INDEPENDENT LUNG VENTILATION AND ONE LUNG VENTILATION

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The application of the independent lung ventilation (ILV) in adults has been described by Carlon and co-workers in 1978 and subsequently by other investigators. In 1983 Hedenstierna and co-workers using a bilumen tube suitable for prolonged intubation, and two Servo Ventilator 900 B (Siemens) adapted for synchronization, treated a wide range of clinical conditions. Following this experience, the potential use of simultaneous independent lung ventilation (sILV) in patients of the pediatric age group has been investigated.

Pathophysiology of monolateral lung injury

In infants with lung injury, the affected lung presents reduced compliance and greater respiratory airway resistance than the less affected lung. When these infants are mechanically ventilated, the ventilated gases are preferentially deviated towards the less pathological lung, thereby over-expanding it and providing little benefit for the more affected lung. The result is that the affected lung receives insufficient ventilation while the less affected lung could be over ventilated, defeating the purpose of mechanical ventilation. Similarly, the application of positive end-expiratory pressure (PEEP) would increase in the thoracic compliance in the more compliant lung and a smaller share of Tidal Volume (TV) for the less compliant lung. An accentuated increase of TV in one lung may result in a greater mismatching of alveolar ventilation (VA) and perfusion (Q). Further, this may lead to the development of iatrogenic diseases, i.e. alveolar ruptures, interstitial emphysema and bronchopulmonary dysplasia (BPD).

Selective bronchial Intubation

Selective bronchial intubation is a difficult method under 8 years of age and only in recent years has its application in anesthesia and intensive care been more widely used, due to suitable tubes and equipment becoming available. Different techniques and devices are available.

1. Bronchial intubation with a tube

Bronchial intubation with a tube can be performed using a cuffed or uncuffed tracheal tube, of a smaller caliber than one which enters the trachea easily, according to the diameter of the bronchus to be intubated. Bronchial intubation can be assisted by placing the child so as to accentuate the anatomical position of the bronchus (raising of the shoulder opposite to the bronchus to be intubated) and/or using a fiberoptic bronchoscope Oral intubation is easy to perform due to the sufficient length of the tube. Nasal intubation, however, often requires a special, longer tube.

2. Use of Univent tube®

Univent tube**®** is a single lumen, tracheal tube with a movable bronchial blocker incorporated into the structure; it has been used widely in adults as an alternative to a double lumen tube. When one lung anesthesia is needed, the blocker is advanced into the bronchus to be excluded). This may be done blindly or under direct vision using a fiberoptic bronchoscope. The blocker can also be positioned to block selected lung segments. Univent tubes are now available in sizes from 3.5 mm diameter. The bronchial balloon must be inflated with large volumes of air to seal the bronchus. This may produce severe mucosal ischemia. Re-expansion of the collapsed lung is difficult because of the mono-lumen tube. The disadvantage of the Univent tube is that fiberoptic bronchoscopy is needed for accurate placement.

3. Bronchial blockade

Fogarty embolectomy catheters have long been used as bronchial blockers in children below the age of six. Arterioseptostomy catheter and Pulmonary artery catheters have the advantage of a central lumen which would permit suctioning or the application of oxygen and CPAP to the affected lung. An arterioseptostomy catheter is also advantageous because of its angled tip. Swan Ganz catheter has been similarly used. The positioning of these catheters requires fiberoptic broncoscopy even though a blind technique can be used. The correct placing is confirmed by auscultation of the lungs or by chest x-ray. A risk of displacement during surgery remains whichever catheter is employed. Their use in small infants and young children is limited due to the reduction in diameter of the trachea producing difficult and inadequate ventilation.

4. Use of bilumen tube.

Over 6-8 years of age, selective bronchial intubation is possible using a cuffed double-lumen tube similar to that used in adults (26-28 Fr. Bronchocath Mallinckrodt®, Bronchoport Rusch®). The Marraro Paediatric Endobronchial Bilumen Tube, produced by SIMS - Portex®, may be used in neonates and children 2-3 years of age. It is uncuffed to maximize the internal diameter of the tube and has no carinal hook, thus minimizing tracheal trauma.

Advantages, disadvantages and limitation of selective endobronchial materials

	Advantages	Disadvantages	Limitation in the use
Bronchial intubation by single tube	- Easy to perform - Total exclusion of one lung - No need of sophisticated equipment	- Easy dislocation of the tube - Inadequate ventilation in case of obstruction - Difficult expansion of collapsed lung	- ILV is impossible
Univent tube®	- Total exclusion of one lung	- Severe bronchial mucosae ischemia - Difficult expansion of collapsed lung	- Need fiberoptic bronchoscopy - ILV is impossible
Bronchial Blockers	- Total exclusion of one lung - Broncho suctioning, O_2 supplementation and CPAP application (Arterioseptostomy and Pulmonary artery catheters)	- Severe bronchial mucosae ischemia - Dislocation during surgical operation - Difficult expansion of collapsed lung	- Need fiberoptic bronchoscopy - Insufficient ventilation due to reduction of tracheal ID - High costs - ILV is impossible
Paediatric bilumen tube	- Total exclusion of one lung - ILV - Bilateral bronchosuctioning - Optimal expansion of collapsed lung	- Easy obstruction of the tube in prolonged treatment	- Positioning needs experience - The use is limited < 3 years

4.1 Selective bronchial intubation using bilumen tube
The introduction of the tube for intubation of the bronchial lumen through the vocal cords takes place under direct laryngoscopy. After passing the vocal cords, the tube is rotated to the right or the left, depending on which bronchus is being selectively intubated. Right bronchial intubation is usually easier because of the anatomical position of the two bronchi, but it is less preferred owing to the exclusion of the upper lobe bronchus. The potential hazard of obstruction of the right upper lobe bronchus with a right-sided double-lumen tube negates the potential benefits of intubating the bronchus of the dependent lung; there is a 90% incidence of right upper lobe obstruction. Uniform ventilation to all lobes is most likely obtained if a left-sided double-lumen tube is used. Complications are essentially due to inexperience in intubation, dislodgment and obstruction of the tube, trauma of the trachea and bronchi. Bronchosuctioning can be difficult due to the reduced diameter and increased length of the tubes. In order to facilitate this maneuver, it is necessary to maintain fluid secretions using adequate humidification and warming of ventilated gases. The correct positioning of the tube must be checked by auscultation of the lungs and chest wall movements, by fiberoptic bronchoscopy or chest x-ray.

Independent lung ventilation
These techniques permit the isolation of one lung from the other and favor the ventilation of either one or both lungs separately. It can be performed using one of the methods described for selective intubation (see above) and it can be carried out using different modes of ventilation.

Application of ILV requires the use of two ventilators suitable for electronic synchronization of the start of respiration and permits the application of different modes of ventilation and different PEEP to each lung. Synchronization ensures avoidance of shifting of the mediastinum which can create an obstacle to venous return and resulting fall in cardiac output. Furthermore, the non synchronous insufflation of the lungs may create serious ventilation disorders. These complications occur mostly at low respiratory frequencies (<30 breaths/min).

The tidal volume of each lung can be set at 50% of the calculated tidal volume of the total lungs or two thirds of the tidal volume can be applied to the more diseased lung and one third to the less affected lung. Appropriate PEEP is applied to each lung. Ventilation of the two lungs is regulated according to the compliance, respiratory airway resistance, end tidal CO_2 from each lung and central venous pressure. Inspired flow of oxygen (FiO_2) and ventilatory parameters are adjusted as indicated by the clinical condition and blood gas measurement.

The method requires well trained nurses and medical staff. The problem of humidifying and heating the ventilated gases and difficulty in bronchosuctioning remains considerable and can lead to severe hypoxemia and hypercarbia.

Indications of independent lung ventilation
1. The main indications in the pulmonary resuscitation field are :
- cases of monolateral pneumonia, emphysema, unilateral atelectasis;
- bilateral lung pathology, both of infectious and degenerative origin, complicated by unilateral atelectasis, pneumothorax and fistula;
- disease of the trachea and of the main bronchi.
2. Indications in cardio-thoracic surgery are based on:
- possibility of complete exclusion of one lung during the surgical operation;

- maintenance of a reduced ventilation in the collapsed lung so as to avoid the formation of atelectasis, without interfering with the surgical operation;
- correct reventilation of the collapsed lung at the end of operation.

3. Indications in post-operative intensive care will be agreed:

- in open-chest surgery, in order to re-expand completely the lung which is kept collapsed and to correct the atelectasis which have been created;
- to rebalance the ventilation/perfusion ratio in the lung which as remained dependent for a long time;
- to treat pulmonary complications, such as aspiration syndromes, pneumothorax, etc: which have occurred during general anaesthesia and the surgical operation.

Possible new indications:

- Bilateral pulmonary pathology may also benefit from ILV since there are characteristic pulmonary areas with different functions. In particular pulmonary pathologies in which areas of emphysema (lobar) alternate with atelectatic areas, such as bronchopulmonary dysplasia, can benefit. In these cases independent ventilation has shown that the lungs are not uniformly affected by pathology and that some areas, particularly in the first 6 months of life, are simply compressed by hyperinflation of the adjoining areas.
- Another interesting application of ILV is in the selective administration of drugs in one lung, such as antibiotic or surfactant. In the last case the benefit brought about by independent lung ventilation is accentuated by treatment with surfactant, through which it is possible to obtain a rapid stabilisation of the terminal bronchiole and the alveolus.

One lung ventilation

This mode of ventilation is well tolerated when the contralateral lung is collapsed and perfusion is excluded. In cases of partial exclusion of one lung, hypoxia and hypercarbia can develop: high level of FiO_2 is necessary to maintain adequate PaO_2 and large tidal volume has to be used to reduce $PaCO_2$.

The tidal volume of the ventilated lung in this situation is generally 12-15 ml/kg body weight to avoid hypercapnia and atelectasis. In any case minute ventilation is used to maintain a $PaCO_2$ of 4.5-5.2 kPa (35-40 mm Hg). Ventilation with tidal volumes less than 5 to 7 mL/kg may exaggerate the effects on gas exchange as airways may remain closed for a greater percentage of tidal volume and may promote atelectasis. Hyperventilation can create an increase of mean airway pressure and of dependent lung pulmonary vascular resistance with consequent reduction of PaO_2 and cardiac output.

A collapsed lung does not re-expand homogeneously after being collapsed. Individual lung segments "snap open" while others remain closed. Distention should be carried out with caution and progressively to avoid alveolar and bronchiolar rupture and interstitial emphysema.

The impairment of gas exchange occurring after one lung ventilation is most important in children because they are potentially more susceptible to airway closure than adults and hypoxemia might be expected to occur at least as frequently, if not more so.

When two-lung ventilation follows a period of one-lung ventilation (20-120 min), PaO_2, shunt and compliance are unchanged from values obtained prior to thoracotomy. Ventilation with PEEP could be useful to stabilize the patency of bronchioles and alveoli and resolve atelectasis.

Clinical implications

Haemodynamic. The application of ILV does not in itself cause any haemodynamic changes that differ from the changes that occur when IPPV is used. Increase in central venous pressure with a reduction of arterial pressure and cardiac output, occur less frequently with ILV than with conventional ventilation, because interference with intra-thoracic pressure is lower.

PEEP. PEEP values of 5 cm of H_2O applied mono or bilaterally in ILV do not cause any haemodynamic change. With high PEEP, the independently ventilated lungs behave according to their pathologies, or the more affected lung withstands higher PEEP levels than the less affected lung before the onset of hemodynamic implications.

PaO_2. Applying ILV a rapid improvement of PaO_2 is obtained because of the recruitment of new areas to be ventilated; this improvement becomes more evident when the best PEEP was applied to the two lungs separately.

End-Tidal CO_2 ($ETCO_2$). Elimination of CO_2 in the more pathologic lung is lower than in the less affected one on account of the smaller ventilating pulmonary area. Applying ILV and using selective PEEP for each lung, a progressive increase in the elimination of CO_2 is noted because of the recruitment of new areas to ventilation.

General observations

The most important advantage of ILV is the rapid resolution of the pathology for which ILV was applied in comparison with the conventional mechanical ventilation. The effective ventilation of the more pathologic lung reduces considerably the time of re-ventilation of the pathologic areas and consequently the recovery of the lung pathology.

No serious lesions of the vocal chords, larynx, trachea or bronchi was noted, even after prolonged treatment. The irritation of mucosae and inflammation occasionally noted were similar to those which occur after conventional ventilation and resolution was noted as the pulmonary pathology improved.

At the beginning of treatment a moderate compliance reduction and an increase of respiratory airway resistence is noted due to the small size of the double lumen-tube. Applying 5 cm of H_2O of PEEP bilaterally the respiratory airway resistance decreases and the compliance increases. This improvement is more evident when different levels of PEEP are applied to each lung.

Bronchial-suctioning is important for the ILV treatment. Suitable aspiration catheters must be used. The frequency of broncho-aspiration cannot e standardized. It must follow the patient's needs: a check should be made every hour. Tracheal-bronchial secretions must be kept fluid and thus easily drainable and removable.

Once the indication for ILV is confirmed, the treatment should begin as soon as possible, since early treatment tends to shorten the total duration of respiratory support.

New unexplored potentials for the application of ILV

Using ILV both unilateral and bilateral lung diseases can be successfully treated. Even the bilateral lung diseases as diagnosed clinically and radiologically still show differences in the lung functions when they are carefully studied separately. Thus, even the seemingly bilateral lung disease may better respond to ILV in lung disease characterized by lobar emphysema with associated portions of atelectasic lung will also be benefited effectively using ILV. Good results have been demonstrated in the management of inhomogeneous lung pathology typical of BPD. In these cases, the ILV shows that lungs are not uniformly affected. Some lobes, particularly in the first 6 months of life, are not severely damaged but are simply atelectasic due to compression from the hyperinflated lobes of the lungs. After the first 6 months, and especially in infants treated with prolonged home oxygen therapy, the lungs are uniformly damaged.

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