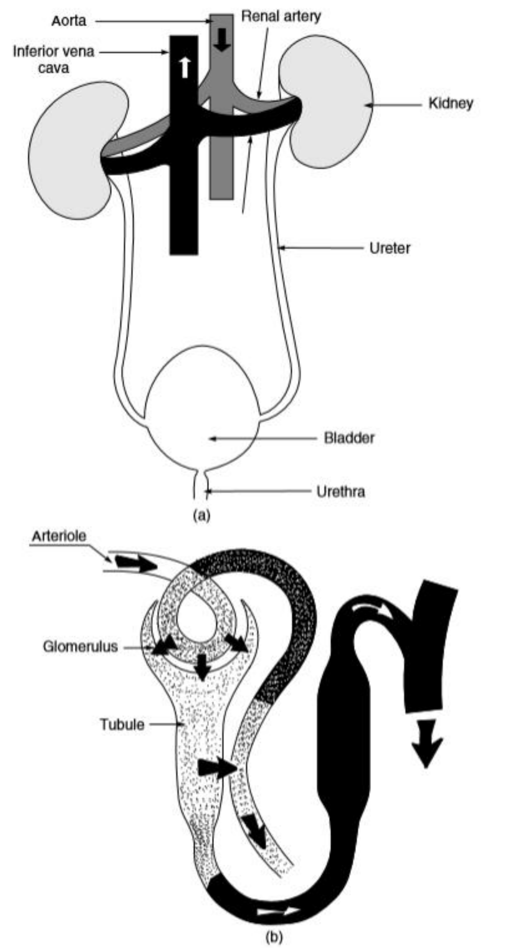
Function of Kidney

Function of kidney

- The human body has two kidneys which lie in the back of the abdominal cavity just below the diaphragm, one on each side of the vertebral column (Fig. 30.1(a)). They are bean shaped and about the size of fist. Each kidney consists of about a million individual units, all similar in structure and function. These tiny units are called *nephrons* whose structure is shown in Fig. 30.1(b).
- A nephron is composed of two parts—a cluster of capillary loops called the glomerulus and a tubule. It is 35-55mm in length. The tubule is closed at one end forms a cup like structure called Bowman's capsule.
- The space inside the Bowman's space includes a cluster of blood capillaries called glomerulus. The tubule runs a tortuous (convoluted path to increase the path length) course and ultimately drains via a collecting duct into the funnel-shaped expansion of the upper end of the ureter, i.e. the tube which conveys urine from the kidney to the bladder.
- All the nephron tubules will get connected to the collecting duct.
- The mechanism by which the kidneys perform their functions depends upon the relationship between the glomerulus and the tubule.

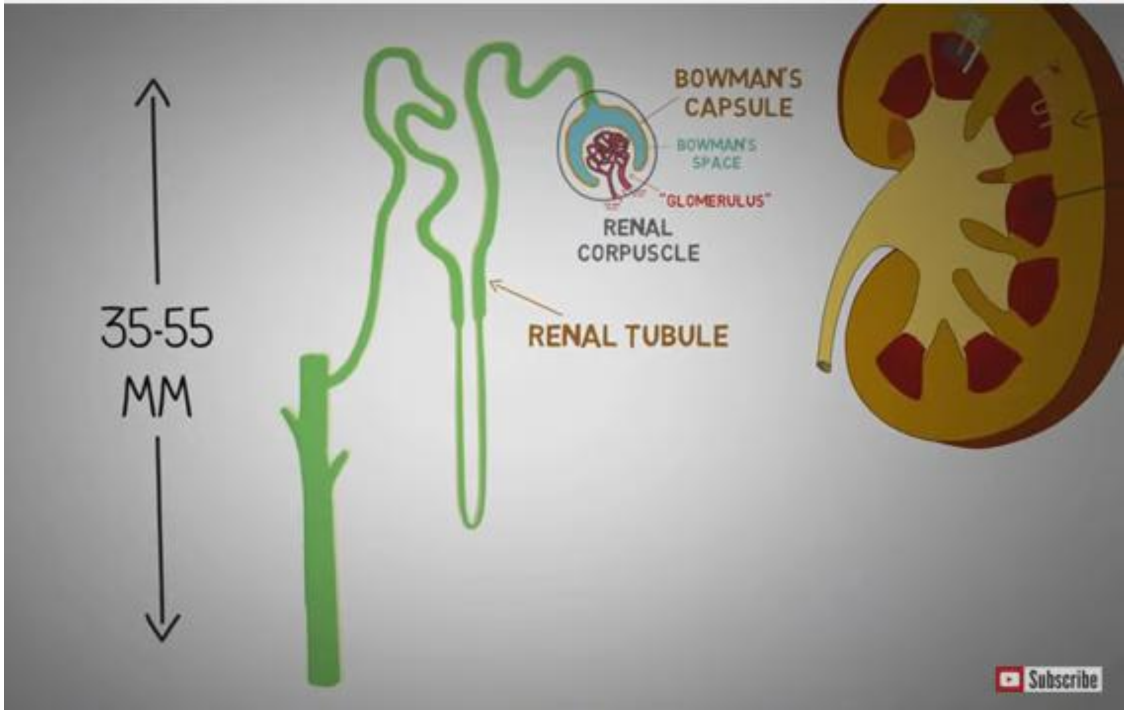
Diagram of Kidney and Nephron



➤ Fig. 30.1(a) *Kidneys and their connection to other organs of the body*
(b) *Structure of nephron*

Function of kidney

The function of the kidney is waste secretion, regulation of blood pressure, maintenance of blood pH & electrolyte concentration in the body fluid. Kidney has two main regions outer cortex and inner medulla. Nephrons a part of it is placed in medulla and a part of it is placed in cortex.



(Fig. internet source)

Structure of Nephron

Function of kidney contd..

- The kidneys work only on plasma. The erythrocytes supply oxygen to the kidneys but serve no other function in urine formation. Each substance in plasma is handled in a characteristic manner by the nephron, involving particular combinations of filtration, re-absorption and secretion.
- The renal artery, part of the aorta carries blood to the kidney and breaks into many arterioles and passes through the glomerulus.
- Glomerulus absorbs the smaller molecules and water from the blood fluid through the thin walls of the capillary and the filtrate absorbed flows from the glomerulus to the tubule. Larger molecules of proteins and blood cells stay in the blood vessels.
- On its flow through the tubule at different points along the convoluted tubule reabsorption of the electrolytes (Na, K, Ca, Cl), Glucose & Amino acids, back by the capillaries and secretion of waste Urea, Uric acid and Creatine takes place. Water is also removed from the tubular fluid
- Tubules are selectively permeable to certain substances, which allows it flow back to the blood capillaries and blocks waste products of metabolism which are excreted as urine

Along the length of the tubule runs the blood capillaries. The renal artery brings the blood to the kidney and the renal vein collects the blood from the kidney. The renal artery divides into smaller capillaries until it reaches the Nephron. The blood enters with high pressure into the glomerulus through afferent artery and the blood pressure inside the glomerulus is around 70-90 mm. The total amount of filtrate within the kidney is around 180 litres per day and the amount of urine is around 1- 1.5 lt. per day. The blood equivalent to the entire body fluid around 15 ltr. Passes through the kidney at a rate of 1.2 ltr./minute. Thus kidney regulates water, electrolytes contents of the body fluid and pH of the blood thus regulates the acid-base balance

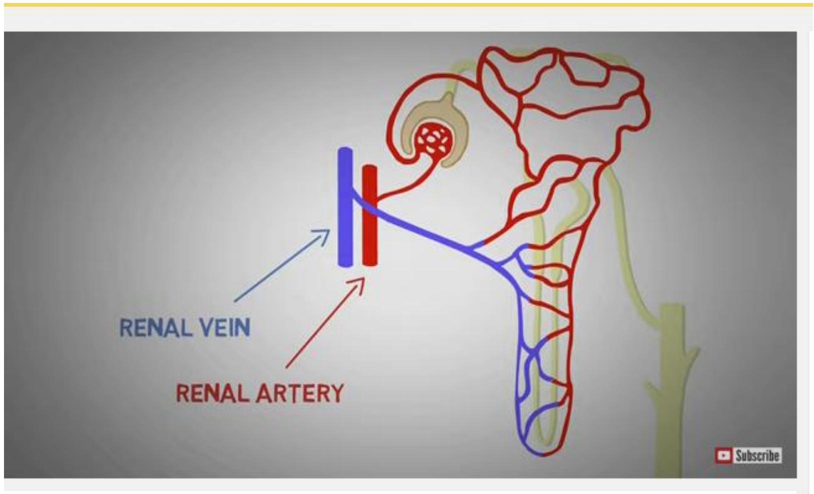


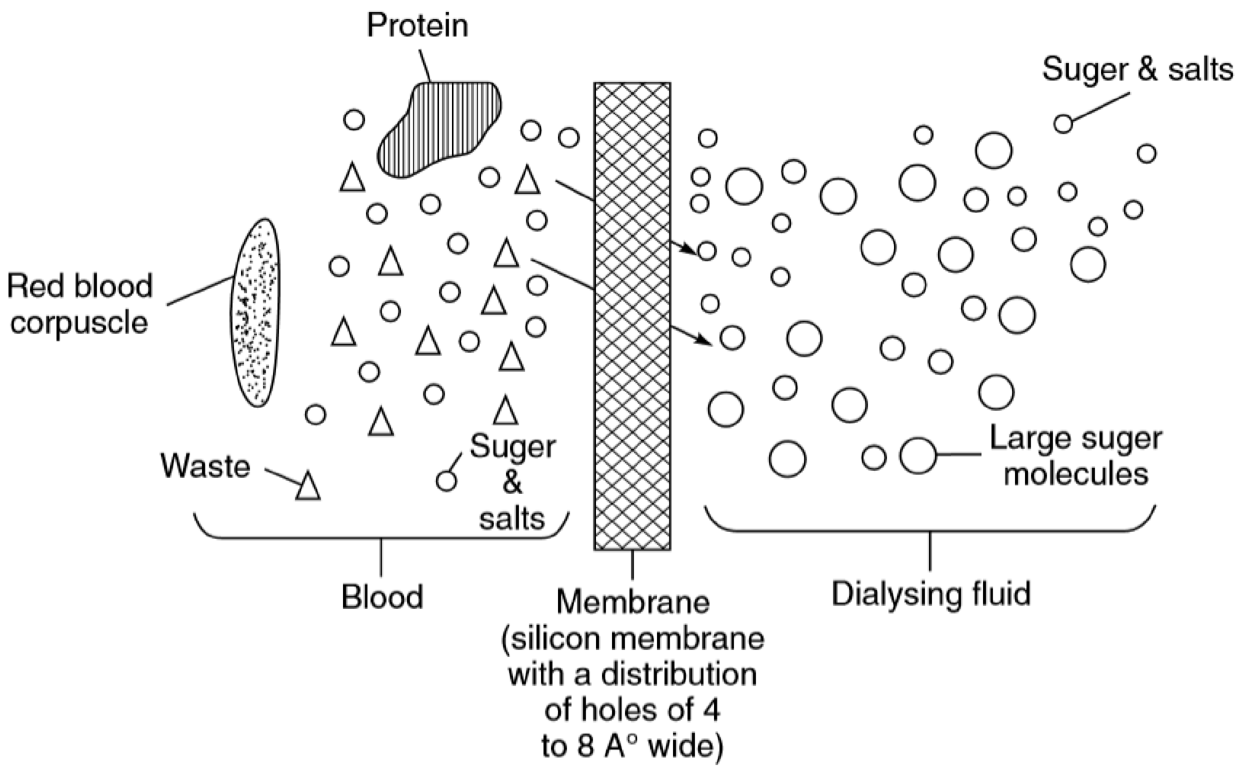
Figure shows the blood capillaries surrounding the tubule where reabsorption takes place. (Internet)

Artificial kidney

Functioning

- Artificial kidney temporarily replaces the function of kidney and thus will reduce the accumulation of waste products and remove toxic substance from the body.
- It receives the patients blood via a cannulated artery through a plastic tube. The dialysate is an electrolyte solution of suitable composition and the dialysis takes place across a membrane of cellophane. The return of the dialyzed blood is by another plastic tube to an appropriate vein.
- The dialyzing membrane has perforations which are extremely small (Fig. 30.2) and are invisible to the naked eye. Waste products in the blood are able to pass through these minute perforations into the dialysate fluid from where they are immediately washed away.
- The perforations in the dialysis membrane have an average diameter of 50 Å with an estimated range of 30 Å to 90 Å . The waste products pass through the membrane because of the existence of a concentration gradient across the membrane.
- The dialysate fluid is free of waste product molecules and, therefore, those in the blood would tend to distribute themselves evenly throughout the blood and the dialysate. This movement of waste product molecules from the blood to the dialysate results in cleaning of the blood.

- The volume of body fluid cannot be controlled by dialysis. Instead, ultra filtration across the membrane is employed. For this, a positive pressure is applied to the blood compartment or a negative pressure established in the dialysate compartment. Either way, fluid—both water and electrolytes—will move from the blood compartment to the dialysate, which is subsequently discarded.
- The degree of ultra-filtration depends both on the pressure difference across the membrane and the ultra-filtration characteristics of the membrane.
- The artificial kidney is thus simply a membrane separation device that serves as a mass exchanger during clinical use. It is unable to perform any of the synthetic or metabolic functions of the normal kidney and, therefore, cannot correct abnormalities that result from the loss of these functions. The only use of the artificial kidney in replacing renal function, therefore, is the transfer of poisonous substances from the blood to the dialysate, so that they might be eliminated from the body



➤ **Fig. 30.2** *Principle of dialysis in the artificial kidney*

Dialyser

- The dialyzer is the part in the artificial kidney system in which the treatment actually takes place and where the blood is freed from the waste products.
- It is the meeting point of two circuits, one in which the blood circulates and the other in which dialysis fluid flows.
- Dialyzers, in routine clinical use, may be classified according to three basic design considerations: coil, parallel plate and hollow fibre type. Each type of dialyzer has certain optimum operating requirements.
- The rate of clearance of substances such as urea, creatinine, etc. from the blood during passage through an artificial kidney is dependent upon the rate of the blood flow. As the flow rate falls, there is a disproportionate fall in clearance. At high flow rates, there is little advantage in further augmentation of the blood flow. The rate and pattern of the dialysate flow also influence overall performance in respect of clearance of waste products. Almost all commercial dialyzers use cellulosic type membranes, the most common being Cuprophan, a regenerated Cellulose, extremely thin, with high tenacity and puncture proof.

- The removal of waste products during dialysis is proportional to the concentration gradient across the membrane. In order to effect the maximum gradient, the concentration of waste products in the dialysate should be maintained at zero. This is achieved in most currently employed machines by using the dialysate only once and then discarding it. In addition, counter-current flow through the artificial kidney is used so that the dialysate enters the kidney at the blood exit-end where blood concentration of waste products is at the lowest level.
- It is desirable for the resistance to blood flow in the dialyzer to be as low as possible, eliminating the need to employ a blood pump. In addition, the design of the blood compartment should be such that all the blood can be easily and completely returned to the patient at the end of dialysis.
- The design must effect an optimum, thin film of blood going through the dialyzer without streaming under perfused areas of membrane surface. Similarly, there must be optimum mixing in the dialysate compartment, effected via the membrane support structure.

Different types of Dialysers

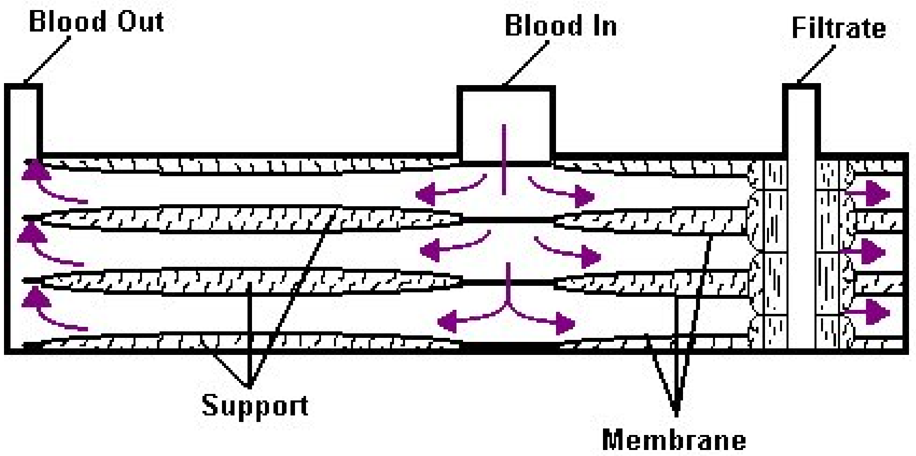
The first artificial kidney was built by a Dutch doctor Willem Kolff during world war II in 1943

- A typical dialyser consists of these parts i. Blood Compartment ii. Dialysate Compartment iii. Semi permeable membrane. The membrane separates blood and dialysate . iv. Dialysate holding structure/frame
- Parallel Plate Dialyser
- Coil Kidneys: Hollow Fibre Dialyser:

Parallel Plate Dialyser

- Parallel Plate Dialyser: This has parallel plates with ridges and grooves in them. The dialysate flows between the grooves or the ridges and a semi permeable membrane sits between the blood flow and grooves. The amount of blood in the dialyser is relatively small and hence at a given point of time the amount of blood outside the body is minimal. The surface area is of contact is large in parallel plate around 1 sq.mtr. and hence the resistance to flow is small, no blood pumps are needed. The arterial blood pressure will be sufficient. The **Kiil dialyzer** developed in Norway by Fred Kiil, has earlier been the most commonly used form of parallel flow dialyzer. It consists of three polypropylene boards with dialyzing membranes laid between them.
- The boards are held firmly with a frame on the top and bottom and are fastened by a series of bolts on the side. A rubber gasket runs along the periphery of the boards inner surface to prevent blood and dialysate leakage. The dialysate enters through a stainless steel port and flows along the grooves running across the board. The blood will flow through the membrane envelop, the membrane separates the dialysate flow and blood flow. Parallel plates can be visualised as flattened tubes inside the flattened space of the tube the blood flows and the entire membrane assembly on either side the dialysate will flow.

The Kiil dialyzer is not disposable. It needs to be cleaned and re-built after each dialysis operation. With this type of dialyzer, a single-pass body temperature dialysate passes through the dialyzer once before going to the drain to obtain higher operational efficiency and to minimise bacterial infection. Several modifications have been introduced in the basic Kiil system. The parallel grooves have been replaced by pyramidal grooves which allow multiple point support for the membranes. This arrangement provides greater clearance of urea and creatinine under the same flow conditions because of increased surface area.



Typical Parallel Plate Dialyser

Coil Haemodialyser

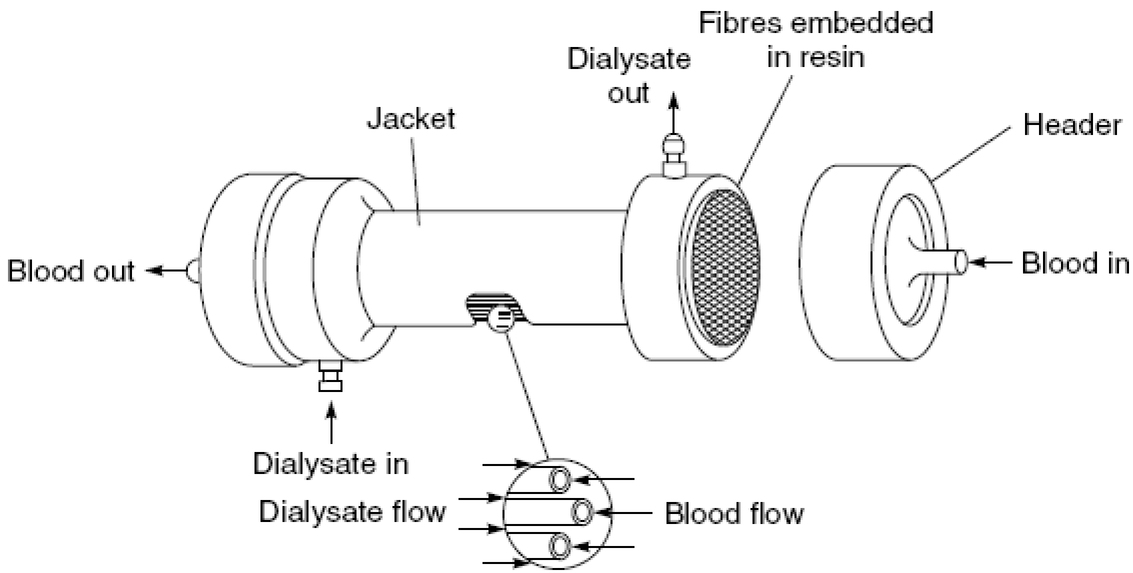
This was the first commercial type kidney, it had a cellulose coil wired around a drum, this had **unpredictable filtration** rate

A coil hemodialyzer comprises a tubular membrane placed between flexible support wrapped around a rigid cylindrical core. The coil is immersed in a dialyzing bath. The tubular membrane can be of cellophane or cuprophane. The average wall thickness of cellophane membrane is 20–30 mm and that of cuprophane in the range of 18–75 mm. Coil dialyzers are available with several design variations, which include the type of membrane, the membrane support, the number of blood channels (1, 2 or 4), the width of the blood channels (38–100 mm) and surface area (0.7–1.9 m2). Coil dialyzers can be pre-fabricated because of their simple design. They are characterized by high dialysate flow rates and high resistance to blood.

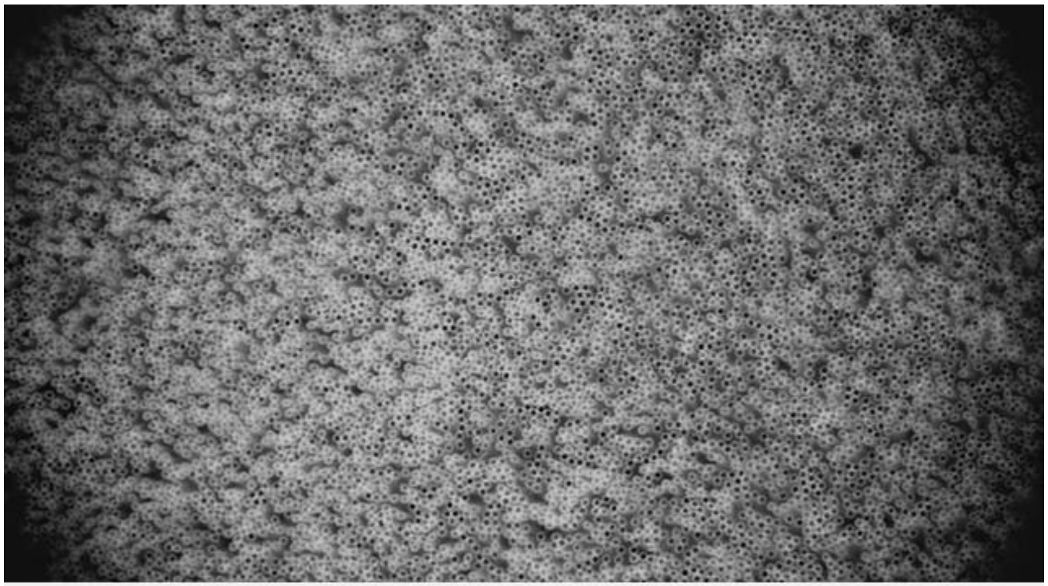
Hollow Fibre Artificial kidney

This is the most commonly used modern haemodialyser . This makes use of counter current flow. Counter current flow is where the blood and the dialysate flows in the opposite direction. This is done to maximize the diffusive solute clearance as this maintains a constant pressure gradient along the length of the circuit. And the efficiency of counter current flow is almost 20% higher compared to the concurrent flow. This is gentle and hence used on the first time patient and pediatric patients. This has thousands of hollow tiny fibers held inside a cylindrical structure and blood flows in and out of the dialyser through manifold headers (multiple inlet and outlet).

The fibres are jacketed in Plastic cylinder of 18 cm. In length and 7 cm. in diameter and the capillaries will have 200mm-300mm Internal diameter and a wall thickness of 25-30µm



➤ **Fig. 30.4** *Constructional details of hollow-fibre dialyser*



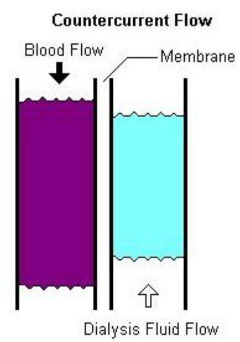
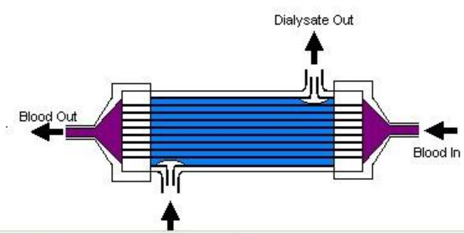
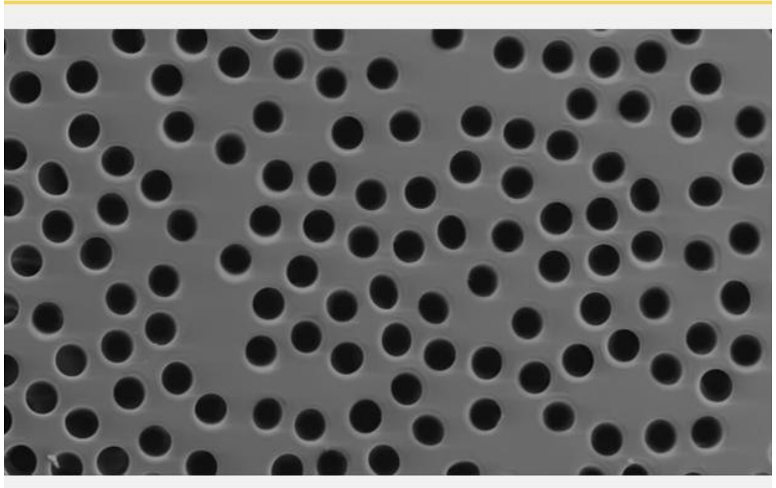


Fig 2

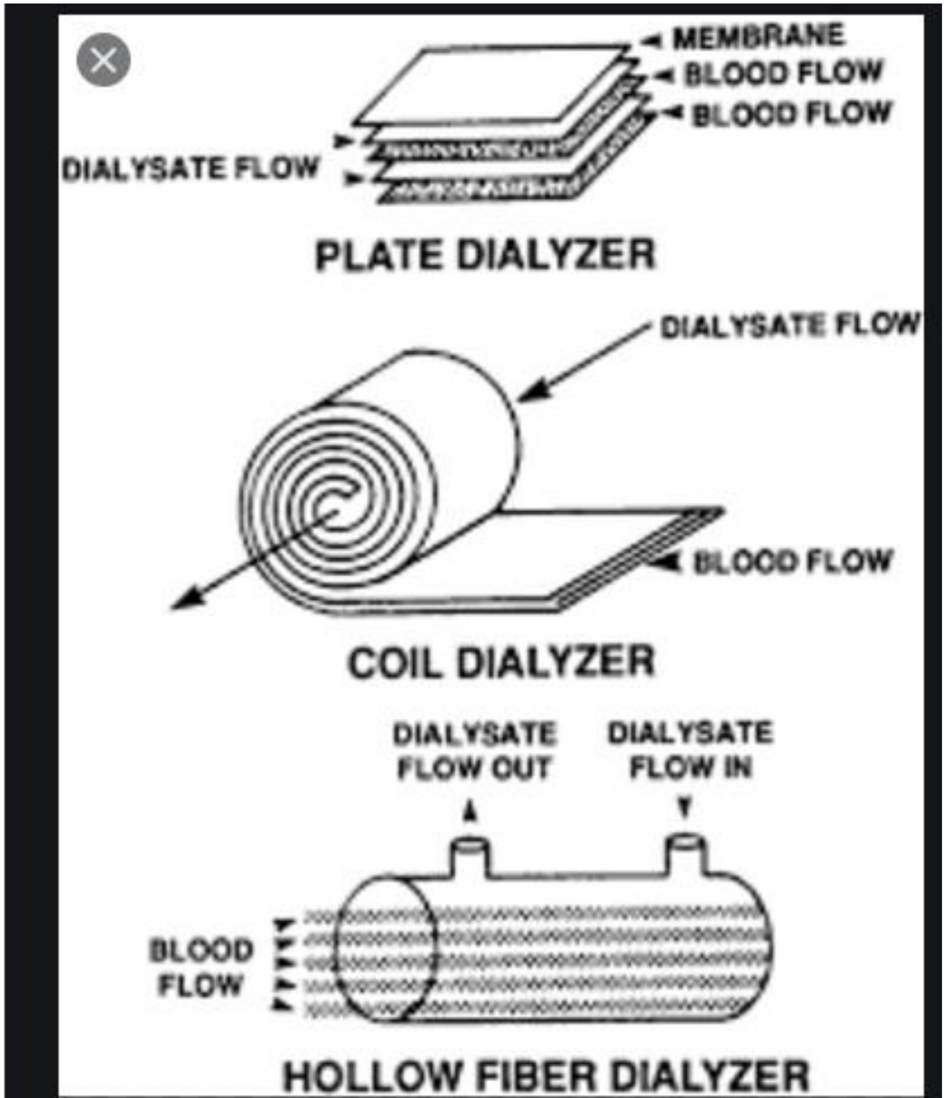
Hollow-Fiber Artificial Kidney



Filtering area of 4 sq.mtr



Fresenius Medical Care - St. Wendel Plant (Update December 2014)


MEMBRANE
BLOOD FLOW
BLOOD FLOW
DIALYSATE FLOW
PLATE DIALYZER
DIALYSATE FLOW
BLOOD FLOW
COIL DIALYZER
DIALYSATE FLOW OUT
DIALYSATE FLOW IN
BLOOD FLOW
HOLLOW FIBER DIALYZER

- https://www.youtube.com/watch?v=3v5dDL6nQpc

Membranes for Haemodialysis

- The efficiency of dialysis is determined by the permeability characteristics of the semi-permeable membrane. The ideal membrane should possess high permeability to water, organic metabolites and ions, and the capability of retaining plasma proteins.
- The membrane should be of sufficient wet strength to resist tearing or bursting and non-toxic to blood and all body cells. Since a fresh membrane is required for each dialysis process.
- It should be inexpensive to produce.
- Virtually all artificial kidneys presently in use, employ cellulosic membranes. Such membranes operate as sieve-type membranes allowing the passage of solutes through micro-holes. Therefore, selective sieving of the blood is based upon the size, shape and density of the solute
- Cupraphan (trademark of Enka Glanzstoff, Germany) is the commonly used membrane for haemodialysis. It is a membrane consisting of natural cellulose and is considered puncture-proof, and of high tenacity and elasticity.
- During haemodialysis, different substances of varying molecular weight are to be removed. The specific membrane permeability values and their dependency on substances with increasing molecular weight are shown in Fig. 30.6.

Cupraphan is a moisture-sensitive cellulose hydrate membrane whose reaction during processing and whose functional value depends upon the water content. If it varies from the fixed standard values, consequently, it exhibits dimensional instability pertaining to a change in dimension and swelling as well as in the handling property during assembly of the dialyzer. Wetting with water results in a three-dimensional change in the length of the cupraphan membranes. The increase in thickness for all types amounts to a factor of 1.9 during the transition from the normally conditioned to the wet state.

Glycerine is added to the membrane as a humectant and plasticizer for smooth processing. The water content of the membrane balances with the humidity level of the surroundings. It should be noted that during all phases of processing, room conditions should be around 35% relative humidity at 23°C which correspond with the equilibrium humidity of the membranes.

For applications in hollow fibre dialyzers, cupraphan fibres are used. With their small internal diameter, it is possible to design dialyzers with a low priming volume, making it possible to combine a large surface area with a low priming volume.

The number of fibres in a dialyzer can be as high as 16,000 giving a density of fibres as 1000 per cm

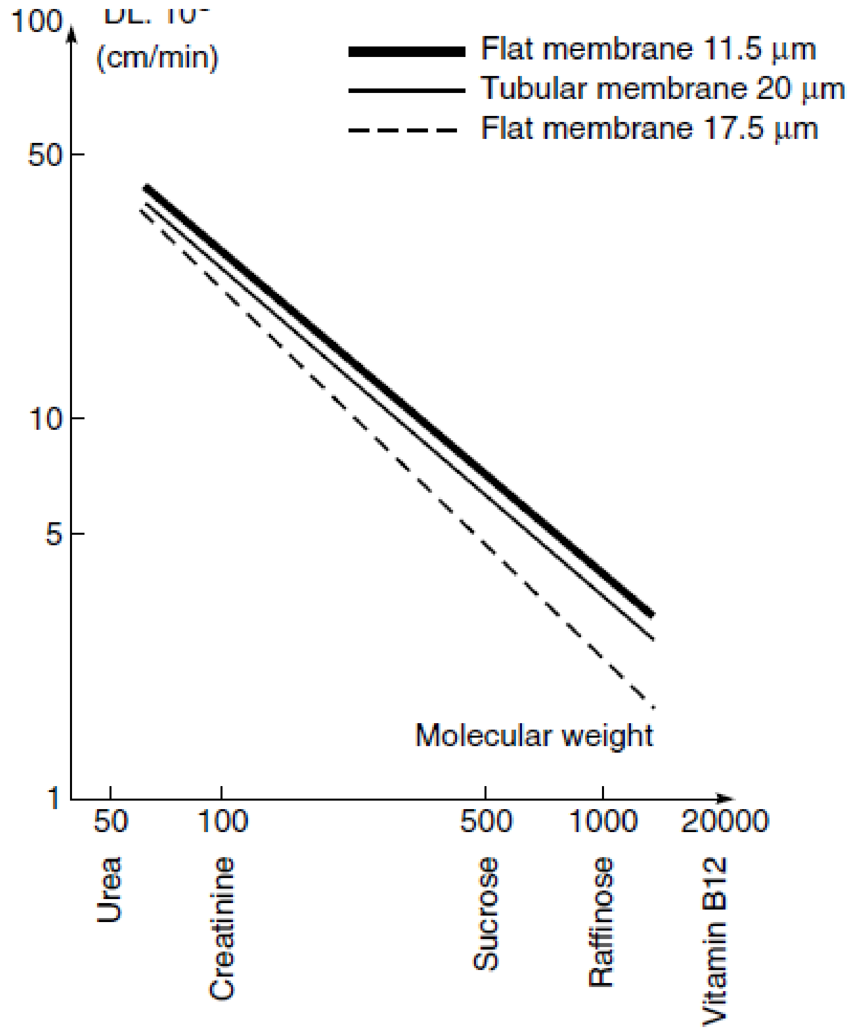


Fig. 30.6 *Relationship between permeability (DL) and molecular weight for different thicknesses of the membrane*

Haemodialyser Machine

A haemodialysis machine is used for the production of warm dialysate which is then circulated through an external dialyzer assembly. It also controls the cycling of the blood from the patient through the artificial kidney (dialyzer) and back to the patient. It continuously monitors and controls all important parameters, automatically halting treatment in the event of parameters going out of pre-set limits.

The haemodialysis machine performs five basic functions.:

(i) mixes the dialysate, (ii) monitors the dialysate, (iii) pumps the blood and controls administration of anti-coagulants, (iv) monitors the blood for the presence of air and drip chamber pressure, and

(v) monitors the ultra-filtration rate.

The machines are designed to be totally adjustable to meet individual therapy requirements.

The machine pumps and controls the flow of blood from the patient through the dialyzer at a predetermined rate and pressure to ensure effective clearances and fluid removal in a specified time period. Some machines also provide an ultra-filtration rate meter that measures the ultra-filtration rate in kilograms per hour. This allows the operator to efficiently and accurately calculate, predict and control fluid removal during dialyses.

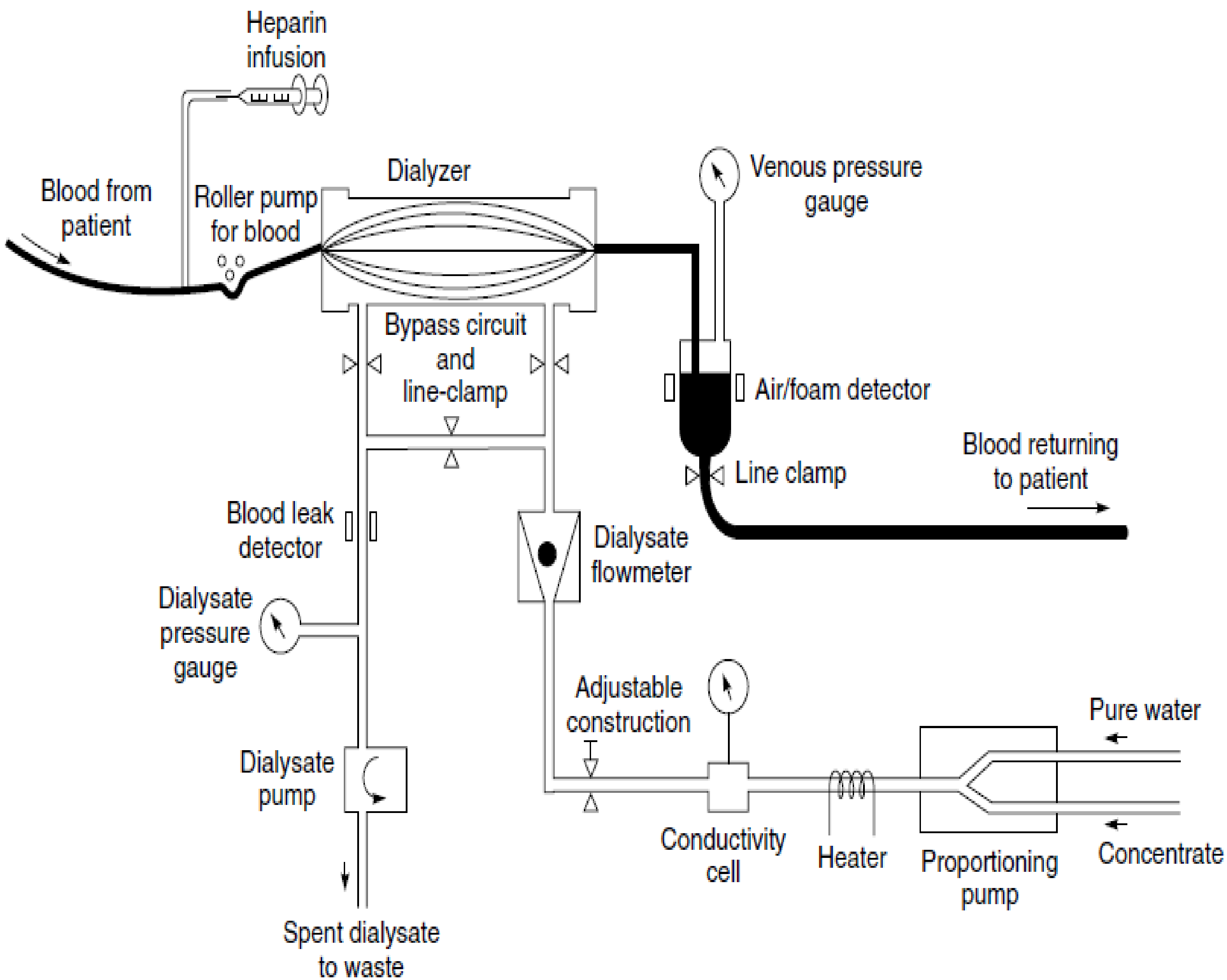


Fig. 30.7 *Schematic diagram of haemodialysis machine. Blood flow path is shown in solid black line and the dialysate circuit as open lines*

Proportioning Pumps: ***Preparing dialysate is a time consuming process,*** When re-circulated, glucose-containing dialysate results in the rapid growth of bacteria unless changed at frequent intervals. Single-pass proportioning systems using liquid concentrate avoid bacterial overgrowth. Proportioning systems of earlier designs used motor driven positive displacement pumps. A fixed ratio (35:1) of water and concentrate is pumped into a mixing chamber.
A steady flow of dialysate is achieved through controlled pumping.

Dialysate Temperature Control and Measurement: The dialysis is normally done at the body temperature. The temperature of the dialysate is, therefore, monitored and controlled before it is supplied to the dialyzer. In case the dialysate gets over-heated, the system should stop the flow to the dialyzer and pass it to the bypass. Dialysis at temperatures lower than the body temperature is less efficient and requires re-warming of the blood before its return to the patient’s body. Temperatures in excess of 40°C tend to damage components of the blood. A temperature control system is used to raise the temperature of the dialysate to the required temperature which can be varied from 36 to 42°C. A secondary safety cut-out ensures that the heaters are switched off if the temperature exceeds 43 °C.

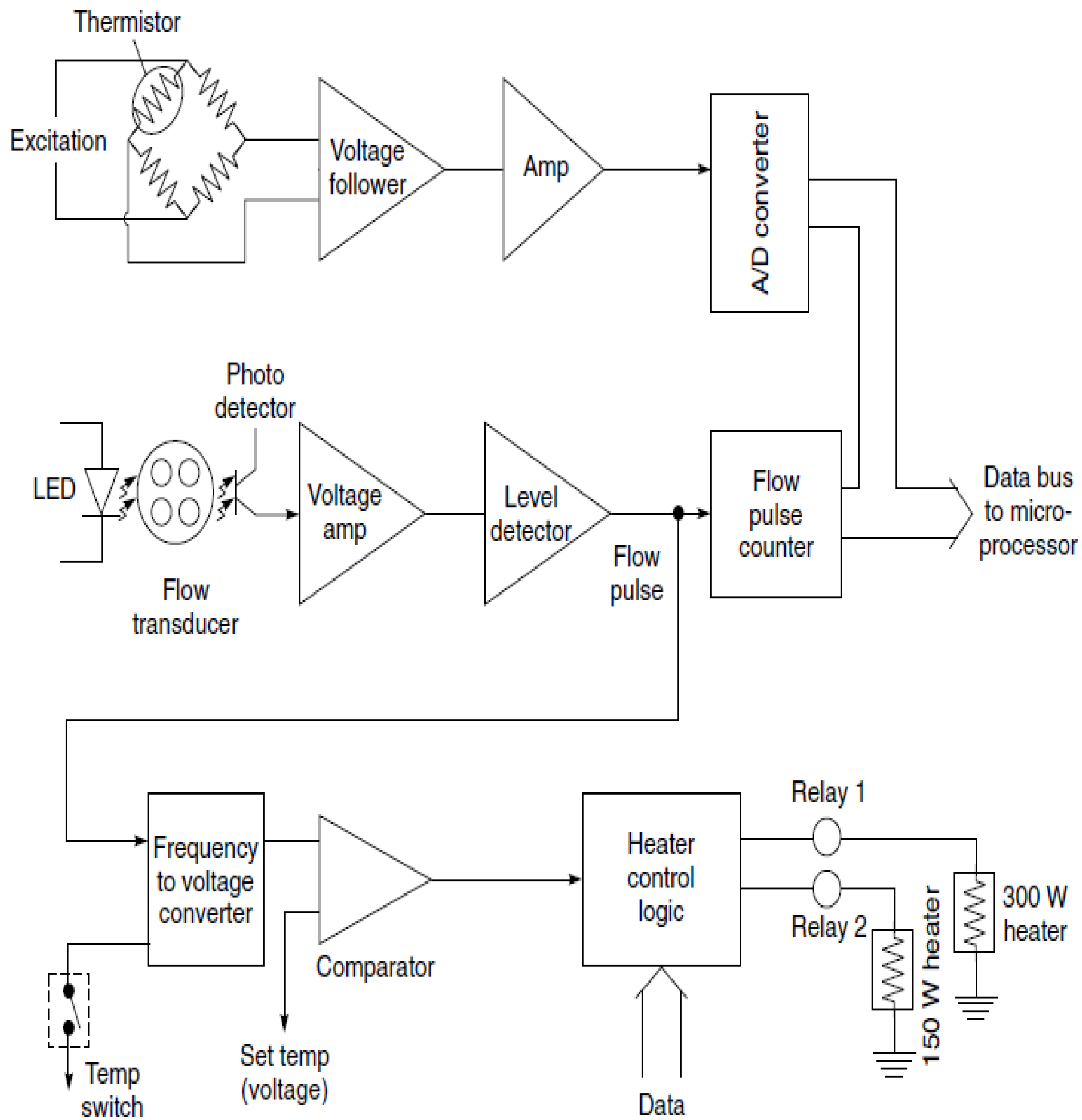


Fig. 30.9 *Temperature monitor and control circuit using multiple heaters*

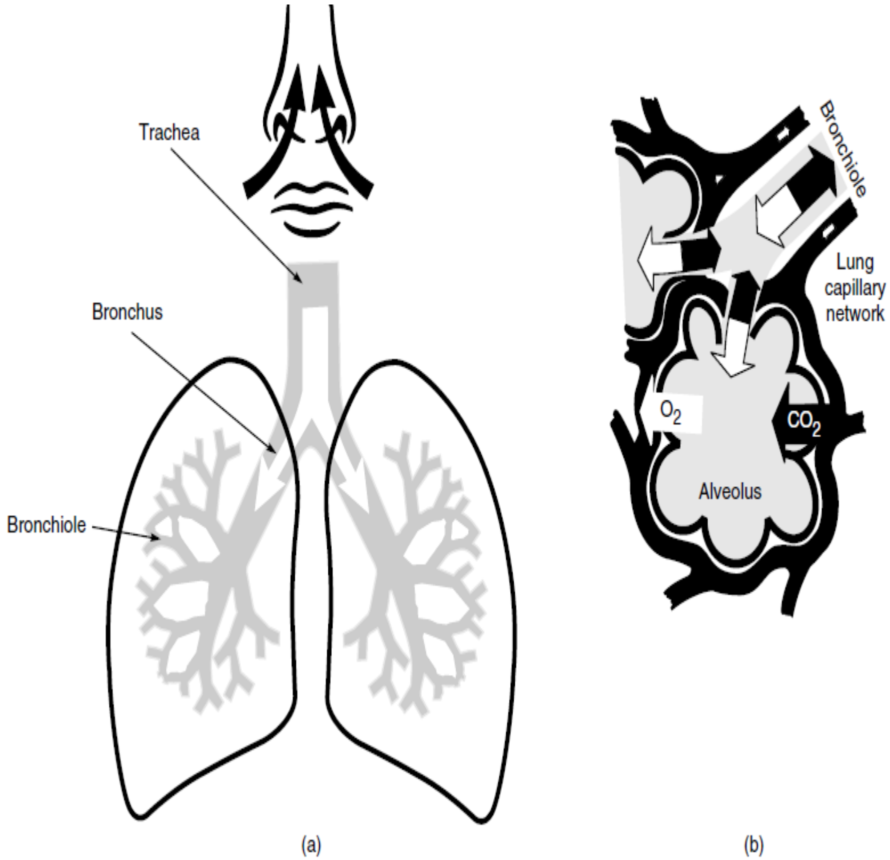
Temperature & Flow Control

- Rotating optical disk generates pulses based on the flow rate. The flow rate measurement is given as feedback to the CPU to control the dialysate flow rate.
- The temperature sensor is normally open if the temperature is within 42 degree celesius and it closes and cuts off the heater if the temperature exceeds. Similarly the flow rate also cutsoff the heater if it falls below a threshold

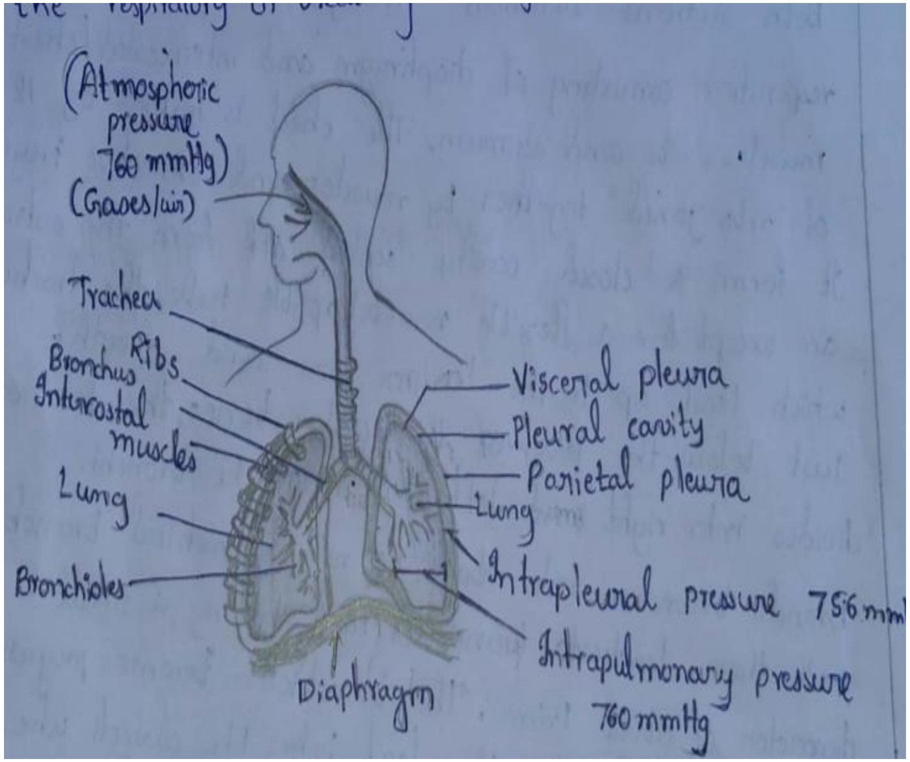
Ventillators

Respiratory Mechanism

Respiratory Organs



➤ **Fig.** 33.1(a) *Organs of respiration* (b) *Diagram of alveolar gas exchange*



Artificial Ventilation

When natural ventilation fails artificial ventilation is given. Artificial ventilation is given under :

Drowning, obstruction trachea, obstructive pulmonary diseases –asthma, chronic bronchitis, pneumonia- ARDS Acute Respiratory Distress Syndrome under these circumstances we need to go for artificial ventilation. Ventilators provide enough O_2 and CO_2 to maintain the PaO_2 & $PaCO_2$ to typical values around 60 & 20 mm Hg. Insufficient oxygen might destroy the vital organs and the condition is called hypoxemic where $PaO_2 < 60$mm Hg, insufficient oxygenation and the other condition is hypercapnic when $PaCO_2 > 45$ and it is because of the failure to ventilate

Artificial Ventilation

Mechanical aids for manual artificial ventilation consist of a mask, breathing valve and self filling bag (Fig. 33.2). The mask, which is of soft rubber or plastic, is held firmly over the patient's mouth and nose so that it fits tightly. The breathing valve serves to guide the air so that fresh air or air enriched with oxygen is supplied to the patient and expired air is conducted away. The bag is squeezed with one hand applying pressure and functions as a pump. When it is squeezed the filled air + oxygen forces its way into the low pressure pulmonary cavity, resulting in inspiration. The position of the valve during inspiration is such as to provide an air passage into the patient. During expiration the gas passes out and the breathing valve position is to let the CO2 out into the atmosphere. Once the air bag is released it expands and fills automatically with fresh air or oxygen when the patient breathes out.

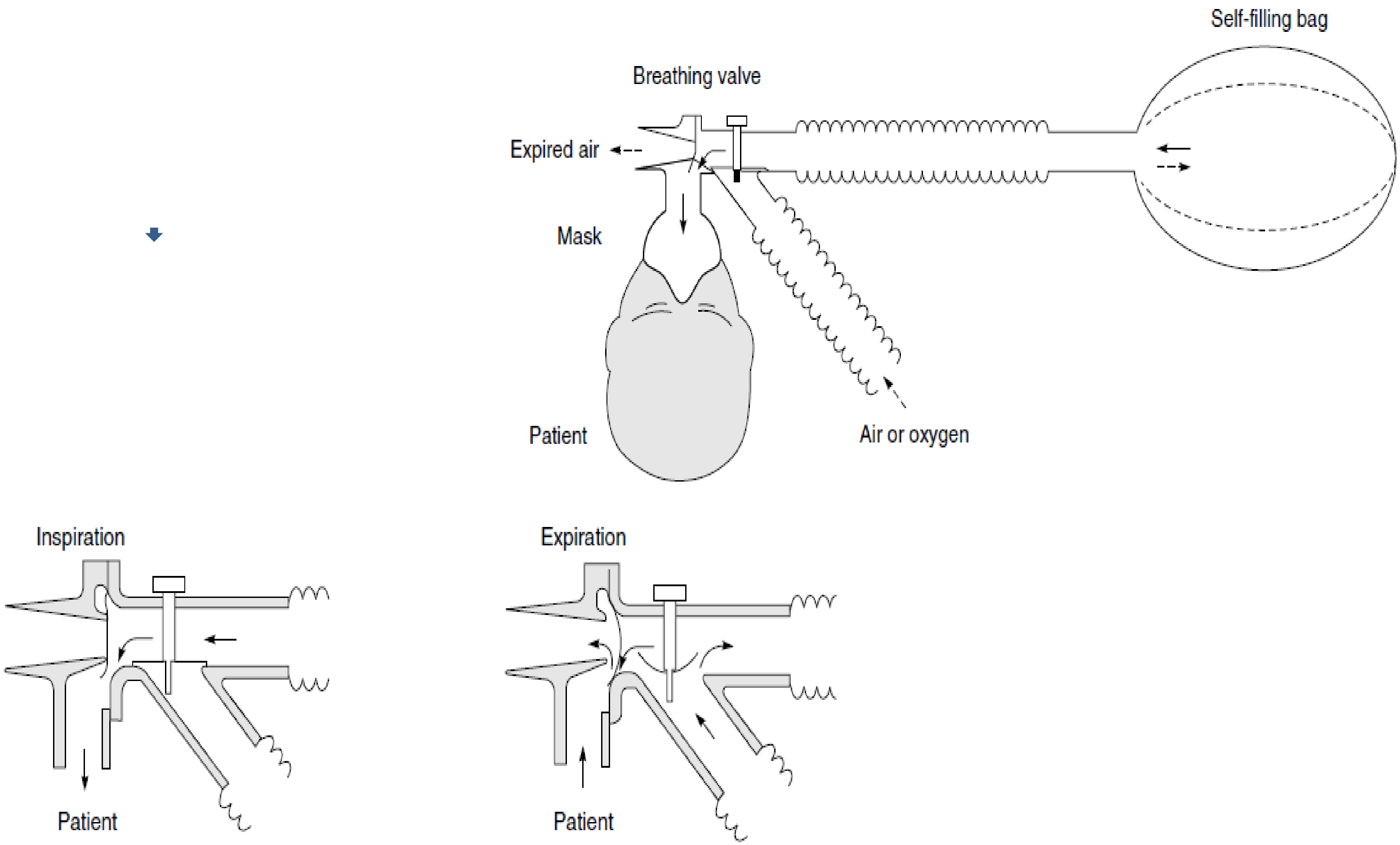
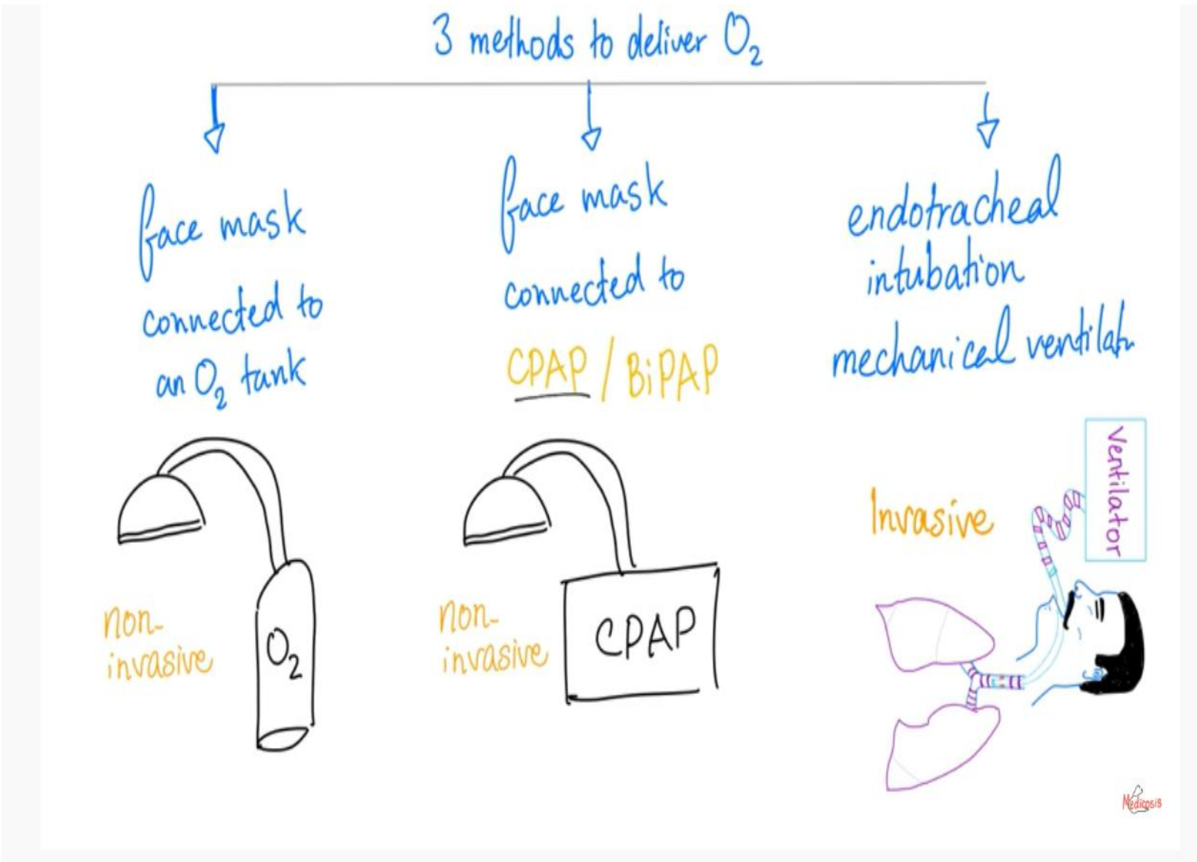


Fig. 33.2 *Mask, breathing valve and self-filling bag for artificial ventilation*

Oxygenation



Ventilators

- When artificial ventilation needs to be maintained for a long time, a ventilator is used.
- Ventilators are also used during anaesthesia and are designed to match human breathing waveform/ pattern.

- These are sophisticated equipment with a large number of controls which assist in maintaining proper and regulated breathing activity. For short-term or emergency use, resuscitators are employed. These depend upon mechanical cycle operation and are generally light-weight and portable.
- The settings of ventilator are Volume control and Pressure control
- Volume Control: the volume of pressurised air delivered is fixed. And the pressure required to deliver the set volume changes from patient to patient.
- Pressure Control: Pressure is set. And the volume of air delivered varies from patient to patient for the set pressure

Natural Respiration occurs when the differential pressure in the pleural cavity goes negative i.e when it goes below the atmospheric pressure. The earlier ventilators based on this principle were called as Negative Pressure ventilators.

Negative Pressure Ventilators: The diaphragm contracts and moves upwards, pushing the thoracic cavity outwards expanding its volume and the pressure in the pleural cavity falls letting the atmospheric air into the lungs. Inspiration and expiration occurs by regulating the pressure cycle in the pleural cavity. Due to engineering problems in implementing the concept, Negative pressure Ventilators have become unpopular.

Positive-Pressure Ventilators generate the inspiratory flow by applying a positive pressure— greater than the atmospheric pressure—to the airways. During the inspiration, the inspiratory flow delivery system creates a positive pressure in the patient circuit and the exhalation control system closes the outlet to the atmosphere.

During the expiratory phase, the inspiratory flow delivery system stops the positive pressure at

the exhalation system and opens the valves to allow the exhaled air to the atmosphere. Positive

Positive pressure ventilators operate either in a) Mandatory b) Spontaneous mode.

Spontaneous Breath Delivery: The ventilator responds to the patient's effort to breath independently. The patient's efforts triggers respiration, so the patient can control the volume and the rate of respiration. Spontaneous breath delivery is used for those patients who are on their way to full recovery but are not completely ready to breathe from the atmosphere without mechanical assistance. In contrast, when delivering mandatory breaths, the ventilator controls all parameters of the breath such as tidal volume Vt, inspiratory flow FiO2, respiration rate RR and oxygen content PaO2 of the breath.

Mandatory Breath Delivery: are normally delivered to the patients who are incapable of breathing on their own. In general, most ventilators in clinical use employ positive pressure during inspiration to inflate the lungs with mixture of gasses (air, oxygen). Expiration is usually passive, though under certain

Ventilator Terms

Lung Compliance: The compliance of the patient's lungs is the ratio of volume delivered to the pressure rise during the inspiratory phase in the lungs.

$c=\frac{\Delta v}{\Delta p}$ expressed as ${}^{litres}/_{cm}\, H_2O$

This includes the compliance of the airways. Lung compliance is the ability of the alveoli and lung tissue to expand on inspiration. The lungs are passive, but they should stretch easily to ensure the sufficient intake of the air. A ventilator and other parts of the breathing circuit also have compliance and some of the delivered volume is used to compress gas or expand gas in these parts. The compliance of a patient's lungs is the ratio of pressure drop across the airway to the resulting flow rate through it. It is also expressed as cm H2O/litres (pressure drop/flow rate).

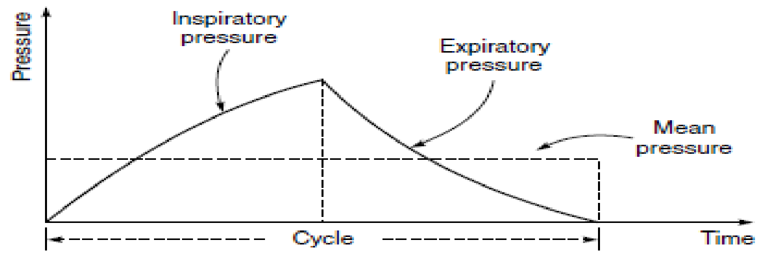
Airway Resistance: Airway resistance relates to the ease with which air flows through the tubular respiratory structures. Higher resistances occur in smaller tubes such as the bronchioles and alveoli that have not emptied properly.

Mean Airway Pressure (MAP): An integral taken over one complete cycle expresses the mean airway pressure

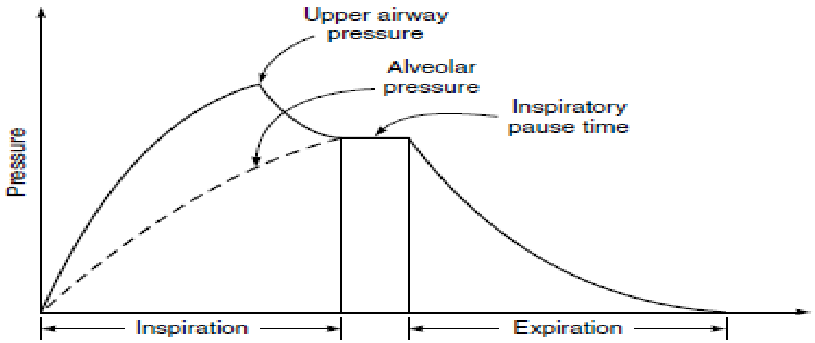
Inspiratory Pause Time: When the pressure in the patient circuit and alveoli is equal, there is a period of no flow. This period is called inspiratory pause time

Inspiratory Flow: Inspiratory flow is represented as a positive flow above the zero line

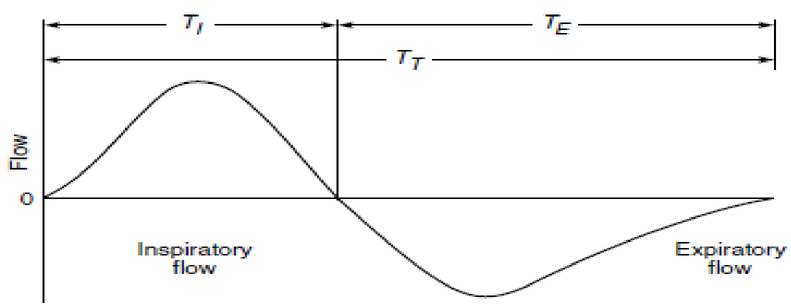
Expiratory Flow: Expiratory flow is a negative flow below the zero line



➤ **Fig.** 33.4 ***Mean airway pressure***



➤ **Fig.** 33.5 ***Inspiratory pause time***



➤ **Fig.** 33.6 ***Inspiratory/expiratory flow, airway pressure and volume-time diagrams, where the flow is approximately sinusoidal***

Ventilator Terms

Tidal Volume: Tidal volume is the depth of breathing or the volume of gas inspired or expired during each respiratory cycle. It can be calculated by multiplying the flow rate (ltr./sec) inspiratory time (seconds). Calibrated tidal volume settings range from 0.010 litre to 4.8 litres. If the flow is set at 0.6 ltr/s and inspiratory time is set at 1 sec, the tidal volume is = 0.6 litres. The normal tidal volume is 500 ml.

Minute Volume: This refers to volume of gas exchanged per minute during quiet breathing. Minute volume is obtained by multiplying the tidal volume by the breathing rate or Respiration Rate RR.

$MV = V_t \times RR$ (Monitoring) 5-10 ltr./minute

Respiration Rate/ frequency: This is the number of breaths per second. It represents total respiratory rate of the patient. In the assist-control mode and SIMV (Synchronized Intermittent Mandatory Ventilation) mode, the ventilator measures the previous four breaths and shows the average total rate, which is prescribed rate plus the additional breaths taken by the patient. (Setting) 5-12

Conventional Mechanical Ventilation (CMV): This provides the force which determines the tidal volume (V_T) at a respiratory frequency (f) to achieve the desired minute ventilation (VE)

$VE = V_T \backslash f$ **(Continuous Mandatory Ventilation)** : There is no spontaneous ventilation in this case and only mechanical ventilation

Intermittent Mandatory Ventilation (IMV): This allows the insertion of a variable time delay between each breath.

Inspiratory Expiratory Phase Time Ratio (I : E Ratio): This signifies the ratio of inspiratory interval to expiratory interval of a mandatory breath. This ratio is normally limited to 1:1, i.e. the inspiratory time should not exceed 50% of the total ventilator cycle time as set by the breath/minute control. Inverse I:E ratio is prevented.

Oxygen Percentage/Oxygen Concentration (FIO2): In all ventilatory modes, oxygen is delivered during the inspiratory phase and the percentage (FIO2) is adjustable from 21 to 91%. Inspirational fraction percentage of oxygen

Peak Airway Pressure: It is the highest level of pressure reached over several breaths.

Peak Inspiration Pressure: Max. Pressure during inspiration Pip, 35 cm H_20

Spontaneous Ventilation: This is a ventilation mode in which the patient initiates and breathes from the ventilator at will.

Bias Flow: In bias flow, mixed gas from the mixer is directed through the patient circuit in-between mechanical breaths. Bias flow stabilizes baseline pressure for spontaneously breathing patients and decreases the response time of the demand valve.

Sensitivity: It is used to detect spontaneous effort by the patient, in order to trigger mandatory ventilation with the set Respiration rate.

Mandatory Minutes Volume Ventilation (MMV): This operating mode applies mandatory ventilation only if spontaneous breathing is not yet sufficient and has fallen below a pre-selected minimum ventilation. Unlike SIMV, the mandatory strokes are not applied regularly but only in cases of insufficient ventilation.

Controlled Mandatory Ventilation: This term refers to mandatory ventilation of patients who are not able to initiate or respire on their own.

Assisted Spontaneous Breathing (ASB): It refers to the pressure support of insufficient spontaneous breathing.

Positive End Expiratory Pressure (PEEP): PEEP is a therapist-selected pressure level for the patient airway at the end of expiration in either mandatory or spontaneous breathing. PEEP is used to increase the end-expiratory lung volume (EELV) or prolong expiration with a potentially similar effect on the EELV (Fig. 33.8). This maintains a constant pressure in the alveoli and helps to improve oxygen concentration. 5-20 cm/H2O

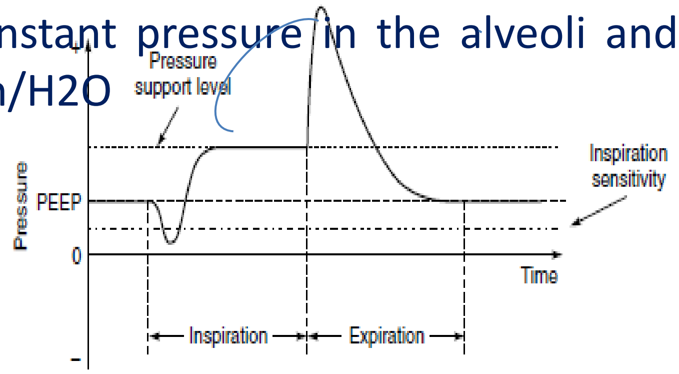


Fig. 33.8 *Concept of PEEP*

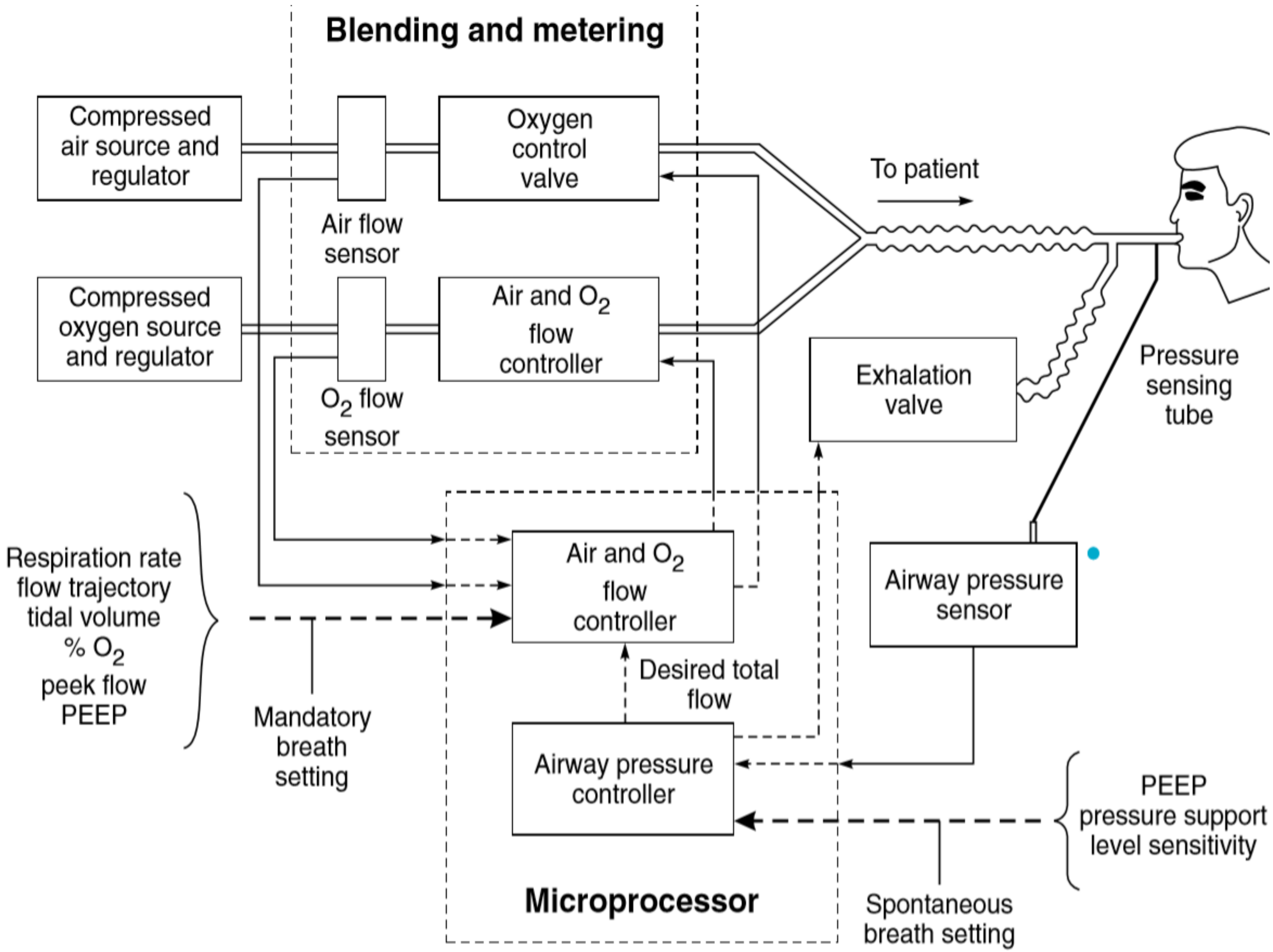
Continuous Positive Airway Pressure (CPAP): CPAP is a spontaneous ventilation mode in which the ventilator maintains a constant positive pressure, near or below PEEP Level, in the patient's airway while the patient breathes at will.

Assist/Control Ventilation: During this process, a positive pressure breath is delivered with each patient's spontaneous inspiratory effort to reach the trigger level setting. In volume controlled assist control, tidal volume is determined by flow and inspiratory time settings. If the patient does not trigger the ventilation, it automatically delivers breaths according to the set rate.

Modern Ventilators

Revise

- Tidal Volume: Volume of air exchanged during each respiratory cycle.
- %Oxygen: Amount of oxygen delivered by the ventilator during inspiration. Set by the doctor
- Spontaneous breath: Patient triggers inspiration and a positive pressure support will be provided
- Inspiration Sensitivity: The minimum pressure drop to initiate inspiration, during assisted/spontaneous breathing
- Peak inspiration pressure: Maximmum pressure during inspiration. Pressure limit will be set
- Respiration rate: set by the doctor during mandatory mechanical ventilation
- Time Phase ratio: Important in case of assisted breathing



➤ **Fig. 33.12** *Block diagram of a microprocessor controlled ventilator*

Microprocessor Controlled Ventilators

- The ventilators needs to monitor & regulate, pressure, volume and flow rate of gas and also raise the alarm and release safety valves. The breathing valve control is very critical in the use of ventilators. And the safety limits have to be maintained all the time.
- The modern day ventilators have two separate system i. Pneumatic system to regulate the air flow ii. The electronic control system
- The pneumatic flow system enables the flow of gas through the ventilator. Oxygen and medical grade air enter the ventilator at 3.5 bar (50 psi) pressure through built-in 0.1 micron filters. The normal operating range is 2 to 6 bar or 28 to 86 psi. These gasses enter the air/oxygen mixer where they combine at the required percentage and reduced to 350 cm H_2O. The gases then enter a cylinder of capacity 8 ltrs.
- The primary objective of the control is to deliver the required percentage and tidal volume of oxygen as per the settings of the doctor

Continued…

Compressed oxygen and air are mixed in the required proportion. The air flow and oxygen flow sensor are included in the inlet section to allow the proper ratio. The oxygen valve also acts as the safety inlet valve to allow the ambient air to the patient when the ventilator fails or when the patient circuit drops to a low pressure as low as -10 cm H_2O.

In the patient breathing section a bi -directional pressure sensor will sense the pressure of air flow in both the direction. If the inspiration pressure exceeds the limit the air way pressure controller will release the pressure through the exhale valve.

The airway pressure sensor will also help in identifying the patient trigger in spontaneous ventilation.

Settings for Spontaneous Ventilation: The air way controller receives the settings for PEEP , support pressure and inspiration sensitivity.

Continued…

In Mandatory Mechanical Breathing mode the microprocessor flow controller unit receives different set parameters such as respiration rate, O2 %, flow pattern (sine, exponential, square etc.),tidal volume, peak pressure, PEEP etc.

Also microprocessor receives from the inlet side the gas flow from the flow sensor. The microprocessor generates the control signal for the valve controller. The microprocessor controls the valve position based on various parameters such as support pressure, PEEP, % O2 , variation in pressure during inspiration, rate of inspiration. And safety valve release using exhale valve & valve control.

The pressure sensors are strain gauges connected in bridge configuration and the O2 Sensors generate current depending on the pressure of O2.

Ventilator Classification

Classification of Ventilators

Ventilators are classified based on different methods.

1. Based on inspiration methods:
   a. **Controlled Ventilation*:*** A ventilator which operates independent of the patient’s inspiratory effort. The inspiration is initiated by a mechanism which is controlled with respect to time, pressure or another similar factor. Controlled ventilation is required for patients who are unable to breath on their own
   b. **Assisted Ventilation*:*** A ventilator which augments the inspiration of the patient by operating in response to the patient’s inspiratory effort. A pressure sensor detects the slight negative pressure that occurs each time the patient attempts to inhale and triggers the process of inflating the lungs. Thus the ventilator helps the patient to inspire when needed. A sensitivity adjustment provided on the equipment helps to select the amount of effort required on the patient’s part to trigger the inspiration process. A pressure support above the PEEP is provided. The *assist* mode is required for those patients who are able to breathe but are unable to inhale a sufficient amount of air or for whom breathing requires a great deal of effort.
   c. **Assistor/Controller:** A ventilator which combines both the controller and assistor functions. In these devices, if the patient fails to breathe within a pre-determined time, a timer automatically triggers the inspiration process to inflate the lungs. Therefore, the breathing is controlled by the patient as long as it is possible, but in case the patient should fail to do so, the machine is able to take over the function. Such devices are most frequently used in critical care units.

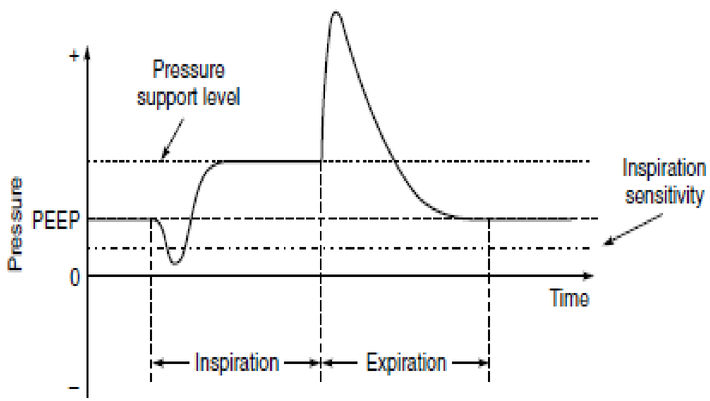
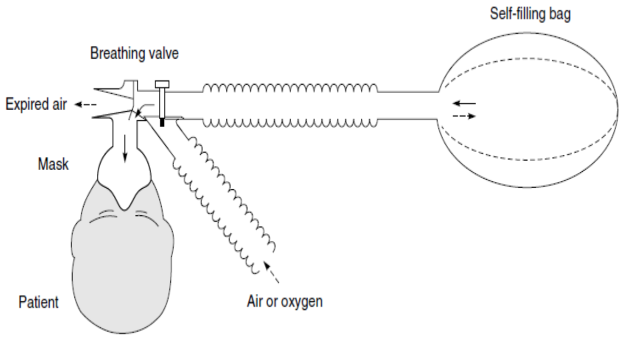


Fig. 33.8 *Concept of PEEP*

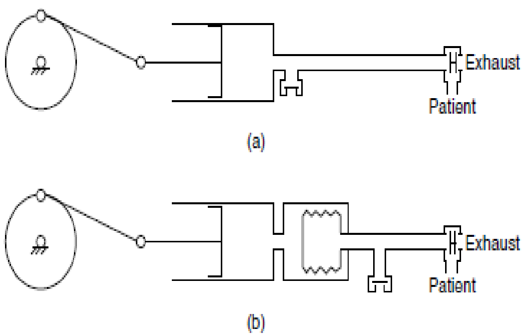
2. Based on Power Transmission

- **Direct Power Transmission:** A ventilator which delivers the gas directly from the source of compressed gas to the patient
- **Indirect Power Transmission:** A ventilator which has separate patient and power systems. The pressure in the power system determines the flow rate.

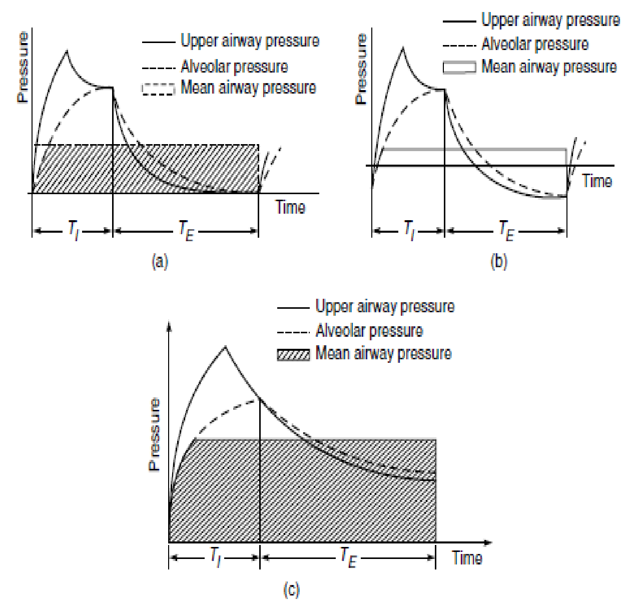


3. Based on Pressure

- **Positive-Atmosphere:** A ventilator which produces a positive pressure in the patient's lungs during inspiration, with an end expiratory pressure that is equal to the atmospheric pressure. In this mode, the mean airway pressure is always higher than the atmospheric pressure and the patient normally breathes spontaneously with this mode of operation



➤ **Fig.** 33.9(a) *Direct power transmission*
(b) *Indirect power transmission*



➤ **Fig.** 33.10 *Pressure-time diagram for*
(a) *Positive-atmosphere pressure pattern*
(b) *Positive-negative pressure pattern*
(c) *Positive-positive pressure pattern*

- **Positive-Negative:** A ventilator which produces a positive pressure in the patient's lungs during inspiration and below atmospheric pressure in the airway during part of expiratory phase (Fig. 33.10b). A positive-negative pressure pattern results in a low mean airway pressure.
- **Positive-Positive**: A ventilator which produces a positive pressure in the patient's lungs during inspiration, with an end expiratory pressure that is greater than the atmospheric pressure (Fig. 33.10c). In order to obtain an end expiratory pressure that is greater than the atmospheric pressure, it is necessary to start the inspiratory phase before the airway pressure reaches the atmospheric pressure.

4. Based on Safety Limit:

- **Volume Limited:** A ventilator in which pre-determined volume cannot be exceeded during inspiration. Volume limit normally refers to tidal volume.
- **Pressure Limited:** A ventilator designed in such a way that predetermined pressure cannot be exceeded during inspiration.

{ $c=\frac{\Delta v}{\Delta p}$ typical lung compliance 0.1-0.4 l/cm H_20}

- **Time Limited:** A ventilator in which predetermined phase time cannot be exceeded. It limits the expiratory phase time if the patient does not initiate the inspiratory phase and is common to ventilators used for assisted ventilation.

5. Based on Cycling Time

Cycling control of a ventilator is the device which determines the change from the inspiratory phase to the expiratory phase and vice versa. The cycling of a ventilator may be based upon different factors such as pressure, volume, time and the inspiratory effort made by the patient. The common types of cycling controls are described below.

- **Cycling from Inspiration to Expiration**
  - ***Volume Cycled:*** A ventilator which starts the expiratory phase after a preset tidal volume has been delivered into the patient circuit. This device normally has a pressure over-ride valve so that if, while the machine is in the process of administering the set volume, the pressure exceeds a predetermined maximal value, the ventilator will cycle whether or not the appropriate volume has been administered.
  - ***Pressure Cycled:*** A ventilator which begins the expiratory phase after a preset pressure has been attained.
  - ***Time Cycled:*** A ventilator which initiates the expiratory phase after a preset time period for the inspiratory phase has passed.
- **Cycling from Expiration to Inspiration**
  - ***Pressure Cycled:*** A ventilator which begins the inspiratory phase after a pre-set end expiratory pressure has been attained.
  - ***Time Cycled:*** A ventilator which initiates the inspiratory phase after a preset time period for the expiratory phase has passed.
  - ***Patient Inspiratory Effort Cycled:*** A ventilator which starts the

- Based on Source of Power
  - **Pneumatic:** A ventilator powered by compressed gas.
  - **Electric:** A ventilator powered by an electrical device such as an electric motor, or similar gadget.

It may be observed that it is necessary to provide for a time delay (pause time) between the cycling of the ventilator and the change from inspiratory flow to expiratory flow in the airway. During this pause time, the flow becomes zero when the alveolar pressure equals the airway pressure and constant volume is maintained in the lungs. Ventilators producing a pause time during inspiration or expiration have certain advantages over ventilators without such a pause and are therefore preferred over the latter. Figure 33.11 shows pressure, flow and volume pattern in a ventilated system with and without pause.

Pressure, Volume and Flow diagrams

The ventilated system consists of the patient circuit, the airway and the alveoli, each having its own compliance. After the start of the inspiratory phase, a certain gas volume is delivered into the system, resulting primarily in an increase of pressure in the patient circuit and subsequently, in a flow through the airway. During the inspiratory phase, the airway pressure and alveolar pressure increase gradually with the airway pressure always being higher than the alveolar pressure.

The equal pressure of the patient circuit and alveoli determines the end of the inspiratory flow

and beginning of the expiratory flow, due to the fact that the pressure in the patient system is

allowed to decrease. The expiratory flow is determined by the difference between alveolar pressure and pressure in the patient circuit. It may thus be noted that:

– an airway pressure higher than the alveolar pressure characterizes an inspiratory flow;

Pressure, Flow and Volume Diagrams

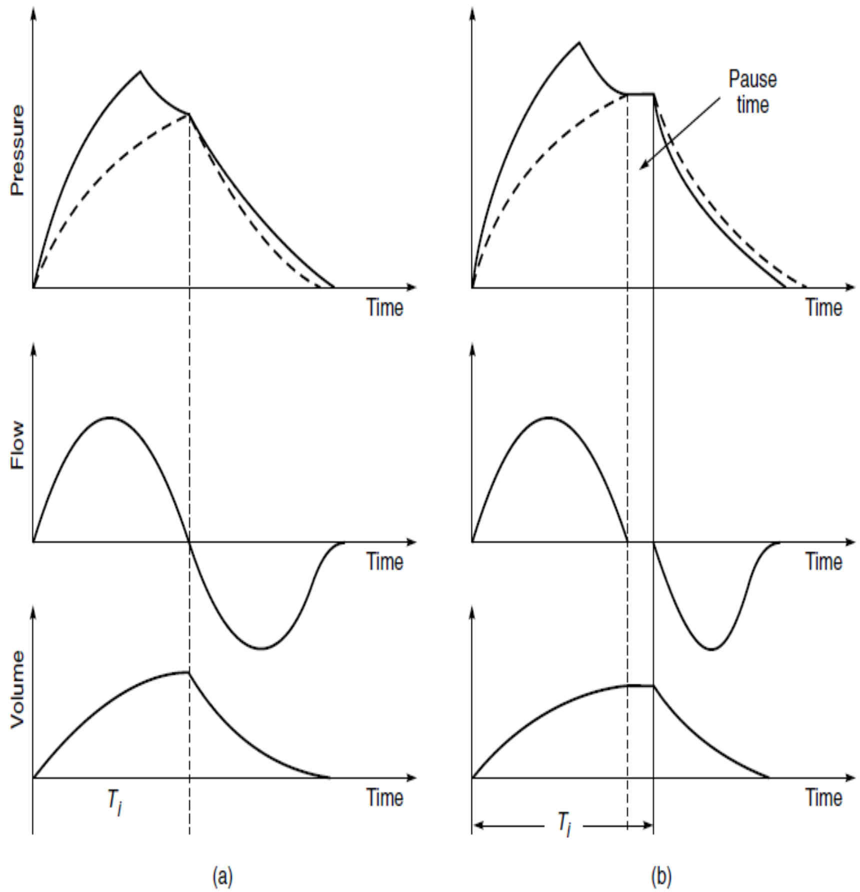
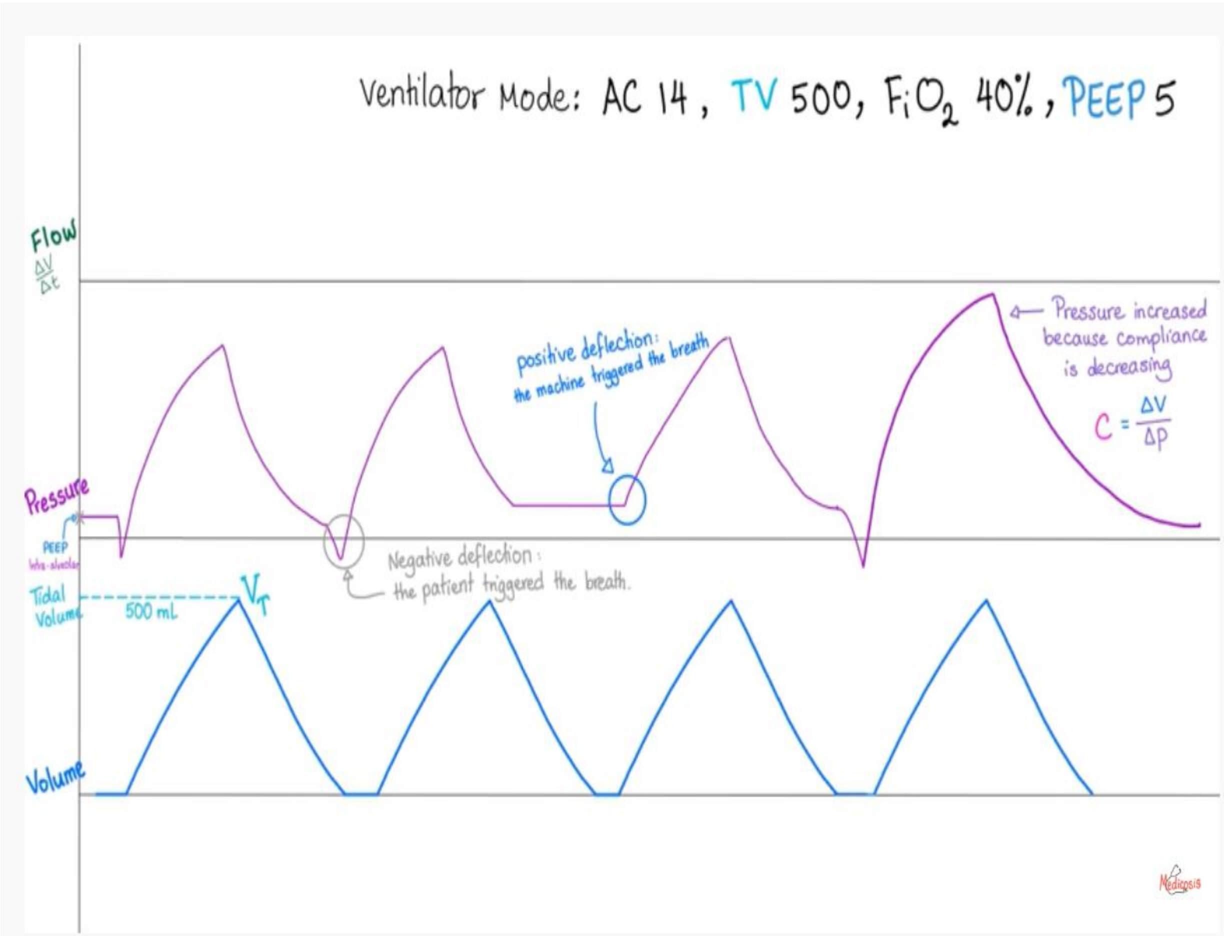


Fig. 33.11 *Pressure, flow and volume diagram*
(a) *without pause time*
(b) *with pause time*



Ventilator Mode: AC 14, TV 500, FiO2 40%, PEEP 5
Flow
ΔV/Δt
Pressure
PEEP
Tidal Volume
500 mL
VT
Volume
positive deflection: the machine triggered the breath
Negative deflection: the patient triggered the breath.
Pressure increased because compliance is decreasing
C = ΔV/ΔP
Medicosis

High Frequency Ventilator

A new technique for ventilating patients at frequencies much higher than the respiration rate has recently been introduced. This method has been shown to improve CO_2 wash out and provide adequate oxygenation without the requirement for high inspiratory pressures.

The high oxygenation pressure can cause different types of trauma to the already injured part. The key principle in this technique is to provide tidal volumes equal to or smaller than the dead space, at very high rates. Dead space is the volume of air occupied in the respiratory parts where gas exchange does not take place. The conducting tracheal tube and thick walls of the respiratory mechanism parts and also the alveolar space where the gas perfusion is not taking place due to injury to the alveolar tissue or any such reason.

The high frequency provides small volumes of air at much higher frequency typically 5-20 Hz. Read 1 Hz as 60 breaths per minute. Hence the total pulses will be 300-1200 pulses per minute. The ventilators should create such high frequency pressure wave.

In conventional method the amount of CO_2 eliminated is determined by the minute ventilation. Gas pressure in the air way is directly related to the amount of oxygenation. Hence increasing inspiration pressure is the method in CMV, but this will add stress to the already injured lungs. The alternate option in high frequency ventilation is to provide low volumes of air at much higher rate compared to the respiratory rate. This will ensure adequate oxygenation and CO_2 elimination.

Gas transport during conventional ventilation is attributed to two basic mechanisms:

(i) convection or flow of gas through the conducting airways, and

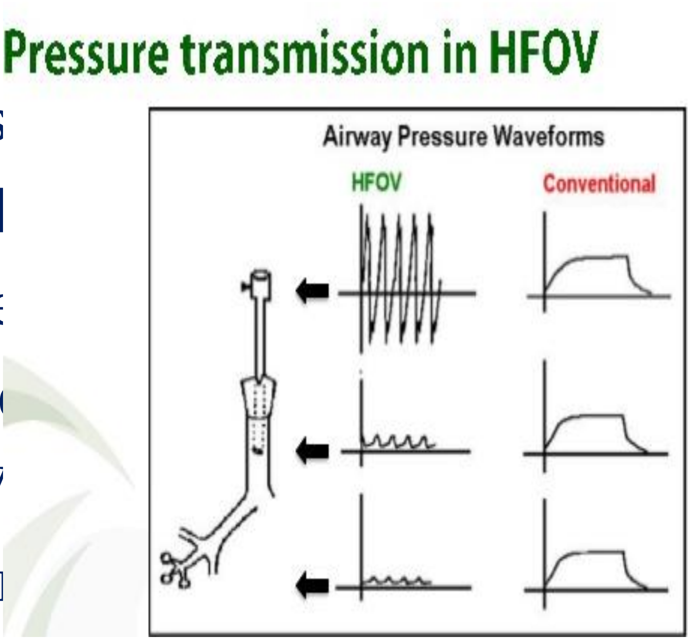
(ii) molecular diffusion of gasses into the alveoli and pulmonary capillaries.

The tidal volume (V_t) applied to the patient at the Y-piece can be divided into the volume used to ventilate the dead space ($\mathbf{V_D}$) and the alveolar volume $\mathbf{V_{alv}}$.Only the alveolar volume takes part in the gas exchange process. Therefore,

$$\mathbf{V_{alv}} = V_t - \mathbf{V_D}$$

The computer controlled ventilators should produce high frequency pressure variations and also maintain precise Time phase ratio I:E. The I:E ratio will typically vary from 1:1 to 1:4

Observe the pressure waveforms in high frequency & CMV mode



The airway pressure goes on decreas
reaches the alveoli it gets reduced wl
reduces the stress on the alveoli, whe
CMV very little drop in pressure tak
The ventilators with combined CMV
have also proved to be effective in i
gas exchange.

Humidifiers, Nebulisers, Aspirators

The humidity of the air should be close to 100% or in terms of water it should be 30mg per litre of breathing gas. Humidifiers should add water content either by bubbling air through water or by vaporising and releasing water content and steam. Otherwise it will damage the lungs as the mucus lining of the lungs will get dried. Upper air way provides the moist and heat in normal breathing when it is bypassed in artificial ventilation using tracheal tubes, humidifiers are suggested for all invasive ventilation patients.

Nebulisers: These are devices which introduce water or medication by breaking the molecules into aerosols or fine spray and mixing through the breathing gas. It is done by passing a jet (jet nebuliser)of high velocity air through the medications and making it hit against baffles so that the molecules break into tiny molecules. Or making it vibrate using UV rays (Ultrasonic Nebuliser) so that the molecules break into aerosols and get carried away by the beathing gas

Aspirators: They are used to remove the liquid waste from the lungs like mucus