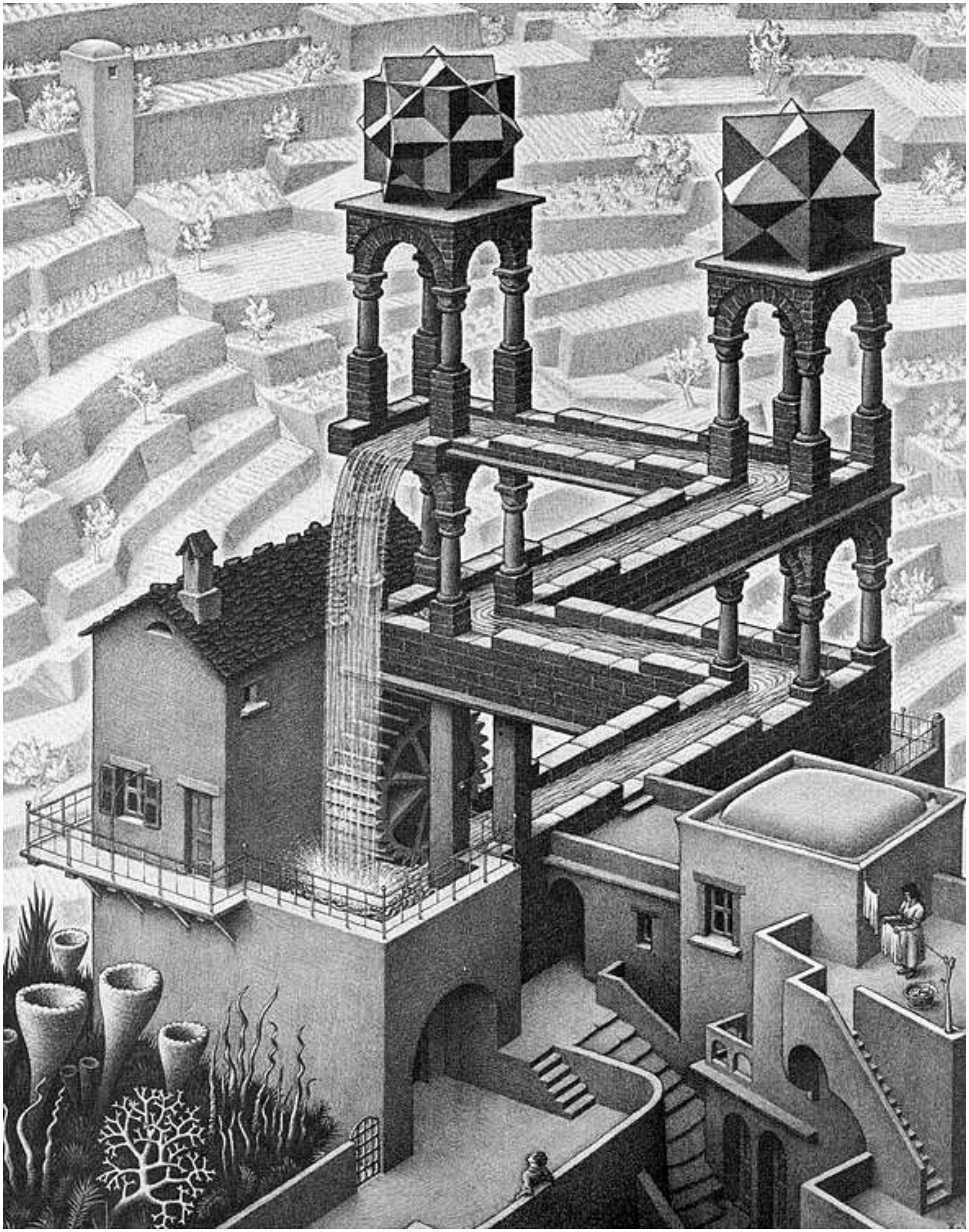
VENTILATION - AIRWAY PRESSURE ASSESSMENT



"Waterfall", Lithograph, October 1961. M. C Escher.

“The water of a fall, which sets in motion a miller’s wheel, zigzags gently down through a gutter between two towers till it reaches the point from which it drops down again. The miller can keep it in perpetual motion by adding a bucket of water now and then to compensate for evaporation.

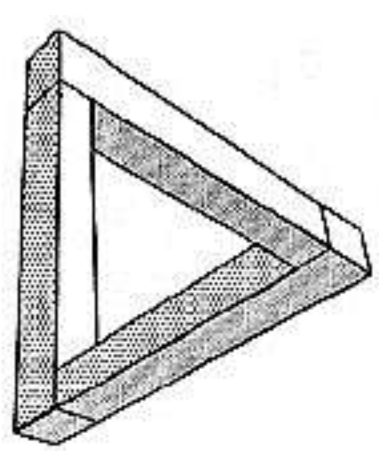
The towers are equally high, yet the left one is a story higher than the other. The polyhedrons on their top have no special significance. I have put them there simply because I like them so much; to the left three intersecting cubes, to the right three octahedrons (original stone image).

The background is a southern Italian terraced landscape, and the lower left corner is filled with greatly enlarged moss plants. The cups are, in reality, only about a tenth of an inch high.

The theme of this self-supporting waterfall is based upon the triangle...of Roger Penrose, a son of the inventor of the “continuous staircase”, in “Ascending and Descending”. It is perhaps worthwhile to quote his article in The British Journal of Psychology, February 1958: “Here is a perspective drawing, each part of which is accepted as representing a three - dimensional, rectangular structure. The lines of the drawing are, however, connected in such a manner as to reproduce an impossibility. As the eye pursues the lines of the figure, sudden changes in the interpretation of distance of the object from the observer are necessary”.

M. C Escher, 1961.

When we find our patients most difficult to ventilate with elevated airway pressures, we must explore with great diligence the entire circuit of oxygen delivery, from ventilator, through to circuit, to the ETT and finally to the patients themselves. At first glance all can appear deceptively normal, but things may not be quite as they seem! As with the circuit of the mysterious Penrose Triangle or an M.C Escher waterfall, we must trace the entire pathway with great care and an acute eye, in order to discover any hidden impossibilities!



Penrose triangle, M.C. Escher, c. 1958

VENTILATION - AIRWAY PRESSURE ASSESSMENT

Introduction

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**

Physiology: 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**
- 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

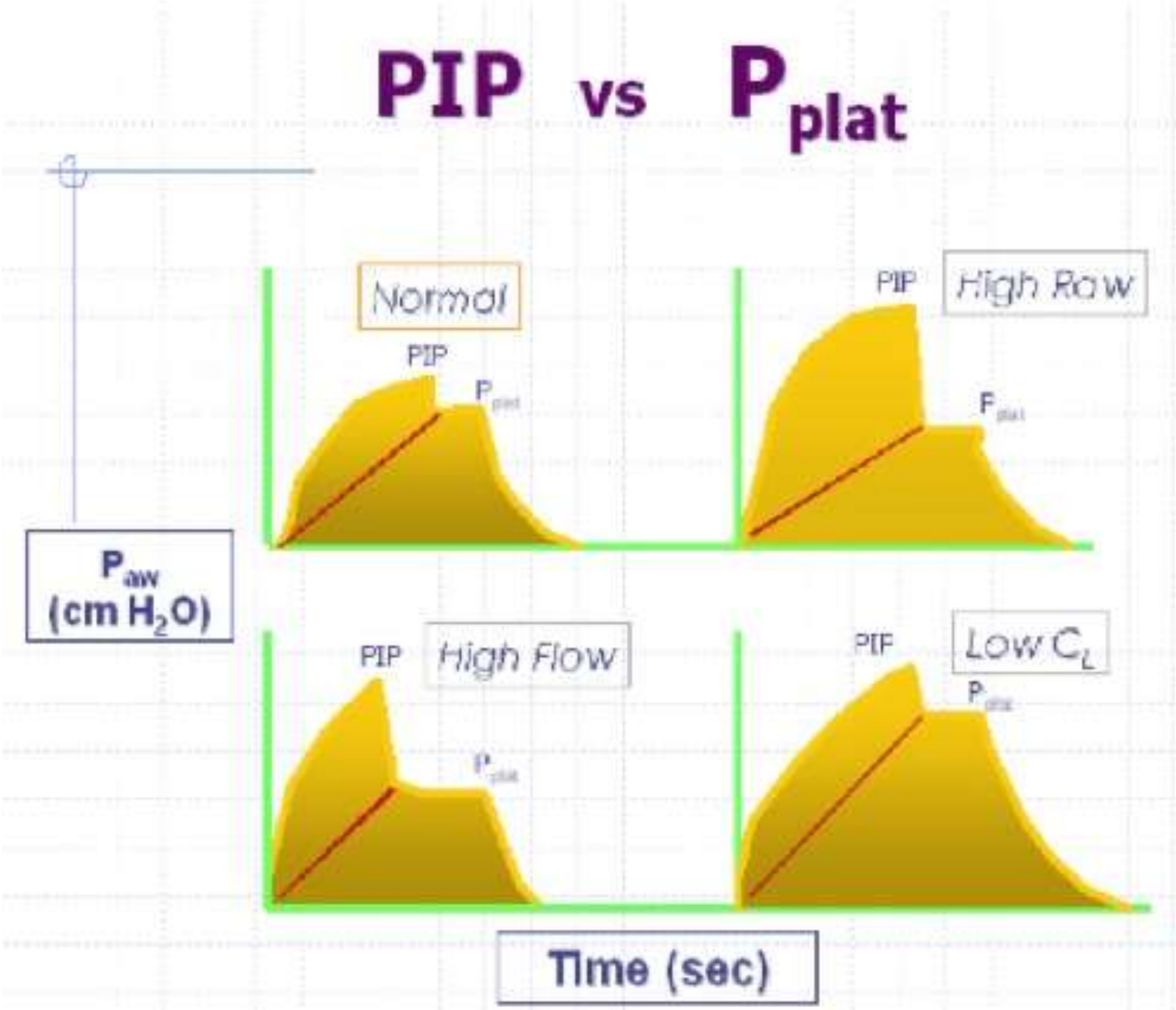
- To prevent lung injury, alveolar pressure (aka the plateau pressure) should be kept < 30 cm H_2O

- 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**

Airway Pressure - Time Curves



Airway pressure versus time graphs

Normal curve – demonstrates normal peak inspiratory pressure (PIP), Plateau Pressure (Pplat), PTA (trans-airway pressure), and Ti (inspiratory time).

The High resistance airway (Raw) curve – shows a significant increase in the PTA that is associated with increased airway resistance.

The High Flow curve – shows that the inspiratory time is shorter than normal, indicating a higher inspiratory gas flow rate.

The Decreased Lung Compliance (C_L) curve – shows an increase in the plateau pressure and a corresponding increase in the PIP that is consistent with decreased lung compliance.

Pathophysiology:

The Effects of High Pressures

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

- Barotrauma:
  - ♥ Alveolar injury may result in ARDS
  - ♥ Air leaks (pneumothorax, pneumomediastinum)
- Excessive intrathoracic pressure:
  - ♥ Decreased venous return, leading to hypotension and potentially cardiac arrest
- Inadequate ventilation.

Ventilator response to high airway pressures:

Inadequate ventilation can occur because many ventilators are set to terminate the inspiratory flow if the upper pressure limit setting is reached.

When this occurs inspiratory volumes are markedly reduced, resulting in low tidal volumes and minute ventilation

Other ventilators do not do this but will simply hold the airway pressure at the pressure limit, resulting in a smaller reduction in tidal volume

Causes of High Airway Pressures:

These include:

1. Ventilator factors:
   - Inappropriate settings
   - Ventilator malfunction
2. Circuit factors:

- Kinking
- Pooling of condensed water vapour
- Wet filters causing increased resistance

3. Endotracheal tube factors:
    - Displacement, e.g. endobronchial intubation
    - Tube kinking
    - Obstruction with foreign material
4. Patient factors:
    - Bronchospasm (e.g. asthma)
    - Decreased compliance:
        - ♥ Lung (e.g. collapse, consolidation, pulmonary edema, ARDS)
        - ♥ Pleural (e.g. pneumothorax, pleural effusion)
        - ♥ Chest wall (e.g. abdominal distention, kyhposcoliosis, obesity)
        - ♥ Patient-ventilator dysynchrony, (e.g. coughing)

Management

Disconnect the patient from the ventilator and manually bag the patient using high-flow oxygen and bag-valve-mask

While the patient is disconnected from the ventilator assess the "feel" of the lungs while bagging:

- If the patient is not difficult to ventilate then the problem is with the ventilator or the circuit
- If the patient is difficult to ventilate it is a problem with the endotracheal tube or the patient's respiratory system

For ventilator and circuit problems:

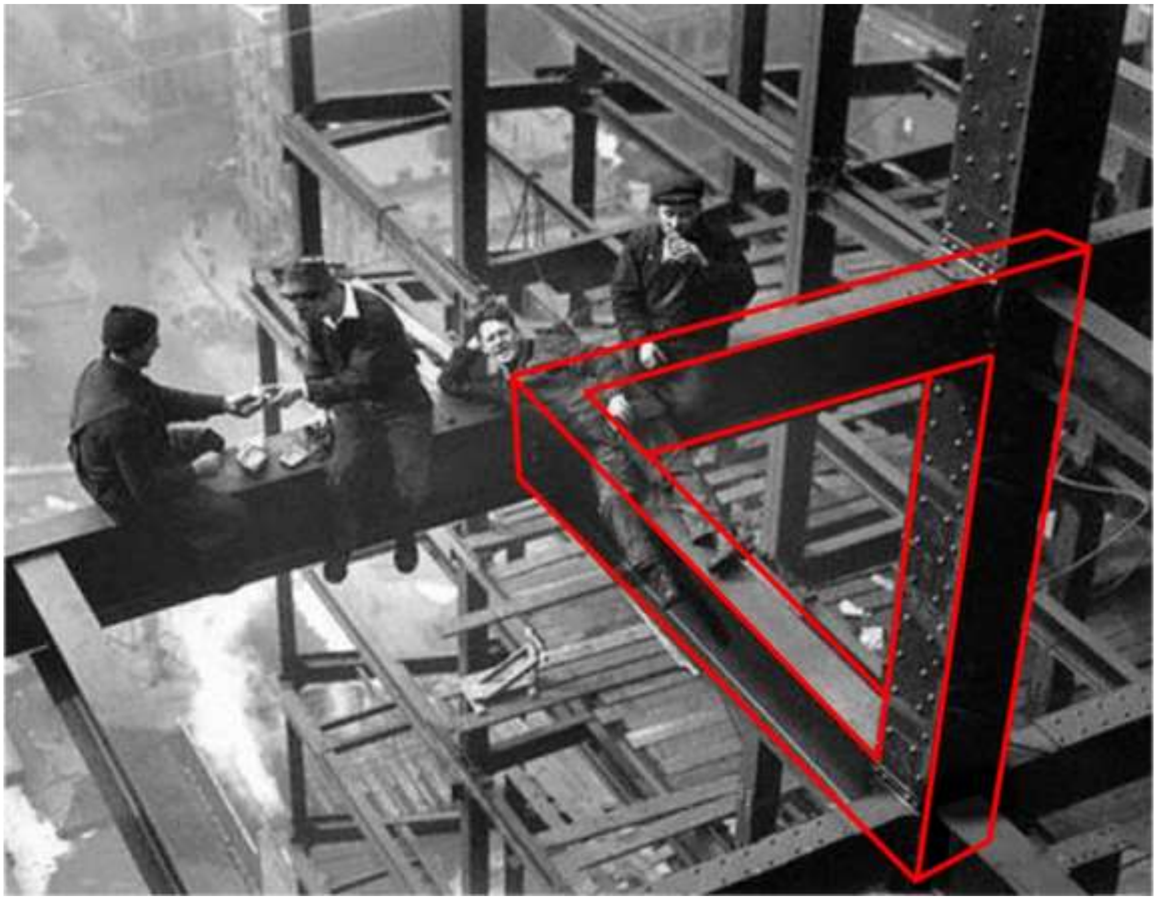
- Check the ventilator settings that it is functioning correctly (e.g. on a test lung)
- Check the circuit for obstruction or kinking

For patient or ETT problems:

- Examine the patient looking for:
    - ♥ Wheeze
    - ♥ Asymmetrical chest expansion
    - ♥ Evidence of collapse
    - ♥ Evidence of dysynchrony
- Pass a suction catheter through the ETT to check its patency
- Use $ETCO_2$ and perform a CXR to check ETT position and look for potential causes of decreased compliance

If the cause is still not clear measure **inspiratory pause pressure** to estimate **alveolar pressure**, in addition to the **peak inspiratory pressure** that reflects airway pressure.

- **If both airway and alveolar pressure are high the problem is due to poor compliance (e.g. pulmonary edema)**
- **If only the airway pressure is high the problem is one of high resistance (e.g. bronchospasm)**



The eye constructs a triangle - but on closer inspection, it is a Penrose triangle - an impossible one.

<u>*References*</u>

1. C. Nickson, High Airway and Alveolar Pressures, in Life in the Fast Lane Website, Accessed August 2015.

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