THE NORTHERN HOSPITAL

VENTILATION - MECHANICAL

"The Lost Balloon" oil on canvas, 1882, William Holbrook Beard

"I was the first man to ever see the sun set twice in the same day….I could hear myself living!….."

Dr. Alexandre Charles, 1st of December 1783

Joseph Banks was worried. Had the French surpassed the British in Natural Philosophy? - surely not! In early September of 1783 he had, as President of the Royal Society, begun receiving top secret reports from Paris from Benjamin Franklin that French science and engineering had achieved something astonishing. They had produced enough quantities of "inflammable air", to enable them to begin experimenting with it. Indeed they had managed to harness the physical properties of the mysterious substance by building an "aerostat" - a conveyance that could potentially carry a man into the clouds! At first Banks was skeptical, but Franklin assured him that Jacques Charles and the Robert brothers had already developed a small successful prototype on August 27, 1783. Banks knew that inflammable air, an elemental component of normal atmospheric air had been discovered by the British Natural Philosophers, Henry Cavendish and Joseph Priestly. Banks and his countrymen were rightly proud of this major discovery that had disproved the millennial years old Aristotelian theory that air was an element. It was now known that indeed it was a mixture of still more fundamental substances, the nature and properties of which were still very mysterious. And yet now rival French Natural Philosophers such as the brilliant Antoine Lavoisier were outdoing their British counterparts, by taking the British discovery and harnessing it for flight! Soon Banks received even more fantastical reports. The Montgolfier brothers, on the 19th of September used the "principle of hot air rising", to construct a hot air balloon, beautifully decorated with heraldic symbols, to demonstrate the feasibly of lifting a man into the clouds. They had attached a wicker basket to the balloon and gave it a crew of three farm animals, a sheep a duck and a cockerel (the French national symbol). The balloon had skimmed across the rooftops of the houses of Versailles, and stayed aloft carrying the animals for a full seven minutes. Eventually it floated back down to the ground when the air had cooled. The sheep, duck and cockerel were all alive and quite well - the first creatures ever to fly in a made device - quite an honour for the sheep and the cockerel - though somewhat ho-hum one images for the duck! It was clear what was to come next- the first flight of man in history!

By this time King Louis XVI had been informed of the remarkable achievements. As the risks appeared very great the King suggested that condemned criminals would be suitable as the first test pilots, but a dashing young Parisian doctor by the name of Jean-François Pilâtre de Rozier, who was also a Professor of Natural Philosophy successfully petitioned the King that he should go by arguing that such an honour of being the first man to "fly" should not be given to a condemned criminal. King Louis agreed, but also recommended that someone of appropriate aristocratic standing should also accompany him into history. An elegant infantry officer, the Marquis d'Arlandes was selected. And so the first "aeronauts" - as the French were now calling them - had been chosen; Jean-François Pilâtre de Rozier, - as he has already piloted a test flight that had been tethered to the ground and so was judged as having "the right stuff" - and the Marquis d'Arlandes …..for being immensely wealthy and having the right connections at court. The Montgolfier bothers however did not mind the Marquis being hoisted onto their historic mission - they simply shrugged their shoulders and agreed - principally because they needed a "counter-weight" to de Rozier on the other side of the balloon!. On the 21st of November, 1783, the first manned Montgolfier balloon sat tethered on its "launch pad" An enormous crowd *gathered to witness the spectacle including the King. The balloon was truly majestic at seventy feet tall and gloriously decorated in royal blues, with golden mythological figures. It truly was a breathtaking sight. The crowd gasped as the tethering ropes were let loose and the Montgolfier - as the balloon was now called - rose swiftly and gracefully into the air, carrying its two "fearless" aeronauts. In short time it had reached an astonishing 900 feet. But as the air cooled and the winds caught the balloon it began to descend again in a staggered series of low swoops across the rooftops of Saint Germain narrowly missing the towers of Saint Sulpice. The crowed oohed and arrhed as the balloon skimmed across the rooftops. Witnesses under its path described how they could hear the exited voices of the two aeronauts shouting back and forth to each other, no doubt enjoying themselves immensely. In fact d'Arlandes, was terrified and screaming at de Rozier to land the Montgolfier, while de Rozier was screaming back to d'Arlandes to stop panicking and keep feeding the brazier fires with straw before they both ditched into the Seine! "Let's work, let's work!" - he kept screaming, "if you keep simply gawking at the Seine we'll both be swimming in it very soon!" Eventually they managed to land onto the Butte aux Cailles near the present Place d'Italie in the 13th arrondissement, just missing two windmills by the narrowest of margins. De Rozier and D'Arlandes were heroes, the first people in history to fly. De Rozier would become a great aeronaut, but once was quite enough for the badly shaken d'Arlandes, he would never fly again. De Rozier and D'Arlandes had proven that balloon flight was possible. Franklin sent breathless word to Banks that the next step would be truly historical. An aerostat had been built that would be powered by inflammable air, he effused. Hot air readily dissipated, it required an enormous amount to lift a payload of two men. Inflammable air on the other hand had been shown to be immensely more powerful in its lift and did not naturally dissipate, so long as it could be contained. An unmanned test balloon filled with inflammable air, which Lavoisier had by now termed "hydrogen", of just six feet in diameter had quickly risen so high it was lost to view. Within a few minutes it had travelled fifteen miles outside of Paris - a distance which a horseman could barely cover in an hour at the gallop. The implications were not lost on Benjamin Franklin.*

Just ten days after the historic Montgolfier flight, on the 1st of December 1783 Dr Alexandre Charles and his assistant M. Robert made the first manned flight in a hydrogen powered balloon. The launch was witnessed by the King and a truly immense crowd of Parisians estimated at over 400,000 people. Dr Charles carried a full payload of sophisticated scientific equipment, that included mercury barometers, thermometers, telescopes, and in the most splendid of French traditions, several bottles of the very finest champagne. The balloon flew above the trees of the Tuileries. The ascent was truly formidable and rose at a terrifying rate of 1000 feet per minute. It reached 10,000 feet in just 10 minutes, all the while Dr Charles calmly taking his observations and recordings, the first in history of the higher atmosphere. He kept taking notes until his hands became so cold he could no longer hold his quill. He would later record, "I was the first man to ever see the sun set twice in the same day. The cold was intense and dry, but supportable. I had acute pain in my right ear and jaw. But I examined all my sensations calmly. I could ***hear myself living****, so to speak!"*

Benjamin Franklin was amoung the witnesses, to Dr Charles', historic flight. The story of the man who visited the clouds electrified not only Paris but the world. The crowd was frantic with awe and delight, and roared their encouragement to Dr Charles. Franklin understood he was witnessing history, and again wrote to Banks. The social commentator *and Gothic novelist, Horace Walpole was anxious about whether aerostats would be turned to sinister use. He wrote, "Well! I hope these new mechanic meteors will prove only playthings for the learned and the idle, and not be converted into new engines of destruction to the human race - as is so often the case of refinements or discoveries in Science. The wicked wit of man always studies to apply the results of talents to enslaving, destroying, or cheating his fellow creatures. Could we reach the moon, we should think of reducing it to a province of some European kingdom". It was a prescient prophecy. Just nine years later the French Revolutionary army employed massed balloons at the battle of Valmy, which they used to direct artillery fire onto the Prussians with devastating effect. The Astronomer William Herschel, discover of the planet Uranus, was perhaps even more prescient still. He speculated that large telescopes could one day be taken up into the upper atmosphere in order to get far clearer views of the cosmos. It was a thought that would eventually come to brilliant fruition in 1997 with the launch of the Hubble Space Telescope. But not all were convinced that flying had a future. The aging Dr Samuel Johnson, by now a fading relic of an earlier age, could not see the point of these so-called "aerostats" or what all the fuss was about. He grumpily wrote to his friend the Artist, Sir Joshua Reynolds, "do not write to me about the balloon….In amusement, mere amusement I am afraid it must end, for I do not find that a balloon's course can be directed, so as that it should serve any purpose of communication; and it can give no new intelligence of the state of the air at different heights, till they have ascended above the height of mountains, which they seem never likely to do".*

Perhaps the last word however should be given to Benjamin Franklin, who by this time had already been pondering the fantastical future possibilities of electricity and magnetism. Amidst all the cheering and waving and crying, he became exasperated by one particular "wet blanket" in the crowd near him, who kept yawning and exclaiming "but what is the point". By way of answer, he produced one of history's greatest retorts; "My dear man", he replied "of what use is a new born babe?".

Those of limited perception and/ or intellect may question the utility of scientific discoveries In truth it may be centuries before the full impact of a novel discovery is realized. Even those of very high intellect may at first struggle to understand the implications of what has been discovered, Joseph Banks FRS, and Dr Samuel Johnson among them! But Benjamin Franklin was a giant of prescience with regard to most of the astonishing discoveries of the Enlightenment. Indeed so were the Montgolfier brothers, in their early experimentation into the feasibility of taking a man into the upper atmosphere. The eminent Intensivist ***Dr Graeme Duke*** *works on a current thesis that their choice of a duck, a sheep and a cockerel, as the first experimental test pilots for human flight, was no mere accident of contingency! Rather it demonstrated an admirable understanding of modern pulmonary physiology! Dr Duke surmises that in fact that the Montgolfiers anticipated, by over one and half centuries the three basic aerostatic patterns of inflating the human lung. They sent up the chicken because they knew it could only breathe (and fly) at low altitude and only then for brief intervals (like a tight lung on a ventilator). They sent up the sheep which they knew could not fly at all (like a stiff lung on a ventilator) to see if it would even survive! They knew the duck would survive because it could breathe (and fly) at altitude for prolonged lengths of time (like a healthy lung on a ventilator). The Montgolfier brothers were more prescient perhaps than even Benjamin Franklin himself!*

VENTILATION - MECHANICAL

Introduction

From the perspective of the mechanical ventilation there are only three "types" of lung:

1. **Normal (or healthy) lungs.**

2. **Airflow Obstructed (or flow limited or tight) lungs**

3. **Restrictive (or stiff) lungs.**

Therefore there are only **3 principle mechanical ventilation strategies** for intubated patients:

1. Ventilation for healthy lungs

2. Ventilation for obstructed lungs

3. Ventilation for restrictive lungs

These strategies aim to deliver sufficient oxygen to prevent hypoxia, while at the same time avoiding the common complications of mechanical ventilation which include:

1. Hypotension

2. Pneumothorax

3. Alveolar damage:

    - Due to collapse

    - Due to over distension

There are only 6 ventilator parameters that need to be manipulated to optimally ventilate the 3 types of lung scenarios listed above, in order minimise, ventilator induced complications.

See also separate document on Ventilator - Airway Pressure (in Critical Care Folder).

The settings for these parameters can be summarized as follows:

Parameter	Healthy Lung	Obstructive Lung Disease	Restrictive Lung disease
Mode	Volume-limited e.g. SIMV or ACV	Volume-limited e.g. SIMV or ACV	Volume-limited e.g. SIMV or ACV
FiO_2	Titrate to SpO_2	↑	↑
Tidal Volume (Vt)	6ml/kg Ideal body weight *See Appendix 1*	↓	↓
Respiratory rate (f)	15/min	↓	↑
PEEP	5-10 cm H_2O	**None**	↑
I:E (Inspiratory to expiratory ratio)	1:2	↓	↑
Summary of changes to standard parameters	Standard	**Decrease all, except FiO_2**	**Increase all, except Vt**

Pathophysiology

Healthy lungs are easily ventilated, however *large tidal* volumes will cause problems by over distending healthy alveoli and low PEEP levels will encourage derecruitment.

Further problems arise when the lungs are **restricted** or **obstructed.**

Restrictive (or stiff) Lungs.

The lungs are difficult to ventilate

It is as though the lung is a small stiff balloon that is hard to stretch and continually wants to collapse.

Even *normal tidal volumes* will over distend healthy alveoli and “normal” PEEP levels will not prevent derecruitment.

The primary problem is one of getting oxygen in (i.e inspiration)

Examples include:

1. Acute:

    - Cardiogenic pulmonary edema
    - Non-cardiogenic pulmonary edema
        - ♥ ARDS (from any cause)
    - Pneumonia
    - Aspiration pneumonitis
    - Chest trauma
    - Morbid obesity/ Gross abdominal distension.

2. Chronic:

    - Pulmonary fibrosis (of any cause).
    - Interstitial lung disease
    - Severe kyphoscoliosis
    - Morbid obesity

Airflow Obstructed (or tight) Lungs:

The lungs are difficult to ventilate

It is as though the patient is trying to breath in and out through a straw!

The primary problem is one of getting gas out (i.e expiration)

Pathologies that lead to tight lungs include:

1. Asthma
2. Severe COPD
3. Other causes of severe bronchospasm:

- Anaphylaxis

Ventilator Parameters

The 6 parameters that are used to ventilate a patient include:

1. Mode:

   There are two main groups:

   - Pressure limited (with variable tidal volume)
   - Volume limited (with variable inspiratory pressure).

   Examples of volume limited modes include:

   - **SIMV** (Synchronized intermittent mandatory ventilation) mode:
     - ♥ This is a variation of IMV, in which the ventilator breaths are synchronized with patient inspiratory effort
   - **CMV** (Controlled mechanical ventilation)
   - **ACV** (Assist - control ventilation):
     - ♥ Patients may receive either controlled or assisted breaths.

2. Fraction of Inspired Oxygen (FiO_2)

3. Tidal Volume (Vt)

4. Respiratory frequency (f)

5. Positive End Expiratory Pressure (PEEP)/ Continuous Positive Airway Pressure (CPAP).

6. The Inspiratory or Expiratory Ration (I:E)

These 6 parameters can be manipulated to optimally ventilate the 3 types of lung scenarios listed above, and so avoid or at least minimise ventilator induced lung injury.

The following describes how these parameters are manipulated for each scenario

Algorithm

Thus a clinical decision algorithm can be thought of as the following:

1. Does this patient have normal lungs and is easy to ventilate?

    - If yes set ventilator as for healthy lungs.

2. If no, does the patient have asthma, COPD, or anaphylaxis?

    - If yes set ventilator as for obstructive lung disease

4. If the patient is difficult to ventilate, but does not have obstructive lung disease, then set ventilator for restrictive lung disease.

Mechanical Ventilation for Healthy Lungs

Introduction:

Examples include patient with depressed conscious state after drug overdose or head injury

Parameters:

Standard adult settings in general are:

1. Mode:

    - Select the ventilator mode that you and staff are most familiar with.

      A **volume-limited** mode, as either **SIMV** or **CMV**, or **ACV** will be sufficient for the majority of patients.

2. FiO_2:

    - Commence all adult patients with an FiO_2 of **1.0.**

    - FiO_2 may then be titrated to a SpO2 90 - 92 %.

    - Some patients however will require ongoing FiO_2 of 1.0 such as CO poisoning or decompression sickness.

      On the other hand other patients will require rapid weaning of FiO_2 e.g. bleomycin or paraquat lung toxicity.

    For chronic or severe lung disease, such as COPD, a SpO_2 of 88 - 90 % (PaO_2 50 - 60 mmHg) will be sufficient.

3. Tidal volume:

    - **6 mls / kg**

      Avoid large tidal volumes (i.e > 8ml / kg) to prevent over distension injury (or volutrauma) of healthy alveoli

      Use ideal body weight, as estimated from height, see Appendix 1 below.

4. Frequency (f):

    - Commence with approximately 15/ minute.

      The above tidal volume and f (i.e. 6 mls /kg x 15) will provide a minute volume of **90 mls/kg/min.**

- Adjust rate according to the $PaCO_2$, (more accurate than the $ETCO_2$).

5. PEEP:

- The purpose of PEEP is to minimize dependent atelectasis (or derecruitment).
- The minimum recommended level is **5-10 cm H_2O.**
- Watch for **hypotension,** and reduce the PEEP if this occurs.

Note that PEEP should **not** be used when ventilating a patient with severe airflow obstruction e.g. asthma or COPD or anaphylaxis with bronchospasm.

6. I:E ratio:

- Usually set at **1:2** (and an inspiratory time of approximately 1 second).

For example; for an average 70 kg (lean body weight) male, 175 cm tall, commence with:

- **15 respiratory rate x 420 mls Vt = 6.3 liter minute volume**
- **FiO_2 = 100 %**
- **PEEP = 5 - 10 cm H_2O**
- **I:E - 1:2**

Additional strategies:

Some patients, may require mild hyperventilation to maintain a therapeutic respiratory alkalosis - such as patients with severe overdose with **sodium channel blocking drugs.**

Mechanical Ventilation for Airflow Obstruction Disease

Introduction:

The primary mechanical problem is an increase in the resistance to gas flow created by narrowing of the small airways.

This means that it is difficult to breath in and out, but the greatest difficulty is actually during exhalation and this results in retention of gas in the alveoli at the end of expiration i.e dynamic hyperinflation, (or gas trapping).

Dynamic hyperinflation causes:

- Volu-trauma (i.e excess volume in alveoli) leading to over-distension, increased work of breathing, pneumothorax
- Barotrauma (i.e. excess pressure in alveoli) leading to over distention and raised intrathoracic pressure producing systemic hypotension from impaired venous return.

Substantial changes to the ventilator settings for "healthy lungs" are required.

The primary goals are:

- Maximize the duration of expiration in order to minimize dynamic hyperinflation
- Provide enough oxygen to prevent hypoxia.
- Monitor but not to treat the hypercapnia or **peak** airway pressure that necessarily occurs with an obstructive ventilation technique.

Prevent excessive plateau pressure (Pplat should be < 30). Pplat is a more accurate measurement of peak **alveolar** pressure.

Parameters:

1. Mode:
   - Select a volume-limited mode, as SIMV or CMV, or ACV.
   - Pressure controlled modes (e.g. Bi-level or APRV) should **not** be used in these patients.
2. FiO_2:
   - Commence with an FiO_2 of 1.0 in all patients.
   - Titrate to $SpO_2 \geq 90 - 92$ %.

3. Tidal volume:

- Do not use more than **6 mls/kg.**

- In severe cases it is necessary to reduce Vt by as much as 50 % to **3 - 4 mls /kg** ideal body weight. This will still provide sufficient oxygen to prevent hypoxia.

4. Frequency (f):

- In severe cases it is necessary to reduce by 50 % to **6-8 per minute**

- Monitor the $PaCO_2$ (and/or $ETCO_2$) but **do not treat hypercapnia (by increasing respiratory rate)**

  This strategy is safe to a pH > 7.1 - (the risk versus benefit at pH values < 7.1 are less clear).

  This technique is known as "**permissive hypercapnia**".

  Note that IV bicarbonate does **not** help. It will only increase the $PaCO_2$ further, lead to hypocalemia and will not improve the circulatory status.

  Increasing the RR to treat hypercapnia may cause pneumothorax or hypotension.

5. PEEP:

- Turn **off** all PEEP**.**

6. I:E ratio:

- Reducing the frequency will reduce the I:E ratio.

- In severe cases reduce inspiratory time $\leq$ 1 second.

- Sometimes an I:E ratio of 1:4 or even less will be required.

Note that most ventilators will register or alarm "low exhaled tidal volume" alarms because they are unable to measure volume when the expiratory flow rate is very low. So check chest rise/fall, capnometry, and SpO_2 to confirm sufficient ventilation is occurring.

Additional strategies:

1. Sufficient sedation is important:

- Long-acting muscle relaxants may be required to prevent any spontaneous breathing, until airflow obstruction is resolving, especially during inter-hospital transfers.

2. Insert naso- (or oro-) gastric tube to decompress the stomach.

3. For hypotension:

   - Disconnect the ventilator for 20-30 seconds to treat dynamic hyperinflation, then reconnect and reduce the respiratory rate (f) by 2 breaths.

   - Check CXR to exclude pneumothorax or right main bronchus intubation.

5. Monitor but do not treat:

   - High $ETCO_2$

   - High $PaCO_2$

   - High PIP:

     ♥ It is safe to increase the PIP alarm (> 40 cm H_20) as long as **Plateau Pressure (Pplat)** remains < 30 cm H_2O.

     If Plateau pressure > 30 mmHg - reduce frequency by 2

6. Avoid:

   - Normal or high frequency respiratory rates.

   - Normal or High Vt

   - High **Plateau pressures**

   - Spontaneous breathing.

Summary:

Ventilation for obstructive lung disease:

- Low Vt

- Low frequency

- Low I:E ratio

- **No** PEEP

- High FiO_2
- Adequate sedation ± muscle relaxants.

Mechanical Ventilation for Restrictive Lung Disease

Introduction:

The primary mechanical problem is an increase in the stiffness of the alveoli, the lung, and/ or the thorax.

This means that it is difficult to get oxygen in but easy to get the gas out.

Mechanical ventilation, even with "healthy lung" settings will cause volu-trauma and barotrauma.

Substantial changes to the ventilator settings for "healthy lungs" are required.

The primary goals are:

1. Oxygenate patient via the small number of healthy alveoli that can still exchange gas.
   - Severe hypoxia (SpO_2 < 88 % or Pa O2 < 50 mmHg) is prevented with high FiO_2 and high I:E ratios
2. Prevent/minimize alveoli from cyclically opening then closing or remaining collapsed, in the **diseased lung** segments by using higher levels of PEEP.
3. Prevent over-distension of **healthy alveoli** in remaining healthy lung segments by reducing the Vt (and so the inflating pressure).

Parameters:

1. Mode:

   Many volume limited and pressure limited options are available, however there is no evidence to indicate that one mode produces better outcomes than any of the others, and so it is best to use the mode with which staff are the most familiar with.

   Options include:

   - Volume limited modes SIMV, CMV, or ACV may be used.
   - Pressure-limited modes (PCV, Bi-Level, APRV)
2. FiO_2:
   - Commence with an FiO_2 of 1.0 in all patients.
   - Then titrate to SpO_2 as required, (see above).

3. Tidal volume:

- Do not use more than 6 mls/kg ideal body weight as a maximum.
- In severe cases reduce to **3 - 4 ml/kg** ideal body weight, especially if:
  - ♥ Peak airway pressure is > 35 - 40 cm H_20
  - ♥ Driving pressure Δ P (i.e. PIP – PEEP) > 20 cm H_2O.

4. Frequency (f):

- Increase the frequency to maintain the desired **alveolar ventilation.**
- Often rates of **18-25 / minute** are used. This will reduce expiratory time, increase the I:E ratio and maintain minute volume.

5. PEEP:

- Increase by 5 cm H_2O increments until $FiO_2 < 0.6$ and SpO2 ≥ 88 %, and the blood pressure is > 100 systolic.
- Often a PEEP level of 10-20 cm H_2O is required.
- The goal is to minimize alveolar collapse ("de-recruitment"), increase lung compliance and improve oxygenation.

6. I:E ratio:

- By increasing the frequency (+/- the inspiratory time) the I:E ratio should increase to > 1:1.
- Consider increasing the inspiratory time, e.g. to 1.2 - 1.8 seconds if hypoxia persists.
- Sometimes an I:E ratio of 2:1 or 3:1 or even higher is required.

Additional strategies:

1. Sufficient sedation is important:

- Long acting muscle relaxants may also be necessary to prevent patient asynchrony with ventilator.

2. Insert naso- (or oro-) gastric tube and decompress the stomach.

3. Treatment of hypotension:

- Hypotension is common due to positive intrathoracic pressure, barotrauma, and the effects of sedative agents, in addition to underlying disease processes (such as sepsis and myocardial depression).

- Do not use more than 20 mls/kg IV fluid loading as this may increase pulmonary edema.

  It is better to use a vasopressor infusion such as **noradrenaline** to support the blood pressure.

- A CXR should be done to exclude a pneumothorax and to check the ETT position, including exclusion of a right main bronchus intubation.

3. Monitor but do not treat:

- High $ETCO_2$

- High $PaCO_2$, and respiratory acidosis.

- A degree of permissive hypercarbia is allowable.

  Bicarbonate infusion will only increase PaCO2 further, lead to hypocalcemia and will not improve the circulatory status.

4. Aim for:

- PIP < 40 cm H_2O

- Driving pressure $\Delta P > 20$ cm H_2O

- SpO_2 of 88-92 %

- $FiO_2 < 0.6$

5. Excessive pressures:

- If PIP > 40 cm H_2O or Driving pressure $\Delta P > 20$ cm H_2O then **decrease Vt**

6. Adjuncts or rescue therapies include:

- Alveolar recruitment manoeuvres:

- Prone position

- Continuous muscle relaxant infusion.

- High-frequency oscillation ventilation

- ECMO

Summary:

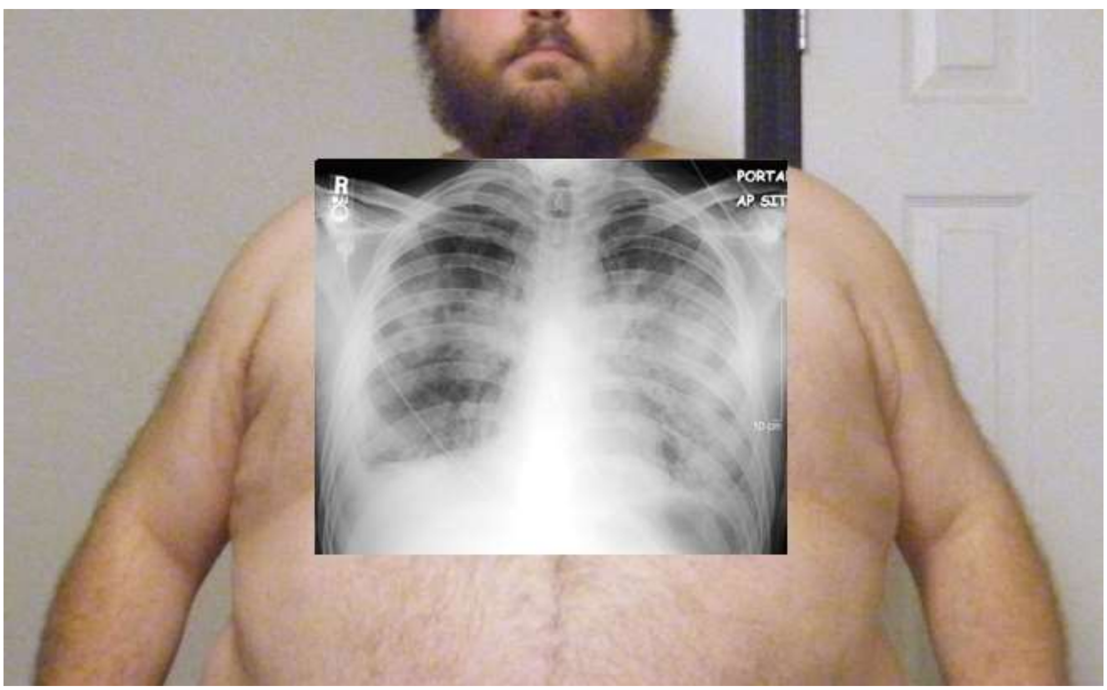
Ventilation for severe restrictive lung disease:

- Low Vt
- High frequency
- High I:E ratio
- High PEEP
- High FiO_2
- Adequate sedation ± muscle relaxants.

Appendix 1 *A summary table of easy-to-remember ideal tidal volumes:*

Height in cm	Ideal Weight in kg	Ideal Vidal Volume in mls
150 cm	50 kg	300 ml
160	60	350
170	65	400
180	75	450
190	85	500
200	95	550

Reduce the Vt by 30 ml for females, (Based on ARDSnet criteria).



CXR superimposed onto large patient - the body habitus is greatly larger than the actual lung capacity! Tidal volume is thus calculated on ideal body weight, not actual (Clinical photograph, courtesy Dr George Douros).

Appendix 2

Airway, Alveolar and Plateau Pressure: [3]

High airway pressures are important because they may:

- Have adverse effects on the patient
- Indicate a deterioration of the patient's condition
- Indicate an equipment problem that needs to be addressed

High airway pressure is not necessarily harmful, unless it reflects high alveolar pressure which can have harmful effects.

It is important to therefore to distinguish between **airway pressure** and **alveolar pressure**

Airway pressure:

Airway pressure = flow x resistance + alveolar pressure

Thus if flow or resistance is markedly altered, a change in airway pressure will not be indicative of a change in the alveolar pressure

- Airway pressure is more conveniently measured than alveolar pressure
- Peak inspiratory pressure (PIP) is displayed on most ventilators
- A maximum acceptable PIP of < 35 cm H_20 is widely used

Alveolar pressure:

- Alveolar pressure is estimated by determining the inspiratory pause pressure, which corresponds to the **plateau pressure (Pplat)**
- The inspiratory pause pressure is determined by observing the **plateau pressure** in an apneic ventilated patient when the "inspiratory pause hold" control is activated
- Because flow is reduced to zero, airway pressure and alveolar pressures will equalize and the airway pressure will correspond to the alveolar pressure at full inspiration

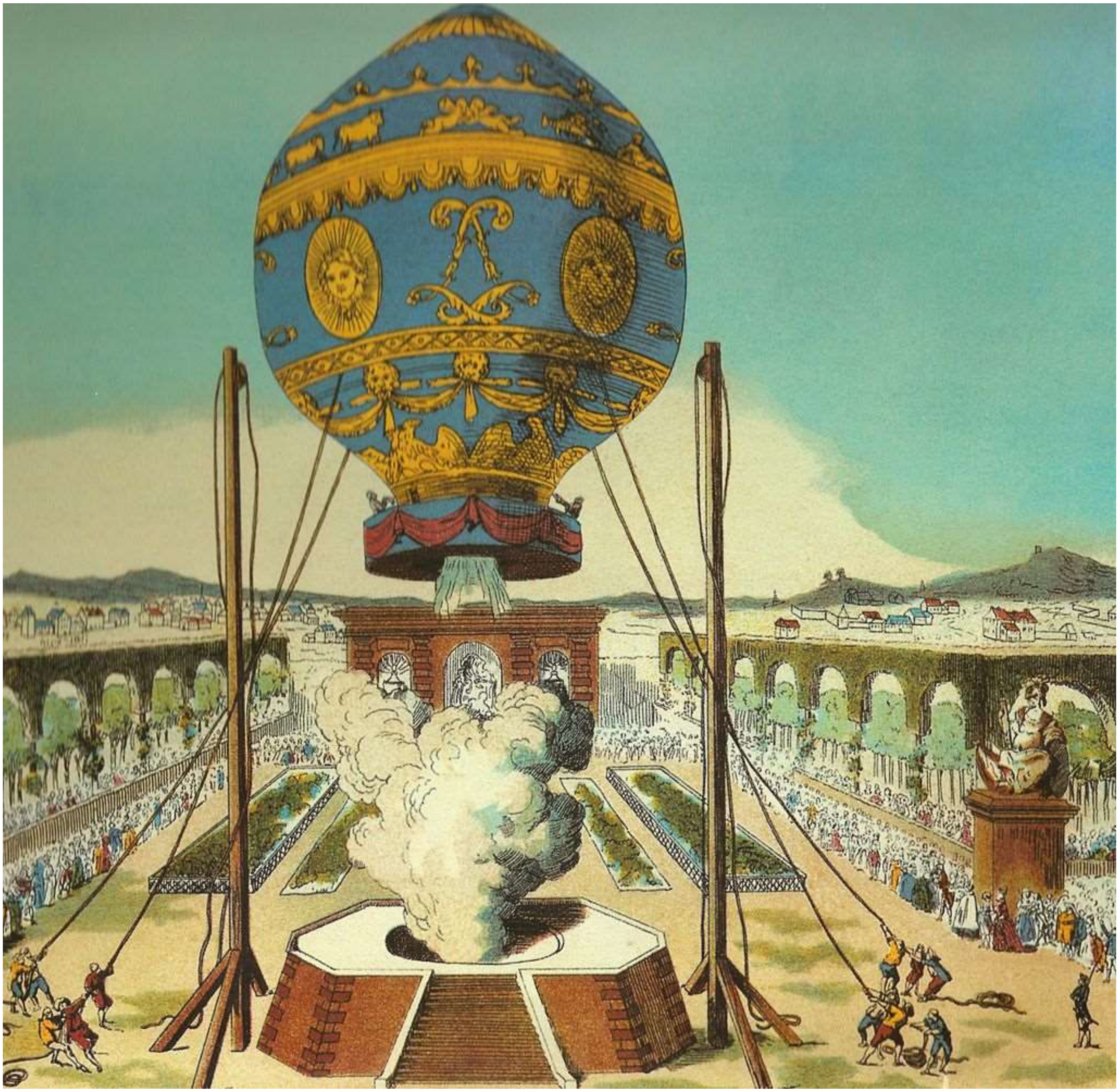
  i.e. Airway pressure = 0 x resistance + alveolar pressure = alveolar pressure

- To prevent lung injury, alveolar pressure (aka the plateau pressure) should be kept < 30 cm H_2O

- High alveolar pressures can be due to excessive tidal volume, gas trapping, PEEP or low compliance as shown by this relationship:

Note also that:

- **Alveolar pressure = (volume/ compliance) + PEEP**



The first manned hot-air balloon, designed by the Montgolfier brothers, takes off from the Bois de Boulogne, Paris, November 21, 1783; 18th Century print.

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