Part II: Respiratory Failure

Chapter 28: Acute Severe Asthma

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Acute severe asthma can be defined as asthma which is life-threatening. It may arise in the absence of therapy or from inadequate or unsuccessful therapy, and is a medical emergency. Admission to an Intensive Care is mandatory.

Clinical Presentation

Acute severe asthma may arise from two clinical backgrounds:

1. *Acute severe asthma* usually occurs in patients whose lung function remains significantly abnormal in between episodes of clinically acute asthma. These patients often have minimal symptoms of asthma because of underperception of breathlessness, denial, and behaviour modification. As a result, they tend not to seek medical attention, and if they do, their asthma may be underestimated. Consequently, the asthma is often undertreated and poorly controlled. Acute severe attacks may devlop over hours to days, but the onset may appear precipitous, as significant symptoms may not arise until asthma is very severe. The response to treatment is variable, and may not be delayed. Thus respiratory fatigue and need for ventilatory support may arise before clinical improvement occurs.

2. *Hyperacute fulminating asthma* is less common and may occur in patients with normal or near normal lung function, but with a high level of bronchial reactivity. These patients may have a history of severe asthma or other evidence of high bronchial reactivity, such as marked diurnal variation of symptom or exercise-induced asthma. However, life-threatening asthma may arise de novo. The attack is usually rapid and may lead to respiratory insufficiency within hours of onset (even respiratory arrest within 30 min in the most severe form). Response to treatment is usually prompt and substantial. Respiratory support is often unnecessary or of short duration.

Asthma mortality and the requirement for mechanical ventilation is associated with these two patient categories. However, there is a spectrum of illness between the two groups, and many patients cannot be clearly categorized. Clinical precipitants include viral upper respiratory tract infections, allergens and irritants. No precipitants, however, can be identified in over 30% of patients.

Assessment of Severity

Clinical Features

The clinical features of asthma are well known and can be used to assess the severity of the attack.

1. Airflow Obstruction

Although expiratory *wheeze* is the hallmark of asthma, loudness of wheezing is not a good guide to airway obstruction. Very soft breath sounds or especially a "silent chest" indicates grossly inadequate airflow ("locked lung syndrome"). *Pulmonary hyperinflation* occurs and usually becomes clinically apparent as asthma becomes more severe.

2. Ventilation - Perfusion Mismatch

Hypoxaemia and the requirement for increased minute ventilation are invariably present due to increased ventilation-perfusion mismatch. The degree of disturbances is roughly proportional to the severity of airflow obstruction.

Although *central cyanosis* can be clinically detected with as little as 1.5 g/dL deoxyhaemoglobin (which corresponds with a PaO_2 of 60 mmHg (8.0 kPa), hypoxaemia can remain undetected until it is severe. Thus hypoxaemia must be sought using arterial blood gases (ABGs) or pulse oximetry, or averted with oxygen therapy.

Tachycardia and arrhythmias may be present and are often associated with anxiety, increased work of breathing and sympathomimetic drugs. Nevertheless, a pulse rate over 130/min suggests severe hypoxaemia.

Increased minute ventilation requirements primarily results in *tachypnoea* because of limited capacity to increase tidal volume. As the severity of asthma worsens, ventilation requirement increases, tidal volume falls, and tachypnoea further increases. A reduction in tachypnoea without improvement in severe asthma indicates fatigue and impending respiratory collapse.

3. Increased Work of Breathing

The increased work of breathing due both to airflow obstruction and hyperinflation, results in an increased requirement for respiratory muscle force generation and use of *accessory respiratory muscles.* This results in *dyspnoea* and, as airflow obstruction worsens, *respiratory distress.* Assessment of the respiratory distress by both patient and experienced doctor can be used to judge the severity and the need for ventilatory assistance in some patients. However, other patients with severe airflow obstruction may have no symptoms and patient assessment of the response to treatment may be inaccurate. Increased work of breathing is also accompanied by assumption of an *upright posture* and *sweating,* both valuable indicators of severity of asthma.

The increased negative intrathoracic pressure generated during inspiration is also responsible for *pulsus paradoxus,* which is frequently present and may be a useful clinical indicator of airways obstruction. Note: pulsus paradoxus is an exaggeration of the normal slight fall in blood pressure and pulse volume on inspiration. A difference in systolic blood pressure between inspiration and expiration greater than 10 mmHg (1.3 kPa) indicates severe asthma. However, the degree of pulsus paradoxus does not necessarily correlate with the severity of the asthma, as it is also dependent on the capacity of the inspiratory muscles to

generate negative intrathoracic pressure. If the inspiratory muscles are weak, or if their force generation is impaired by hyperinflation and fatigue, then pulsus paradoxus may be small or even diminish as airflow obstruction becomes more severe.

4. Ventilatory Failure

Ventilatory failure is manifested by a rising $PaCO_2$. This is usually accompanied by marked *distress, restlessness* and *anxiety.* As higher levels of $PaCO_2$ are reached, *flushing, further sweating,* and *bounding pulse* are seen, and may be accompanied by *exhaustion,* obtundation and a *depressed level of consciousness.* At this stage, ventilatory assistance is almost invariably required and should be instigated urgently.

Investigations

1. Arterial Blood Gases and Pulse Oximetry

Continutous pulse oximetry is desirable, and frequent blood gas estimations mandatory, until asthma is controlled. Hypoxaemia is almost invariably present in the patient with severe asthma breathing room air. Bronchodilators may transiently increase hypoxaemia by increasing ventilation perfusion mismatch (but should not be withheld for this reason).

Minute and alveolar ventilation are initially increased in an acute attack, leading to hypocarbia and respiratory alkalosis. As asthma severity and ventilation-perfusion mismatch worsens, the minute ventilation required to achieve the same alveolar ventilation increases. However, at the same time, it becomes increasingly difficult to meet this increased ventilatory requirement, and ventilation may diminish because of increased work of breathing, hyperinflation and fatigue. Thus a $PaCO_2$ rising towards normal represents clinical deterioration, rather than improvement, leading eventually to hypercarbia.

Acid-base status and serum bicarbonate levels may also be disturbed. Patients with poorly controlled asthma over several days may develop a mild non-anion gap metabolic acidosis (i.e. serum bicarbonate 22 ± mmol/L, presumably due to renal compensation for persisting hypocarbia). More severely ill asthmatics may develop lactic acidosis. The cause of this is uncertain but high doses of IV beta-2 agonists may contribute. The metabolic acidosis results in serum bicarbonate levels < 20 mmol/L and further increases ventilatory demand.

2. Ventilatory Function Tests

The asthmatic patient may be too breathless or distressed to perform even simple bedside lung function tests. However, forced vital capacity (FVC), one-second forced expiratory volume (FEV1) or peak expiratory flow rate (PEFR) are useful indices in assessing response to treatment, if they can be obtained. Usually, in severe asthma, FVC is less than one litre, FEV1 is less than 500 mL, and PEFR < 100 L/min. A ventilatory function test should be performed as soon as possible during an acute asthma attack and used to follow progress therafter.

3. Chest X-Ray

A chest X-ray is taken to exclude pneumothorax or mediastinal emphysema. The classical radiological features of acute severe asthma are a narrow central heart shadow, flattened diaphragms, raised "bucket handle" ribs, and generalized hyperaeration. Any associated pulmonary parenchymal infection may be detected on the X-ray.

4. Electrocardiogram

Although the ECG is usually normal, in severe asthmatic attacks in young patients, ECG changes of right heart strain may occur (i.e. right axis deviation (RAD), P pulmonale, right bundle branch block (RBBB), S1Q3T3 pattern, and inverted T on anterior leads).

Diagnosis

The diagnosis of asthma is usually obvious. However, the combination of wheeze and dyspnoea are not infrequently caused by other illnesses. Left ventricular failure, aspiration pneumonia, upper airway obstruction, inhaled foreign body, and pulmonary embolism need to be remembered and excluded. Wheeze and dyspnoea arising in hospitalized patients not admitted with asthma, is more likely to be due to the above diagnoses than asthma.

Management

If acute asthma is judged to be severe, urgent treatment is warranted. Details about recent use of bronchodilators must be obtained with regard to type and dosage, especially aerosol sympathomimetics and slow-release theophylline preparation.

A. Primary Treatment

Initial pharmacotherapy of acute severe asthma should include some or all of the following:

1. Oxygen

Hypoxaemia should be promptly reversed with oxygen therapy. Although high inspired oxygen may lead to increased hypercarbia in patients with severe chronic airflow obstruction, this phenomenon is highly questionable in acute severe asthma and adequate oxygen therapy should not be withheld. The use of a pulse oximeter enables accurate titration of oxygen therapy to ensure SaO_2 of 96% or more. In a patient with severe chronic airways disease, inspired oxygen may be titrated to a lower SaO_2 without risking significant hypoxaemia.

Humidification of the inspired oxygen is desirable but poses practical problems. Heated water bath and gas-driven humidifiers produce droplets of a size which do not reach the small airways and may largerly settle on the oxygen face mask. Ultrasonic nebulizers are effective but are cumbersome and expensive. The cold aerosol may also increase airways resistance.

2. Nebulized Beta-2 Adrenergic Agents

Use of a nebulized beta-2 adrenergic agent remain first line bronchodilator therapy for severe asthma. Agents include salbutamol, terbutaline, fenoterol, and isprenaline.

(a) Salbutamol

Salbutamol acts rapidly and causes fewer side effects than the non-selective agents, but tremor and tachycardia may be problems. It may be nebulized using an oxygen mask and a disposable jet nebulizer unit (i.e. "Hudson", "Acorn", and "Inspiron"). The nebulizing dose is 1-2 mL of 0.5% solution every 4 hours. A minimum initial reservoir volume of 4 mL (with additional diluent) and an oxygen flow rate of 6-8 L/min are advocated to optimize nebulizer output. During the initial phases of severe asthma smaller, more frequent doses should be used (0.5-2 hourly intervals of 0.5-1 mL of 0.5% solution made up to 2-4 mL).

(b) Terbutaline, Fenoterol

Other beta-2 adrenergic agents, terbutaline and fenoterol, may be used as alternative. Their solution concentrations, 1.0% and 0.1% respectively, are such that similar volumes as for salbutamol are required. There is little difference in clinical effect compared with salbutamol.

(c) Isoprenaline

This may also be nebulized but is not preferred because of its non-selective beta action and hence increased propensity for tachycardia.

Metered aerosol bronchodilators generally are not completely effective in acute severe asthma because:

(i) patients with profound airways obstruction cannot inhale an aerosol effectively; and

(ii) have unusually repeatedly tried their own inhaler without much success before admission to hospital.

The inhalation technique of metered-dose inhalers is important. After exhalation, one puff of the inhaler is taken (either into the open mouth or with lips closed around the inhaler) just at the start of a slow, deep breath through the mouth. The breath is then held at full inspiration for 2-10 seconds. For those who cannot co-ordinate this manoeuvre, alternative methods of administration including a variety of tube spacers and dry powder inhaler (salbutamol "Rotacaps") are available.

As with nebulized bronchodilators, there are no major clinical differences between available aerosol beta-adrenergic inhalers. Although less than 10% of the dose is delivered to the airways, this is enough to be effective.

3. Ipatropium Bromide

Ipatropium bromide is an anticholinergic bronchodilator with no systemic atropine-like effects and no inhibition of mucociliary clearance. Although its bronchodilator action is not potent, it has good synergy with beta-2 agonists and has an accepted role in the treatment of asthma when used in this combination. It can be given in combination in the nebulizer solution, i.e. 1 mL 0.025% ipatropium with 1-2 mL 0.5% salbutamol.

4. Steroids

Although steroid therapy in acute severe asthma has been criticized, their use has become well established, with significant reductions in severity and hospital admission rates from short-term IV steroids. The exact mode of action is unknown but may be due to suppression of the inflammatory response, stabilization of mast cells, and potentiation of endogenous and exogenous catecholamines. The peak response is 6-12 hours after an IV injection, but the steroid effect may be seen as early as one hour.

The dosage is controversial. "High" doses (i.e. methylprednisolone 1 g every 6 hours) have been advocated in severe cases, but are probably not necessary. A suitable regimen is: hydrocortisone by continuous IV infusion of 0.5 mg/kg/h, or if given intermittently, 4 mg/kg every 3-4 hours. The duration of IV steroid therapy is usually several days but a single dose may be given. Intravenous steroids may be withdrawn abruptly if treatment is of short duration or replaced by a tapering dose of oral steroids (i.e. prednisolone commencing 40-60 mg/day in two divided doses) depending on the degree of lung recovery. Steroids should still be used in a pregnant woman with acute severe asthma. The risk of foetal anoxia from the asthma is far greater than any risk associated with correct use of steroids.

5. Aminophylline

Aminophylline contains 80% teophylline. The role of theophylline in asthma has been questioned and synergism with beta-2 agonists is debatable. In addition, IV aminophylline is associated with significant side effects which may outweigh benefits. Nevertheless, it remains an important treatment for those not responding to nebulizer treatment. Other potential effects of increasing cardiac output and diaphragmatic contractility may also be useful. If required, the IV loading dose of aminophylline is 5-6 mg/kg over 20-30 minutes. Aminophylline is continued as an infusion of 0.5 mg/kg/h but the doise is reduced in patients with cirrhosis, congestive heart failure, chronic obstructive lung disease, acute fevers, or receiving cimetidine, erythromycin or antiviral vaccines. The dose may need to be increased in young patients, smokers without chronic airflow obstruction, or regular alcohol consumers without liver disease.

Serum theophylline concentrations should be monitored with the therapeutic with the therapeutic range being 5-20 mg/L (30-110 micromol/L). Toxic effects include headache, nasue, vomiting, and restlessness, with life-threatening arrhythmias and convulsions at concentrations above 40 mg/L (200 micromol/L). Some 4% of adults are unable to tolerate even low serum levels. Initial serum levels correlate poorly with the history of the amount previously taken. Pharmacokinetic predictions of serum concentrations may optimize

aminophylline infusions. Toxicity from duplicate prescribing (i.e. additional oral or rectal preparations) must be avoided.

Serum theophylline levels are used to monitor both the loading dose and the infusion rate. A serum level within 1-2 hours of the loading dose will identify inadequate or excessive loading, necessitating a further loading dose or temporary cessation of infusion. If load adjustment occurs, serum theophylline should be remeasured. Once the patient is optimally loaded, early steady state serum levels, usually 12 and 24 hours later, should be assayed. Levels should be monitored 24 hourly thereafter.

6. Intravenous Beta-2 Adrenergic Agent

Salbutamol may be given IV to patients with more severe asthma. It is given in a bolus dose of 100-300 microg, or a loading infusion up to 500 microg over one hour, followed by an infusion of 5-20 microg/min. The rate of infusion is limited by side effects, particularly tachycardia and tremor. Lactic acidosis, hyperglycaemia and hypokalaemia may be associated with IV salbutamol - the mechanisms are uncertain, but synergy with aminophylline may have a role. The acidosis may compound respiratory acidosis and distress and should be averted. Lactate levels respond within hours to reductions in the salbutamol infusion rate.

B. Other Treatment

Many other forms of therapy have been advocated for acute severe asthma, but they are either not advocated for routine use, nor always necessary or widely accepted.

1. Adrenaline

It is doubtful that adrenaline produces additional bronchial smooth muscle relaxation after full doses of beta-2 adrenergic agents. However, it may have equivalent treatment value without side effects and significant benefit may arise from its alpha-adrenergic actions of vasoconstriction and mucosal shrinkage, which may increase airway diameter beyond the effects of beta-2 adrenergic agents.

Adrenaline can be used by the subcutaneous route as 0.1 mg - 0.5 mg, repeated if necessary, 2 or 3 times at 30 minute intervals. Intravenous adrenaline may avert mechanical ventilation in very severe cases which have failed to respond to the above drugs. Since the patient is invariably hypoxaemic and hypercarbic, it has to be used with extreme caution, with mandatory continuous ECG monitoring. An IV test dose of 10 microg is given slowly over 3-5 minutes. If relief occurs promptly, a continuous infusion of 1-10 microg/min is started. The patient is gradually weaned off adrenaline when the acute attack is no longer life-threatening. Nebulized adrenaline is also effective and may be preferred to parenteral administration.

2. Other Drugs

Antihistamines have not been proven to be beneficial in acute severe asthma, even in patients whose asthma is known to be provoked by allergic exposure. Their anticholinergic

effects may cause inspissation of secretions and worsening of airways obstruction. Mucolytic agents are also not considered to be effective.

Ketamine, a dissociative anaesthetic agent, has been reported to be useful in severe asthma. It decreases airways resistance, probably from increased circulating catecholamines from blocking their uptake into adrenergic nerve endings.

Halothane, droperidol, isoflurane and *enflurane* have also been reported to improve asthma but their benefit beyond optimal doses of standard bronchodilators is uncertain. *Calcium channelblockers* may have a role but this has not been clinically established.

3. Antibiotics

Acute asthmatic attacks are occasionally preceded by viral upper respiratory tract infections. Antibiotics are indicated only if there is clinical evidence of lower respiratory tract infection. However, antibiotics are not required in the majority of cases. Prophylactic use of antibiotics is not helpful.

4. Hydration

Patients with prolonged severe attacks may become dehydrated. Most patients on presentation are usually too breathless or exhausted to take fluids orally, and IV fluids are required. The role of fluids in decreasing sputum tenacity is uncertain. Usually a volume of 2.5-3.0 L/day is required and care must be taken against overload. Replacement of electrolytes, especially potassium, is given according to serum biochemical results.

5. Physiotherapy

During the initial phases of treatment, physiotherapy is ineffective, may be poorly tolerated, and may occasionally worsen airway narrowing. However, there is usually significant sputum plugs within the lungs and chest physiotherapy is an important adjunct to removal once sufficient bronchodilation has been achieved.

6. Sedation

There is no "safe" sedative in the management of the spontaneously breathing asthmatic. All sedative drugs carry a risk of central depression and increased morbidity and mortality. Patients with severe asthma should never be sedated unless being mechanically ventilated. Reassurance is important in reducing anxiety that may contribute to further increases in respiratory effort.

7. Non-Intravenous Medication

Althoug beta adrenergic agents are available for IM and subcutaneous use, and aminophylline is available in suppository form, these forms of administration have little or no role in the treatment of acute severe asthma.

C. Progress and Monitoring

Preventable morbidity and mortality may still occur usually as a result of a deterioration in asthma or patient status that is inadequately identified or treated. The major contributing factors are inadequate observation and measurement. Severe asthmatics should not be left unattended and attention is paid to the following.

1. *Close observation* - in an ICU or a specialized respiratory unit. This implies direct nursing observation and immediate abailability of medical staff.

2. *Regular measurement of asthma severity* - by a peak flow meter or portable spirometer. Clinical estimatation of asthma severity is not always reliable, whereas falls in peak flow or FEV1 can provide early warning of deteriorating status. Once the patient is capable, measurements should be made 2-4 hourly during the initial phases of management.

3. *Regular measurement of blood gases and oxygenation status* are required.

4. *Close treatment monitoring* - this includes assessment of serum theophylline levels, frequency and dose of nebulised agents, and treatment side effects.

Mechanical Ventilation

Mechanical ventilation of patients with acute severe asthma may be life saving, but has a hgih risk of complications (especially barotrauma and hypotension) and an overall mortality of 13%. The most common single cause of death is cerebral hypoxia (Table 1) resulting from pre-hospital cardiorespiratory arrest. However, in the next 4 categories accounting for almost 50% of all deaths, mechanical ventilation potentially contributed to the deaths. Of all patients being ventilated for asthma, 14% developed pulmonary barotrauma (pneumothorax in 9% and pneumomediastinum or subcutaneous emphysema in 5%) and 38% developed hypotension.

Inadvertent pulmonary hyperinflation or gas trapping has been suggested as a major factor in ventilation associated complications. Following mechanical tidal expiration, normal or stiff lungs return to the passive relaxation volume of the respiratory system or the functional residual capacity (FRC). However, in severe asthma, there is significant prolongation of expiratory airflow and incomplete exhalation, prior to the next mechanical breath. Thus, a hypoventilating asthmatic initiated on mechanical ventilation, will undergo progressive hyperinflation. As lung volume increases, so too does airway calibre, thereby improving expiratory airflow, and proportionately less of each successive mechanical breath will be retained. Eventually, a steady state is reached in which there is sufficient hyperinflation for expiration of all the inspired volume. This process usually takes only 5-10 mechanically ventilated breaths.

The gas volume thus retained has been variously termed gas trapping, pulmonary hyperinflation, or increased end-expiratory lung volume. It may be measured during a period of apnoea long enough to allow complete exhalation of trapped gas (30-60 s). The pressure exerted in the alveoli by this trapped gas at the end of tidal expiration, has been termed auto-

PEEP, and may be measured by observing airway pressure during transient expiratory airway occlusion at the end of expiration.

Table 1. Cause of Death in Patients Requiring Mechanical Ventilation for Acute Severe Asthma

1. Cerebral ischaemia/hypoxia	26%
2. Hypotension	18
3. Sepsis with hypotension	10
4. Tension Pneumothorax	10
5. Technical complications with ventilator	10
6. Arrest post extubation	4
7. Inability to ventilate, hypoxia, perforated duodenal ulcer, peritonitis, aspiration, pneumonia	12
8. Not specified	8

Although hyperinflation may seem an appropriate physiological adaption to reduce airflow obstruction, the increased intrathoracic pressure can lead to two life-threatening problems - hypotension and barotrauma. The total lung volumes reached are within the capacity of a normal lung to expand safely, but there are large variations of airway calibre within the obstructed lung. This results in greater overexpansion of the more obstructed segments, with consequent risk of alveolar rupture.

The extent of hyperinflation is dependent on three prime factors:

1. The amount of air inspired - tidal volum (V_T).

2. The time allowed for expiration - expiratory time (T_E).

3. The severity of airflow obstruction.

Thus, an increase in minute ventilation, either by increasing V_T or increasing rate (reducing T_E) or both, is the biggest factor in increasing hyperventilation. At a constant minute ventilation, the ventilatory pattern giving the least hyperinflation is surprisingly one with a low V_T and a relatively higher rate. At any level of minute ventilation, hyperinflation will be reduced by increasing inspiratory flow rate, thereby allowing a longer T_E for a constant respiratory rate. However, the effects of increasing inspiratory flow on the distribution of ventilation within the lung remain controversial.

Ventilatory requirements to achieve normocarbia are highest during the initial phases of ventilatory support because of a high CO_2 production rate and ventilation: perfusion mismatch which reduces the efficiency of CO_2 excretion. The ventilatory requirements to normalize pH may be higher still if a metabolic acidosis is present. However, the ventilatory capacity of the lung is usually at its worst at this time, and attempts to normalize PCO_2 and pH will result in unsafe levels of hyperinflation in a significant number of patients.

Indications for Mechanical Ventilation

Ventilatory support should be avoided if possible, but initiated when there is significant risk of ventilatory collapse. The need for ventilatory support usually arises under two circumstances:

1. *Rapid fulminating asthma:* In this group airflow obstruction is so severe that only a very low level of minute ventilation is possible and pulmonary hyperinflation occurs to a degree where inspiratory muscles are ineffective, even in the absence of fatigue. These patients may present following a respiratory arrest or the need for ventilatory support arises shortly after presentation. Initial $PaCO_2$ levels are frequently > 80 mmHg (10.6 kPa) and may fall rapidly with prompt aggressive therapy, thereby averting the need for mechanical ventilation.

2. *Severe prolonged asthma:* In this group, although inspiratory muscles can sustain sufficient ventilation to initially achieve a $PaCO_2$ near or below normal, the increased work of breathing will ultimately lead to respiratory muscle fatigue. If therapy is inadequate or ineffective, these patients will manifest a rising $PaCO_2$ and will require ventilatory support at a much lower level of $PaCO_2$ than the first group.

Thus the decision to initiate ventilatory support should be based on the following considerations:

1. *Assessment of patient distress* is the single most important factor.

2. *State of treatment* - whether the patient has not yet received effective therapy or has failed to improve despite adequate therapy.

3. *Direction of change of $PaCO_2$* and clinical state. A single $PaCO_2$ measurement is the least important consideration.

Ventilatory Technique

1. *Initial ventilatory setting:* The initial stages of ventilatory support are the most critical and care must be taken to commence with a low level of minute ventilation (< 170 mL/kg/min or < 12 L/min in a 70 kg man). This should be achieved with a low tidal volume (< 10 mL/kg or 700 mL in a 70 kg man), a high inspiration flow rate (> 80 L/min), and rate adjusted to achieve the desired minute ventilation (< 20 breaths/min). Most asthmatics will be well oxygenated on 50% O_2 or less, unless there is another disease process present (such as pneumonia, aspiration or pulmonary oedema). This level of ventilation will usually result in hypercarbic acidosis, and patients will need sedation and often paralysis to disable attempts to increase their minute ventilation. Paralysis has the additional benefit of reducing CO_2 production. If significant hypotension occurs, minute ventilation should be further reduced by rate reduction and fluid loading given.

2. *Assessment of ventilation:* Once mechanical ventilation has bee initiated blood gases and the degree of pulmonary hyperinflation should be assessed. Hypercarbic acidosis should

not be corrected by increasing ventilation without first assessing the degree of hyperinflation or its effects by any of these methods:

(a) Hypoventilation, maintaining peak ariway pressure < 50 cm water (4.9 kPa) until there is clinical improvement. This technique is simple and has proved effective. However, peak airway pressure is largely related to inspiratory flow rate and only representative of hyperinflation if inspiratory flow rate is constant and low.

(b) Measurement of plateau airway pressure during 0.5 sec end-inspiratory exhale occlusion - represents the alveolar pressure at the end of inspiration, which is directly proportional to the degree of hyperinflation, and should be maintained < 20 cm water (19,6 kPa). This corresponds with an approximate lung volume of 1.6 L above FRC, as most asthmatics have a near normal respiratory system compliance of approximately 80 mL/cm water.

(c) The end-expiratory exhale occlusion pressure (auto-PEEP) represents the alveolar pressure at the end of expiration and is proportional to the trapped gas volume. This value should be maintained < 12 cm water.

(d) Total exhaled volume (in steady state tidal ventilation of a paralysed patient) during a period of apnoea long enough (30-60 sec) for exhalation to be completed and the lungs to return to FRC. This volume should be maintained <20 mL/kg.

(e) A central venous catheter or an oesophageal ballon can both provide useful information on hyperinflation. The internal jugular route should be used, as the increased risk of pneumothorax from the subclavian route should be avoided. Pulmonary hyperinflation elevates intrathoracic and, hence, central venous and oesophageal pressures. The fall in these pressures and the increase in blood pressure during the period of apnoea, will indicate the degree of circulatory tamponade due to hyperinflation.

3. *Subsequent ventilatory adjustment:* If ventilatory assessment suggests a safe degree of hyperinflation, minute ventilation may either be maintained at that level or increased by increasing respiratory rate. If hyperinflation exceeds safe limits, then minute ventilation should be reduced *irrespective* of $PaCO_2$ or pH. A pH as low as 7.10 is generally well tolerated by patients with asthma. Even lower pHs may be corrected by IV sodium bicarbonate (100-200 mmol) given over 1-2 hours. During the initial stages of ventilation, the maximum safe level of ventilation is usually significantly less than the minute ventilation required for normocarbia. As asthma improves, both the ventilatory requirement for normocarbia reduces and the safe level of ventilation increases. When these two measurements are equal then the patient is ready for weaning and extubation.

PEEP and CPAP

The use of continuous positive airways pressure (CPAP) either via the endotracheal tube or by occlusive mask has recently been advocated to reduce the work of breathing in patients with COAD who are becoming fatigued. There is theoretical and some clinical evidence for benefit under these circumstances. However, this cannot be extrapolated to the

use of PEEP during mechanical ventilation, as this has been shown to increase hyperinflation, airway and intrathoracic pressures, and depress the circulation.

Pneumothorax

There is a high incidence of pneumothorax in asthmatic patients undergoing mechanical ventilation which contributes to mortality. Once a pneumothorax has developed, airflow obstruction, which is worse during expiration, will favour continued gas loss through the ruptured alveolus rather than return of gas through the obstructed airway, thereby increasing the propensity for tension pneumothorax. A pneumothorax will reduce ventilation to the affected lung and increase ventilation to the unaffected lung. This in turn, increases hyperinflation of the unaffected lung, thus increasing the risk of developing bilateral pneumothoraces.

Prevention of pneumothoraces is by maintaining low levels of minute ventilation and hyperinflation, but awareness must be maintained, and careful safeguards instituted. A rise in peak airway pressure during steady state ventilation is a valuable warning sign. Sedation and paralysis eliminate random patient respiratory movements which would normally cause transient rise in airway pressure.

Mortality

The reported overall mortality of asthma is significantly higher in Australia and New Zealand than in North America and has been increasing since the 1970s. While the majority deaths occurs prior to medical intervention, a significant proportion still occurs after medical help has been sought. The latter should be largely preventable.