with growing diameter of the jet or diminishing diameter of the airway. Prediction of the jet-caused AP is impossible due to anatomical and technical deviations from the standard technical jet, which is especially true with infraglottic jet ventilation (3). Because of almost no dead space and jet mixing low tidal volumes (TV) are sufficient for CO_2-elimination, but low compliance (obesity) may cause hypoxia due to intrapulmonary shunting (2).

In contrast to conventional ventilation, the jet gas does not remain in the ventilator but is pumped inside the airway. Therefore, besides other rare causes, any obstacle in the expiratory airway may cause barotrauma. Possible aspiration of contagious material (and smoke) is a special threat with supraglottic jet ventilation. Intraoperative video display of the vocal cords and monitoring of airway pressure decreases incidence of barotrauma, pulse oximetry that of hypoxia (2). LASER surgery-caused fire in the airway can be avoided using non-inflammable equipment and oxygen concentrations below 30% (4).

With appropriate equipment for jet ventilation, difficulties with ventilation and oxygenation are not different from those with ventilation through intubation tubes. Large or stenosing processes in the airway can be treated without tracheotomy only with jet ventilation. Training, experience, and monitoring equipment help to avoid complications with all types of jet ventilation (1, 4). From the ENT-surgeon's point of view, the negative impact of avoidable complications with jet ventilation is obviously outweighed by the improved working conditions and possibilities.

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Jet ventilation in rigid bronchoscopy

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For some indications, rigid bronchoscopy (RB) is to prefer to fiberoptic technique or a combined approach should be used (large foreign object, massive bleeding, stent implantation, laser surgery). Different ventilation modes can be used in these procedures. Jet ventilation (JV), however, offers several advantages.

JV represents constant pressure ventilation. Changes of driving pressure will cause analogue changes in tidal volume and influence primarily the carbon dioxide elimination and secondarily the oxygenation. Depending on the respiratory rate (and the I:E ratio, too), the exspiratory time may be that much shortened with high frequency jet ventilation (HFJV) that intrinsic PEEP occurs. Beside from these parameters, the patient's respiratory mechanics as well as the length and the diameter of the jet device and its position influence pulmonary ventilation. Obstacles distal to the jet orifice (tumor, blood clots, foreign objects, instruments passed through the bronchoscope) reduce the gas flow to the lungs. Owing to the proximal position of the jet nozzle at bronchoscopes, hypoventilation is more likely than barotrauma to occur. Nevertheless, due to the small dimensions of the airways in children exspiration is easily compromised. Thus, the driving pressure must be raised cautiously from virtually zero to values, at which ventilation becomes effectively.

With RB, inflammation during laser application can be avoided to a large extent. Additionally, with HFJV the jet stream promotes cooling in the laser target area and supports scavenging of smoke and soot particles by continuous exspiratory gas flow. Because of the less occurring chest movements the laser fiber can be guided with maximal accuracy. The "loose coupling" between jet source and the airways of the patient permits handling including insertion of instruments without any interruption of jet ventilation which is a common restriction in intermittent positive pressure ventilation. With JV rigid bronchoscopy serves the double purpose of a channel for instrumentation and of a safe airway.

For RB intravenous anesthesia with propofol, remifentanil and complete muscular relaxation i.e. with mivacurium is recommended. This is necessary to gain deep anesthesia as well as gentle tube passage down to the bifurcational region. Gas exchange has to be monitored by reliable, possibly non-invasive methods basically consisting of ECG, non-invasive measurement of blood pressure and pulse oximetry. With newer bronchoscopes ventilation gas composition and airway pressure in the trachea can be monitored across a separate sampling channel alongside their tubes. By intermittent switching to low frequency, capnography becomes possible also for HFJV to adapt driving pressure and efficiency of ventilation accordingly. Additionally, a hindrance to ventilation can be quickly detected. Continuous measurement of FiO_2 is useful during laser interventions to reduce the risk of inflammation within the airways. Alternatively, transcutaneous blood gas monitoring can be employed.
According to these insights, RB with JV offers a useful and safe technique.

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Jet ventilation in thoracic surgery

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In thoracic surgery, jet ventilation is attractive because of its two main advantages arising from the high gas flows (1): Loose coupling between the ventilator and the patient's airways will suffice to provide ventilation across severed or even transsected major airways (2). Pulmonary gas exchange can be maintained at tidal volumes markedly smaller than the physiologic dead space. This allows for an almost motionless surgical field even if ventilation of the operated lung is indispensable. In tracheal surgery, smaller sized catheters for ventilation will distinctly facilitate overall view and surgical access during transsection of the airway, repair of defects or removal of segments, placement of sutures and subsequent reanastomosis.

High frequency jet ventilation across appropriate catheters affords gas exchange in the physiological range for periods exceeding 90 min. In adults it is debatable whether gas climatization and monitoring of respiration might be preserved by conventional intubation across the surgical field. However, in children and small infants small-sized catheters and jet ventilation have made airway surgery feasible without resorting to cardiopulmonary bypass. In appropriate cases the jet catheter may even be introduced across a laryngeal mask. Thus, in proximal tracheal stenosis patient, the surgeon and the anastomosis is relieved from the annoying presence of the endotracheal tube (1, 3).

More recent generators provide humidification of the jet gas. In double lumen jet catheters, airway pressures and gas composition can be measured. The close correlation of data from intermittent lowfrequency capnography to blood gas analysis has been demonstrated (4).

Surgery on the tracheal bifurcation, mainly for sleeve pneumonectomy, is markedly facilitated during the decisive steps of fitting the bronchus to the tracheal stump, placing the sutures and completing reanastomosis, when a small catheter for high frequency jet ventilation is being used instead of a customary endotracheal tube. It can be passed even inside the bronchial lumen of the double lumen tube employed during exploratory and preparatory steps. Maintaining the gas exchange can be more demanding due to a peripheral dislodging of the catheter tip and due to blood or secretions soiling the bronchus. These circumstances are reflected in the more pronounced scatter of pO_2 and pCO_2 values observed and require constant attention and cooperation of anesthetist and surgeon to keep the airway viable.

In airway stenosis involving the main bronchi with jet ventilation, the risk of barotrauma from impeded exspiration must strongly be considered and in small children may prompt to eventually preserve gas exchange by cardiopulmonary bypass.

During thoracic surgery requiring one lung ventilation the function of the dependent lung may be compromised to an extent that necessitates the operated lung to be recruited for gas exchange. With high frequency jet ventilation to the nondependent lung barely perceptible changes in pulmonary volume may be achieved despite its decisive contribution to gas exchange (2).

The advantage of high frequency jet ventilation providing adequate ventilation at tidal volumes smaller than physiological dead space is exemplified even more in pneumo-necto-mized patients requiring surgery on the remaining lung. In cases of open thoracotomy as well as in video-assisted thoracoscopy, jet ventilation then affords access and overview with oxygenation well preserved albeit at the cost of mild hypercapnia to 50 mmHg.

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Jet ventilation: Superimposed applications

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We report our 10 year experience with superimposed HFJV (sHFJV), a jet technique which is characterised by the simultaneous application of 2 jet streams. The combination of a high-frequent (3 - 15 Hz) and a low-frequent (< 0.5 Hz) jet stream resulted in the typical airway pressure profile. Airway pressures were measured continuously downstream the jet nozzles and were adjusted by selection of driving pressures. Several studies examined the effects of sHFJV (double jet technique) during total intravenous anaesthesia.

Supraglottic sHFJV has been performed in over 1000 patients (adults and children) undergoing elective laryngotracheal surgery by means of a jet-laryngoscope (*C. Reiner,* Vienna, A) with integrated jet cannulae (id 1.5 mm) during total intravenous anaesthesia. The jet nozzles in the proximal half of the laryngoscope were designed to direct both jet streams along the centre of the laryngoscope from its supraglottic position through the glottic opening. Airway pressure was monitored at the tip of the laryngoscope. Jet respirators facilitated application of jet streams gated by electronically (Alexander 1, Festo, Vienna, A; Acutronic Laryngojet 4000, Jona-Rapperswil, CH) or pneumatically (Bronchotron, Percussionaire, Idaho, USA) controlled valves.

Increased weight was associated with enhanced driving pressures, lower values of oxygenation and higher values of pCO_2. However, sHFJV facilitated the supraglottic ventilation of heavy patients (max 121 kg) and/or in the presence of airway stenoses during laryngotracheal surgery without need to use maximum driving pressures, and enabled tracheal stent insertion avoiding phases of apnea. Average supraglottic airway pressures were 11 - 12 cm H_2O. The average duration of sHFJV was < 30 min, the longest duration of sHFJV was 180 min. Superimposed HFJV Laser surgery was performed without complications at $FjetO_2jet$ 0.6.

Conventional mechanical ventilation has been successfully combined with monofrequent HFJV to treat patients with pulmonary insufficiency. Based on the effectiveness to eliminate CO_2 during sHFJV we studied sHFJV as an alternative ventilation strategy in experimental lung injury (pigs) and in healthy volunteers. A special jet-adapter for connection with the endotracheal tube was designed consisting of a T-piece and four central, small-bore cannulae (id 1.2 mm) to apply two jet streams, to measure airway pressures continuously, and to facilitate humidification and warming of inspired gases. An additional port, which was opened for endotracheal suctioning or bronchoscopy, made it unnecessary to disconnect the jet-adapter from the endotracheal tube. Peripheral airway pressures were measured during various settings of sHFJV and compared with central airway pressures. Applying similar levels of PEEP in oleic acid induced ALI, sHFJV improved oxygenation and CO_2-elimination in the presence of lower peak and mean airway pressures compared with CPPV.

Similarly, sHFJV was associated with better oxygenation and ventilation compared with CPPV performed at same levels of airway pressures. Furthermore, data from a CT study indicated that a pulsatile PEEP generated by the high-frequent jet pulses (500 bpm) combined with a second jet may be more efficient in reopening collapsed alveoli than static pressure PEEP.

Tubeless superimposed HFJV is an established ventilation technique during laryngotracheal surgery. Its effectiveness as an alternative ventilatory approach to bridge ALI and to improve outcome will be examined in future studies.

Elective and emergency transtracheal jet ventilation

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In the widely accepted practice guidelines of the ASA (1), the transtracheal approach to the airway is incorporated in a subordinate place of the algorithm. Since this algorithm is too complicated to be observed in an emergency situation, I suggest a 4-steps escalation table, which contains 4 categories of airway securing techniques only:
1. simple techniques;
2. minimal invasive techniques;
3. non-surgical invasive techniques, and
4. surgical techniques.

They are arranged according increasing complexity, invasivity and risks. In this context the transtracheal oxygenation and ventilation techniques can be allocated to the 3rd class of non-surgical but invasive methods. The basic philosophy of this model is to have at least 2 or 3 techniques of each category available. Therefrom one has to solve the prevailing airway problem beginning with the lowest possible class, which has to be followed by the next level in case of persistent failure to achieve sufficient oxygenation. Since about 10% of airway difficulties remain unpredictable, some of these cases lead to the so called "cannot intubate, cannot ventilate" scenario. This may occur after anaesthesia induction and is characterised by both, the inability to secure the airway and to maintain oxygenation by means of face mask ventilation. This represents a justifiable indication for any kind of transtracheal oxygenation technique. Among the available transtracheal cannulas there has to be distinguished between narrow ones for puncture and wide ones for cannulation. The main difference between these 2 categories concerns the choice of gas transmission which is suited for that specific device. Wide cannulas are designed for regular ventilation with alternating in- and exhalation, while narrow cannulas are feasible for one way oxygen insufflation only. If the gas pressure exerted on the proximal inlet of the cannula can be elevated to app. 200 - 300 mbar, continuous apnoeic oxygenation is possible. However, in this case CO_2 elimination is either very poor or not present at all, which limits the practicability of apnoeic oxygenation to about 15 - 20 minutes. Nevertheless, this may be sufficient to create an alternative ventilation pathway. If the gas source delivers a pressure of more than 1 atmosphere, jet ventilation is possible and not only oxygenation but also CO_2 elimination can be maintained for a long duration. The only and most decisive condition for transtracheal puncture and oxygen insufflation or jet ventilation is a free gas exhalation pathway. If this is not guaranteed, transtracheal puncture is absolutely contraindicated (2). A retrospective investigation of 90 elective transtracheal jet ventilation cases has revealed quite a high percentage of unsuccessful or even life threatening applications (3). Another possibility to practice transtracheal puncture and jet ventilation under realistic conditions is the patient who is prepared and anaesthetised for laryngectomy. In conclusion, TTJV is a safe and efficient oxygenation and ventilation technique, provided that stringent safety rules are considered. It has to be regarded as a 3rd line technique that may be applied if 1st line simple techniques and 2nd line minimal invasive techniques could not be successfully performed and a return to sufficient spontaneous ventilation seems unlikely.

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Reflection on swine and dogs as models in experimental anaesthesiology

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Swine and dogs are being used extensively in biomedical research. During the last 15 years, there has been a transition from dogs to swine especially for investigations of human cardiovascular physiology and pathophysiology. One reason for this shift is the ethical discussion and the growing criticism for using the "companion" dog in experiments. Researchers are also more and more attracted by the swine, because this species shows many similarities to humans. Human and swine have the similar phylogenetic development, both consume an omnivorous diet and have a sedentary life style and a relative lack of daily aerobic exercise. There are similarities with respect to various anatomical and physiological parameters such as a similar coronary anatomy and a lack of native collateral cardiac blood vessels. In contrast the dog has a coronary artery anatomy, coronary vasodilator function, and cardiac metabolism, which is different from that of humans and swine.

Also many differences exist between lungs when an inter-species comparison is made between swine and dogs. The porcine lung is very small in relation to the body mass which requires a higher basic ventilation. In the dog lung, lobules are absent while porcine lung lobes show a strong interlobular segmentation. Following this, interlobular air drifts do not exist in the lung of swine. Since the porcine lung does not have any collateral airways (broncho-alveolar or inter-alveolar "channels"), alveolar ventilation is markedly reduced in any case of airway obstruction. Thus, swine are very sensitive to develop atelectases and ventilatory asynchronisms. Furthermore, dead space ventilation is much higher in swine (> 50 % of tidal volume) than in dogs (approximately one third of the tidal volume). While the pleura is extremely thin in dogs, the pleura and interlobular septa are thick in swine leading to a higher tissue resistance and a lower compliance of the total respiratory system in this species. In swine, arterial supply to the pleura is provided by the bronchial artery (systemic circulation) but in dogs by the pulmonary artery (pulmonary circulation). The swine has a obviously better developed Tunica muscularis of the small pulmonary arteries than the dog. This detail needs to be considered for the predicted strength of pulmonary vasoconstriction in response to alveolar hypoxia. Swine have a vigorous acute hypoxic pressure response while acute hypoxia increases pulmonary arterial pressure by less than 10 mmHg in dogs. In contrast to swine, dogs fail to develop pulmonary hypertension under conditions of chronic alveolar hypoxia.

When using swine in research, the investigator should take into consideration that differences exist between domestic and miniature swine. Miniature swine are more mature than domestic ones at the same body weight. Comparisons of the response to various anesthetic agents in swine should be made with caution when the experimental animals are not of the same stock, age and weight.

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Jet ventilation in lung radiotherapy

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Stereotactic single-dose radiosurgery is a new therapeutic option for patients with lung cancer or lung metastasis. Due to the high applied biologically effective doses the respiratory movements of the lungs may lead to radiation injury of normal lung tissue. Therefore, single-dose radiotherapy requires immobilization of the lungs minimizing respiratory movements. This goal can be achieved by high frequency jet ventilation (HFJV) but not by apneic oxygenation, because a long period of respiratory movement immobilization is required.

The principle of single-dose radiosurgery of lung tumors is to radiate the tumor with stereotactic guided high dosage fields, allowing to perform single-dose treatment with high biologically effective doses. The amount of normal lung tissue in the high-dose region can be reduced, because of safety margins considering respiratory movements and daily set-up errors. Precise patient positioning and tumor stabilization is mandatory in order not to cause radiation injury to normal lung tissue adjacent to the tumor. This is achieved by patients' immobilization in an individually shaped vacuum mattress, which is fixed tightly to a three-dimensional stereotactic frame.

For treatment planning a spiral computed tomography (CT) scan is performed under general anesthesia and HFJV. For anesthesia we use a TIVA technique with propofol, remifentanil and muscle relaxation by rocuronium or cis-atracurium. The trachea is intubated with a special jet ventilation tube (Rüsch, Germany). In addition to standard anesthesia patient monitoring, continuous blood gas measurement was used initially. Now HFJV is controlled by pulse oximetry and intermittent arterial blood gas measurements. During treatment planning CT scan of the chest, HFJV is adjusted individually to achieve tumor stability with minimal respiratory movements and sufficient oxygenation. The VOXELPLAN software is used for three-dimensional treatment planning. Treatment plans are designed using 5 to 6 coplanar, irregular shaped, isocentric beams, ideally distributed in 30º angles along an 180º gantry rotation. These complex calculations take about two days. The clinical target volume only marginally exceeds the gross tumor volume. Radiosurgery is performed using a Siemens Primus linear accelerator under general anesthesia and HFJV. Anesthesia is provided as TIVA according to the individual patient's behavior during the planning procedure. To decrease the risk of acute radiation reaction patients are treated prophylactically with dexamethasone. Since nobody but the patient is allowed to be in the radiation theatre during radiosurgery, the anesthetized patient has to be monitored via video and HFJV is remote controlled. HFJV is adjusted according to the individual set up, which provided adequate oxygenation and minimal tumor movement during the planning CT-procedure. The patient fixation has to be done very carefully, because the linear accelerator requires rotation along a 180º gantry. In a single treatment fashion, radiation doses of 19 - 26 GY were administered to more than 30 patients. This time and personnel consuming procedures took 1.5 to 5.25 hours. Although most of the patients had poor cardiac and pulmonary function, they were anesthetized without complications and single dose high energy radiation could be applied safely. Patients tolerated the procedure well. It promises high local control with a reduced overall treatment time. Follow up examination up to 24 month showed even in stage I non small cell lung cancer local recurrence-free survival of 67,5%. Therapy related perifocal normal tissue reaction occurred in 79% of all treated patients, although no clinical signs were seen. Stereotactic single-fraction radiosurgery is a safe and effective procedure for treatment of lung tumors. HFJV enables this new treatment option by reducing respiratory movement.

High frequency jet ventilation for minimally invasive coronary artery bypass operation

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Introduction: In minimally invasive direct coronary artery bypass (MIDCAB) procedures, one-lung-ventilation (OLV) is required to create optimal conditions for the surgeon. In this randomized, prospective study we compared the use of high frequency jet ventilation (HFJV) of both lungs with the routinely used OLV using a double-lumen-tube (DLT) during MIDCAB surgery.

Method: With approval of the ethic committee, 20 patients undergoing elective MIDCAB procedures were included. The patients were assigned to two groups: Group A was treated with a commonly used DLT. OLV was started at skin incision. At the end of the operation, the DLT was replaced by a single-lumen-tube to facilitate respiratory weaning in the intensive care unit. Group B received a single-lumen-tube (SLT). An O_2-insufflation catheter (Baxter, Germany) was introduced through the SLT and connected to the HFJV device (Monsoon, Acutronic, Suisse). At skin incision HFJV of both lungs was started. At the end of the operation the O_2 insufflation catheter was withdrawn. The Mann-Whitney U-Test was used to evaluate significance differences.

Results: 28 patients were included in the study, 14 patients in each group. The conditions for the surgeon during the operation were similar in both groups. Values for peak inspiration pressure (PIP), arterial PO_2, and PCO_2 during conventional ventilation at the beginning of the operation (Cvstart), during OLV or HFJV as well as at the end of the operation with conventional ventilation (CVend) are shown in the following table and expressed as mean ± standard deviation (*P < 0.001):

	CV start	OLV/HFJV	CV end
$P0_2$ (DLT)	437 ± 66	214 ± 77,6	298 ±78
$P0_2$ (HFJV)	395 ± 70	272 ± 100,5	271 ± 117
PCO_2 (DLT)	34.3 ±3.4	34.4* ± 4.1	32.6 ± 3.4
PCO_2 (HFJV)	33.8 ± 3.2	43,6* ± 6.2	38.2 ±4.6
PIP (DLT)	21.6 ± 6.9	32.5* ± 4.8	22.8 ±4.5
PIP (HFJV)	20.5 ± 4.8	9.9 *± 2.2	21.1 ± 5.3

Postoperative chest x-ray showed mild to severe atelectasis of the left lower lobe in 8 patients of group A (DLT) vs 4 in group B.

Discussion: Oxygenation is safe with HFJV. CO_2 elimination is impaired, but is still in a clinically acceptable range. The peak inspiration pressure with HFJV is very low, so that the left lung does not disturb the surgeon during the MIDCAB procedure. We think that HFJV of both lungs during MIDCAB procedures seems to be an alternative method to create optimal conditions for the surgeon.

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High frequency jet ventilation in the ICU

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High frequency jet ventilation (HFJV) is potentially very useful in patients with severe lung injury and ARDS. The concept of ventilator induced lung injury (VILI) (1) caused by lung stretch describes a major component of lung damage to repetitive inflation and collapse of alveoli when the lungs are not "opened and kept open" (2). Thus, if the lungs are kept recruited, and the cyclic excursion of the lung is minimized, damage due to mechanical ventilation can be reduced. Since HFJV has the effect of recruiting lung volume with a high auto-PEEP and small tidal volumes, it may serve these goals and improve outcome in patients who require ventilatory support.

Despite this rationale, data showing a favorable effect of HFJV in patients with ARDS are lacking. A number of studies compared HFJV with CMV in patients with severe lung injury and found both techniques to be comparable.

Carlon and colleagues compared HFJV with CMV in a series of 309 patients (3). Although no difference was found with regards to mortality, they did find that patients reached an endpoint of improved oxygenation sooner with HFJV than with CMV.

HFJV is an established therapeutic modality in patients with bronchopleural fistula and has been described as a useful modality in patients with severe blast injury to the lung (4). Hurst et al compared CMV with high frequency percussive ventilation in 100 patients in a surgical ICU. They found that there are no clinical differences between the two ventilatory modes (5).

There is now renewed interest in high frequency oscillation as a salvage therapy for patients with severe ARDS who cannot be adequately ventilated by conventional means. Mehta et al assessed HFO in patients with ARDS and found it to be successful for salvage therapy. They also suggested that early use of this ventilation mode may be useful (6). The combination of HFV with other modalities may be beneficial. Varkul et al described the use of high frequency oscillation combined with inhaled NO and prone positioning as a successful strategy in treatment of a patient with severe ARDS (7).

To date, the data concerning HFJV in patients with severe lung injury would suggest that there is a need for further research to define the role of this interesting therapeutic modality.

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Jet ventilation: Research considerations

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This research group focuses on physiological effects of HFJV as well as changes in blood gases, consequences of CO_2 diminution on parameters of mechanics of breathing, ways and effects of hypocapnia correction, on hemodynamic changes, study of a airway mucosa or surfactant system damage during HFJV, plasma catecholamine levels as well as characteristics of defensive airway reflexes during HFJV.

Increase in Raw and a decrease in Cdyn were found in hypocapnia by HFJ hyperventilation. However, the magnitude of these changes was small, probably due to the dynamic PEEP during HFJV. The external addition of CO_2 into the nozzle of the generator during the constant ventilatory mode normalized $PaCO_2$ and pH. PaO_2 values were improved.

Plasma catecholamines levels were increased after two-hours of ventilation in both IPPV and HFJV subgroups. The highest rise in catecholamine level, the lowest systemic blood pressure and increase in the right-to-left pulmonary shunts (R-L) were found in the IPPV subgroup.

Damage of airway mucosa by HFJV was studied during one-hour of HFJV in rabbits. Histopathological changes were present only above the opening of the endotracheal tube. Examination did not show significant differences neither in the phospholipid content in BAL fluid nor in surface activity of BAL fluid even after 5 hours of the HFJV.

Sneezing and coughing evoked by mechanical stimulation of the airways in non-paralyzed anaesthetized rabbits during HFJV were present but with an inhibition of their inspiratory component. Active expiratory efforts and expulsive effects were not affected by HFJV.

The effects of "asymmetric" HFJV on the movement of liquids or solid particles in the airways was studied. With Ti : Te = 1 (ti = 0.5) inspiratory and expiratory kinetic energies are equal - the mean position of moveable material in airways does not change. With ti < 0.4 the inspiratory kinetic energy is greater than the expiratory energy - material is transported into bronchoalveolar compartments (inpulsion). An expulsion occurs at ti > 0.6 (1).

The inpulsion effect of HFJV was used for exogenous surfactant instillation in rabbits. After surfactant administration, a trend to faster improvement of dynamic lung compliance (Cdyn) and total resistance of respiratory system (Rtot) was found.

The expulsion effect was tested by installation of silica particles transported to the. The biggest amount of silica (26%) was eliminated by using a HFJV expulsion regime. The results indicate that lavage by means of the expulsion effect (high-frequency jet lavage - HFJL) is an effective, experimental method for withdrawal of material from the bronchoalveolar compartment in acute as well as in chronic experiments.

Enhancement of the expulsion effect by simulated artificial cough in anaesthetized paralyzed rabbits was studied by injection of Evans blue dye. Most material (41%) was eliminated after ventilation with an expulsion regime (ti = 0.7) combined with an artificial cough without an interruption of HFJV (300/min). The expulsion regime alone eliminated 24% and the neutral regime (ti = 0.5) 14% of the material. The results show that expulsion effect can be augmented by the use of the artificial cough modulated with the superimposed HFJV.

Experimental results demonstrate that HFJV can be used successfully in some special indications e.g. to transport material to the bronchoalveolar compartments and to assist to cleaning the airways. Experimental work in vivo animal laboratory can help to understand mechanisms and concomitant effects of HFJV and to find new fields of applications.

This contribution is dedicated to the memory of Ondrej Brychta.

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POSTER

High frequency jet ventilation (HFJV). Hemodynamic effects

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A comparative study of hemodynamics was undertaken on three groups of 50 patients each with either surgery on the lungs (lobectomy, pneumonectomy), on organs of the abdominal cavity (resection of stomach, cholecystectomy), or of the retroperitoneal space (prostatectomy, nephrectomy). Parameters were recorded in sequence of VCV and HFJV 30 minutes after establishing the appropriate regime.

The VCV regime: Vt 8 - 10 ml/kg, RB 14 - 16 min^{-1}, I : E 1 : 2. The HFJV regime: f 100 min^{-1}, VE 18 - 20 l/min, I : E 1 : 2. It was determined that by surgery on lungs and by HFLV irrespectively of age the SVI parameters increased by 43.1% ($P < 0.001$), CI increased by 48.1% ($P < 0.01$), CVP by 33.6% ($P < 0.001$), the SVR decreased by 40,3% ($P < 0.001$).

Only the patients, who were elder than 60 years, had the authentic differences by surgery on organs of abdominal cavity and retroperitoneal space and with use of HFJV. In these patients, SVI increased by 20.6% ($P < 0.001$), CI increased by 12.8% ($P < 0.05$), and SVR decreased by 19,3% ($P < 0.001$). In conclusion, hemodynamic effects of HFJV depend on the surgical area and on the patient's age.

Planning and implementation of a unique method of ventilation during carinal resection

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Surgical interventions involving the tracheobronchial tree are challenging on several levels. Technically demanding from the perspective of the surgical team, they impose obstacles to ventilation for the anesthesia provider. Introduced in 1977 by Klain and Smith, HFJV has emerged as the ventilatory mode of choice during many of these procedures (1, 2). We present a case report of a unique method of management of ventilation during complete carinal resection and reconstruction. Our discussion focuses on both the preparation for this procedure, including testing our airway management plan in a simulated respiratory circuit, and on the intervention during surgery.

A 65-year-old male presented to our medical center for complete carinal resection and reconstruction. We decided to utilize HFJV as it delivers small tidal volumes at low pressures, resulting in less movement of the surgical field. Another advantage is the ability of HFJV to be delivered through small diameter catheters presenting a low profile allowing for more complete access to the entire circumference of the involved airways (2, 3 - 6). Because transection of the trachea and the right and left bronchi was planned, we needed to be able to ventilate both lungs independently. The method chosen was dual catheter, independent lung HFJV. As carinal resections are not common, we could find only one other case in the literature describing a similar method of ventilation (6, 7). The method we describe is distinguished by allowing for fewer devices in the airway and less manipulation of these devices after placement. These include an Univent tube with its integral bronchial blocker and a 4.0 mm Cook Airway Exchange Catheter. Each was connected to a separate Accutronic AMS-1000 High Frequency Jet Ventilator.

One important feature of our approach was the ability to plan and test the intervention preoperatively. We utilized a simulated respiratory circuit to determine whether adequate ventilation could be provided through both the Univent bronchial blocker and the Cook Airway Exchange Catheter (8). The simulated circuit included a Michigan Instruments Training/Test Lung Model #1600, Gould P231D transducers, Hewlett-Packard 8805D Pressure Conditioners, a Perkin Elmer 1155 VMS ultrasonic flow meter and an angular displacement transducer fitted to the lung model. Computer hardware included a Hewlett-Packard workstation with analog signals collected via a Data Translation Model DT2821 A-D conversion card. Software was designed and written in house. Using this system we were able to confirm the adequacy of our plan for ventilation. The software package is currently being migrated to National Instruments LabVIEW 6.1 software for use on a Power Macintosh G-4 Dual Processor.

During the procedure, the patient remained hemodynamically stable. Pulse oximetry values ranged from 86% to 99% while HFJV was utilized. The small diameter catheters enhanced surgical access and anastamosis. By the end of the procedure the patient was breathing spontaneously and was extubated prior to transport to the intensive care unit.

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High frequency jet ventilation in adult laryngeal CO_2 laser surgery – How do we do it?

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Laser surgery of laryngeal tumors may include one of the following methods of ventilation and equipment:
- Conventional ventilation with a laser resistant tube (i.e. *Ruesch*, Germany)
- Supraglottic jet ventilation (JV) via a jet cannula attached to or integrated in a suspension laryngoscope
- Subglottic JV via a transglottic or transtracheal laser resistant catheter.

The mode of ventilation will depend mostly on the lesion itself (localization and extent of the tumor, risk of bleeding), other patient factors (i.e. expected difficulty for direct laryngoscopy, body mass index, aspiration risk, ventilation mechanics) as well as experience and personal preference. In suitable patients there are two modes of High-frequency JV (HFJV) which we most commonly use:

1. For laser surgery of small glottic lesions we prefer supraglottic JV via a double lumen jet cannula (Karl Storz, Germany) attached to the suspension laryngoscope. The second lumen allows continuous measurement of FiO_2 and intermittently of $etCO_2$ – when briefly switching to low frequency JV. The risk of barotrauma is minimal but an anatomical obstruction to gas influx may become a limiting factor.

2. Subglottic JV is employed for laser surgery of larger or supraglottic lesions. We use an orotracheal laser resistant catheter (Xomed, USA or VBM, Germany). The jet lumen itself allows continuous (expiratory) airway pressure monitoring. The second monitor and sampling lumen measure (peak) airway pressure as well as FiO_2 continuously and $etCO_2$ intermittently. In this setting, an impeded gas outflow may be a limiting factor. Therefore an automatic inflation stop feature is necessary to prevent barotrauma, if either of these pressures are exceeded.

We use the Monsoon Universal Jet Ventilator (Acutronic, Switzerland) with ventilation frequencies from 100 - 120/min, an I:E ratio of 30 - 40% and variable driving pressure and oxygen concentration of the driving gas ($FjetO_2$). We use total intravenous anesthesia consisting mainly of remifentanil, propofol, and mivacurium according to our own dosing table. Patient monitoring includes noninvasive BP, pulse oximetry, ECG, peripheral nerve stimulation, and body temperature. The intraoperative monitoring of $etCO_2$ taken with consideration of the arterio-alveolar CO_2-gradient gives sufficient information about ventilation, usually obviating the need for blood gas analysis. JV gives especially good exposure for the surgeon:
- unhindered view of laryngeal structures
- exact determination of tumor extent (posterior commissur, subglottic areas).

High frequency JV offers a number of other advantages during laser surgery:
- airway protection through auto-PEEP
- less movement of tissues
- good evacuation of fumes
- convective cooling of tissues.

We reduce FiO_2 to the lowest level that still gives an adequate $SpaO_2$. An emergency protocol for potential laser induced airway fire has to be in operation. Special consideration has to be given to postoperative airway management.

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Comparing transcutaneous and endtidal CO_2-Monitoring for microlaryngoscopy during subglottic high frequency jet ventilation

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Objective: Monitoring of respiration for microlaryngoscopy (Kleinsasser) during HFJV is still a topic much under discussion. Two new non-invasive techniques have been established over the last years. But there is no consensus whether the endtidal and transcutaneous ventilatory monitoring are of the same clinical value (1, 2, 3, 4, 5). The aim of this study is to compare both methods in the setting of laryngoscopy during subglottic high-frequency jet ventilation using arterial blood gas monitoring as a reference.

Methods: Twelve patients scheduled for microlaryngoscopy were enrolled. Subglottic HFJV was applied via a double-lumen laser-safe Hunsaker Mon-Jet tube (Xomed, U.S.A.) for 42 minutes. Settings of the jet ventilator were kept constant except for driving pressure which was initially adapted to ensure normal ventilation. Respiratory data were recorded simultaneously at 2-min intervals. Intermittend endtidal capnography (Datex Capnomac, Finland) and transcutaneous data (MicroGas 7650, Kontron, Switzerland) were correlated against intraarterial blood gas monitoring. Bland-Altman test was performed to evaluate the agreement of the monitoring techniques.

Results: The comparison between endtidal capnography and arterial capnometry showed a correlation coefficient of r = 0.93. Bland and Altman analysis revealed a mean difference of - 0,78kPa with limits of agreement of ± 0.72kPa. The comparison between transcutaneous capnometry and arterial capnometry for the steady state showed a correlation coefficient of r = 0.63. Bland and Altman analysis resulted in a mean difference of - 0.61kPa with limits of agreement of ± 1,68kPa.

Conclusion: Intermittent endtidal capnography offers a reliable and accurate capnographic monitoring of HFJV. Transcutaneous monitoring showed a good correlation to intraarterial capnometry. However, according to the results of Bland-Altman test transcutaneous capnometry cannot be used interchangeable with intraarterial monitoring. Thus, we cannot recommend transcutaneous respiratory monitoring for the specific indication of microlaryngeal surgery using HFJV. Since new sensors for transcutaneous capnometry on the ear lobe become available another evaluation should be performed.

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High frequency jet ventilation via a double lumen catheter – A case in tracheal surgery

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We present the case of a 45 year old patient (87 kg, 180 cm) who suffered from a 3 cm tracheal stenosis following long term intubation after multiple trauma. The proposed operation was a resection of the stenosed tracheal segment. When operating on the large airways, the advantage of jet ventilation (JV) via thin catheters compared to normal endotracheal tubes (ETT) is the greatly improved access to the posterior tracheal wall during anastomosis.

The adequacy of gas exchange can be monitored during JV in three different ways:

- Intermittent arterial blood gas sampling (reference method; $PaCO_2$, PaO_2, pH)
- Continuously transcutaneous measurements ($PtcCO_2$, $PtcO_2$)
- Endtidal measurements (intermittent: $EtCO_2$ via a separate sampling channel) in combination with pulse oximetry (SpO_2).

In this case we used a double-lumen jet catheter (Acucath™, IfM, Germany) attached to a *Monsoon* Universal Jet Ventilator (Acutronic, Switzerland). Basic settings: impulse rate 120/min, I:E ratio 30%, and $FjetO_2$ 1.0. The expiratory airway pressure was monitored via the jet lumen while the monitor or sampling lumen was used to measure peak airway pressure. Simultaneously, the sampling lumen gave intermittent $etCO_2$-readings. For the latter, a brief switch to manual jet ventilation at a frequency of 10 - 12 impulses/min is necessary to allow for sufficient expiration time to receive a proper capnographic reading on the monitor (Datex Capnomac, Finland).
However, in this case the jet catheter had contact with the endotracheal wall obstructing the sampling channel during the low frequency intervals leading to inappropriate $ETCO_2$ readings. We therefore had to intermittently draw arterial blood gas samples.

Oral midazolam and subcutaneous atropine was given for premedication. Anesthesia was induced with propofol, mivacurium and a small dose of sufentanil. For maintenance propofol, remifentanil, and mivacurium was continuously applied. The patient had routine monitoring plus a radial artery catheter and a nerve stimulator.

Airway procedures:

- Orotracheal intubation (6.0 mm Magill ETT), fibreoptic control of tube position, conventional ventilation.
- When the trachea was opened, the ETT was withdrawn right underneath the glottis, proximally shortened, and a jet catheter was advanced through the shortened ETT into the lower third of the trachea. High-frequency JV (HFJV) was commenced.
- Removal of the jet catheter followed tracheal closure, after which the trachea was re-intubated with a Woodbridge tube (ID 7.5 mm), conventional ventilation, fiberoptic tracheobronchial toilette and visualization of the anastomosis.
- Extubation following application of a cranio-thoracic corset for the prevention of extreme head-neck extension.

This example demonstrates, that even with modern jet catheters, which have a separate monitor lumen, technical difficulties can occur which then necessitate the availability of an alternative mode of ventilation monitoring.

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Comparison of transcutaneous and endtidal CO_2-Monitoring for rigid bronchoscopy during high frequency jet ventilation

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Objective: To compare intermittent endtidal and transcutaneous respiratory monitoring of high-frequency jet ventilation in rigid bronchoscopy by a controlled, prospective study. Both techniques provide noninvasive measurement of pCO_2 and pO_2 and were compared to continuous intraarterial blood gas monitoring (1, 2, 3, 4).
Methods: Fifteen patients scheduled for interventional bronchoscopy were enrolled. HFJV was applied via rigid bronchoscopy for at least 42 minutes. Settings of the jet-ventilator were kept constant except for driving pressure which was initially adapted to ensure normal ventilation. The driving pressure was then changed twice by ± 30% from the initial driving pressure in intervals of 14 minutes. Respiratory data were recorded simultaneously at 2-min intervals. End-tidal and transcutaneous data were correlated with intraarterial blood gas monitoring. Bland-Altman-Test was performed to evaluate the agreement of the monitoring techniques. Data were analysed separately for the time just after changing the driving pressure (8 min, dynamic state) and the remaining time until the next change of the driving pressure (6 min, steady state).
Results: The comparison between endtidal capnography and arterial capnometry showed a correlation coefficient of r = 0.96 for the steady state. Bland and Altman analysis revealed a mean difference of -0.21kPa with limits of agreement ranging from -1.03 kPa to 0.6 kPa. For the dynamic phase, correlation coefficient was r = 0.94. Mean difference was -0.25 kPa and the limits of agreement ranged ranging from -1.29 kPa to 0.79 kPa. The comparison between transcutaneous capnography and arterial capnometry for the steady state showed a correlation coefficient of r = 0.83. Bland and Altman analysis resulted in a mean difference of -0.89kPa with limits of agreement ranging from -1.03 kPa to 2.81 kPa. For the dynamic phase correlation coefficient was r = 0.72. Mean difference was 0.92 kPa and the limits of agreement ranged from -1.11 kPa to 2.95 kPa.
Conclusion: Intermittent endtidal capnography offers a reliable and accurate capnographic monitoring of HFJV concerning both steady state and dynamic conditions. Transcutaneous monitoring showed a good correlation to intraarterial capnometry in steady state conditions. For the dynamic phase we found a significantly lower correlation to intraarterial capnometry. According to the results of Bland-Altman-test transcutaneous capnometry cannot be used interchangeable with intraarterial monitoring. Thus, we cannot recommend transcutaneous respiratory monitoring for the specific indication of rigid bronchoscopy using HFJV. Since new sensors for transcutaneous capnometry on the ear lobe will become available another evaluation will be performed soon.

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Effects of application of high frequency jet ventilation (HFJV) or continuous positive airway pressure (CPAP) on the non-dependent lung during one-lung-ventilation (OLV) in pigs

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Background and Goal of Study: Hypoxia is a frequent complication during OLV. One strategy to deal with hypoxia during one-lung anesthesia is the employment of HFJV on the operated lung. A simple alternative is the application of CPAP to the non-ventilated lung. In our study we compared the effects of the application of HVJV or CPAP on oxygenation and hemodynamic parameter during OLV in pigs.

Materials and Methods: With approval of the local Animal Protection Committee (Landesverwaltungsamt Thüringen, Germany) 15 premedicated female pigs (32 ± 2kg) were anesthetized (propofol, remifentanil, pancuronium, O_2/N_2O 1 : 1), orally intubated and mechanically ventilated. Following placement of femoral arterial and pulmonary artery catheters, the orotracheal tube was replaced under fiberoptic control by double lumen tube (DLT) via tracheotomy. The pigs were then positioned in the right lateral decubitus position, OLV of the right lung was started, and a left-sided thoracoscopy was performed to confirm lung collapse. During the study, correct DLT placement (and lung collapse) was verified by continuous dual capnography, by fiberoptic bronchoscopy, and by thoracoscopy. Ventilation during OLV was provided by a constant volume/pressure ventilator. After these measures, remifentanil and N_2O were discontinued and the FiO_2 was adjusted at 1.0. We set ventilation pressure at 25 cmH_2O, expiratory pressure (PEEP) at 5 cmH_2O. OLV was continued in random order with 5 cmH_2O PEEP on the dependent lung or with 5 cmH_2O PEEP on the dependent lung and HFJV of the non-dependent lung (f 100/min, I:E 1 : 1, FiO_2 1.0) or with 5 cmH_2O PEEP on the dependent lung and 5 cmH_2O CPAP on the non-dependent lung. Cardio-pulmonary parameters were measured after equilibration times of at least 30 minutes. Statistical tests were performed with the computing program "Statistical Packet for the Social Sciences" SPSS (10^{th} version, SPSS Inc., Chicago, IL, USA). A P value of < 0.05 was considered statistically significant.

Results: Oxygenation during OLV was improved both with application of CPAP and HFJV on the non-dependent lung. Ventilation was comparable between the 3 groups.

Conclusion: In our porcine model of OLV the positive effects of the simple application of CPAP on oxygenation and ventilation were comparable with the effects of HFJV.

Table 1: Cardiopulmonary variables during OLV

	MAP (mmHg)	PAP (mmHg)	CO (l/min)	PaO_2 (mmHg)	$PaCO_2$ (mmHg)	$EtCO_2$ (mmHg)
OLV	83 ± 17	22 ± 4	3.9 ± 1	325 ± 123$^{\#}$	45 ± 8	39 ± 6
OLV/HFJV	84 ± 18	22 ± 5	3.4 ± 0.9§	461 ± 94	39 ± 7	38 ± 6
OLV/CPAP	85 ± 20	20 ± 4*	3.9 ± 1.2	423 ± 116	45 ± 7	38 ± 6

MAP: mean arterial pressure; **PAP:** mean pulmonary arterial pressure; **CO:** cardiac output;
*p<0.05 for OLV/CPAP vs. OLV or OLV/HFJV; §p<0.05 for OLV/HFJV vs. OLV or OLV/CPAP; $^{\#}$p<0.05 for OLV vs. OLV/HFJV or OLV/CPAP.

HFJV and lung lavage with exogenous surfactant in experimental meconium aspiration syndrome

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Aim: The aim of the study was to evaluate effects of high-frequency jet ventilation (HFJV) combined with surfactant lung lavage on blood gases, lung compliance, right-to-left pulmonary shunts (RLS) and removal of meconium in a rabbit model of meconium aspiration.

Methods: Adult rabbits were anesthetized, tracheotomized, paralyzed and connected to the pressure-controlled ventilator Beat-2 (Chirana, Slovakia) with ventilatory settings: f 30/min, FiO_2 0.21, Ti 60% and PEEP 0. A suspension of human meconium (25 mg/ml, 4 ml/kg) was instilled into the tracheal cannula to obtain the model of meconium aspiration. From this time point, all animals were ventilated with FiO_2 1.0 and PEEP 0.3 kPa. After 30 min, when respiratory failure developed, ventilation was converted to the HFJV (Ti 70%, PEEP 0.5 kPa) and lung lavage was performed either with diluted exogenous surfactant (Curosurf, 100 mg phospholipids/kg, 10 mg/ml) or normal saline. Total dose of the lavage solution (10 ml/kg) was divided into 3 portions. Portions of the solution were instilled into the tracheal cannula by the syringe and were suctioned after 1 and 5 min by the suction pump. After the lavage, all animals were further ventilated by HFJV (Ti 50%, PEEP 0.5 kPa) for additional 1 hour. Blood gases and ventilatory parameters were recorded before and after meconium administration and 10, 30, 60 min after the lavage. RLS were calculated by special computer program by the Fick equation. Amount of removed meconium in lavage fluid was evaluated spectrophotometrically and by the mecokrit method.

Results: Administration of meconium caused comparable changes in dynamic lung-thorax compliance, RLS and blood gases in both groups. Surfactant lung lavage improved lung compliance 60 min after the lavage ($p < 0.05$) and oxygenation (expressed as PaO_2/FiO_2 and oxygenation index) in all time points after the lavage ($p < 0.05$ and $p < 0.01$, respectively) in comparison with the saline lavage group. Increase in arterial pH were observed 10 min ($p < 0.05$) and decrease in $PaCO_2$ ($p < 0.05$) and RLS ($p < 0.05$) 10 and 60 min after surfactant lavage. Amount of removed meconium evaluated by the mecokrit method was significantly higher in surfactant lavage group ($p = 0.001$).

Conclusion: HFJV combined with surfactant lung lavage improved gas exchange, lung compliance and reduced right-to-left pulmonary shunts in experimental meconium aspiration syndrome. Moreover, this approach was more effective in removal of meconium than HFJV combined with saline lavage.