Artificial organs – internal & external (Ventilators)

Spontaneous Ventilation

- An important phase in providing respiratory therapy to a recovering pulmonary patient is weaning the patient from the respirator.
- As the patient recovers and gains the ability to breathe independently, the ventilator must allow the patient to initiate a breath and control the breath rate, flow rate, and the tidal volume. Ideally, when a respirator is functioning in the spontaneous mode, it should let the patient take breaths with the same ease as breathing from the atmosphere.
- This, however, is difficult to achieve because the respirator does not have an infinite gas supply or an instantaneous response. In practice, the patient generally has to exert more effort to breathe spontaneously on a respirator than from the atmosphere.
- However, patient effort is reduced as the ventilator response speed increases. Spontaneous ventilation is often used in conjunction with mandatory ventilation since the patient may still need breaths that are delivered entirely by the ventilator.
- Alternatively, when a patient can breathe completely on his own, but needs oxygen-enriched breath or elevated airway pressure, spontaneous ventilation alone may be used.

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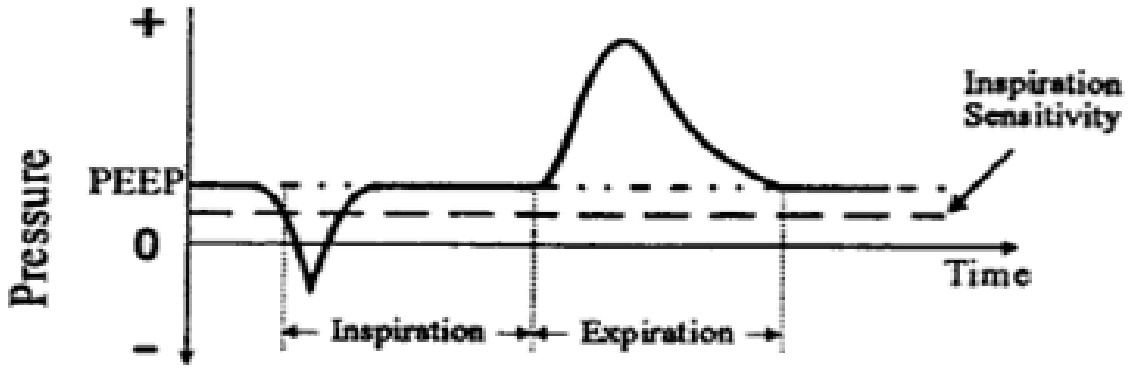
- Several modes of spontaneous ventilation have been devised by therapists. Two of the most important and popular spontaneous breath delivery modes are described below.

Continuous Positive Airway Pressure (CPAP) in Spontaneous Mode

- In this mode, the ventilator maintains a positive pressure at the airway as the patient attempts to inspire.
- Figure 6 illustrates a typical airway pressure waveform during continuous positive airway pressure (CPAP) breath delivery. The therapist sets the sensitivity level lower than positive end-expiratory pressure (PEEP). When the patient attempts to breathe, the pressure drops below the sensitivity level and the ventilator responds by supplying breathable gases to raise the pressure back to the PEEP level.
- Typically, the (PEEP) and sensitivity levels are selected such that the patient will be impelled to exert effort to breathe independently. As in the case of the mandatory mode, when the patient exhales the ventilator shuts off the flow of



gas and opens the exhalation valve to allow the exhaled gases to flow into the atmosphere

Figure 6, Airway pressure during a CPAP spontaneous breath delivery

Pressure Support in Spontaneous Mode

- This mode is similar to the CPAP mode with the exception that during the inspiration the ventilator attempts to maintain the patient airway pressure at a level above PEEP.
- Figure 7 shows a typical airway pressure waveform during the delivery of a pressure support breath. In this mode, when the patient's airway pressure drops below the therapist-set sensitivity line, the ventilator inspiratory breath delivery system raises the airway pressure to the **pressure support level** (>PEEP), selected by the therapist. The ventilator stops the flow of breathable gases when the patient starts to exhale and controls the exhalation valve to achieve the set PEEP level.

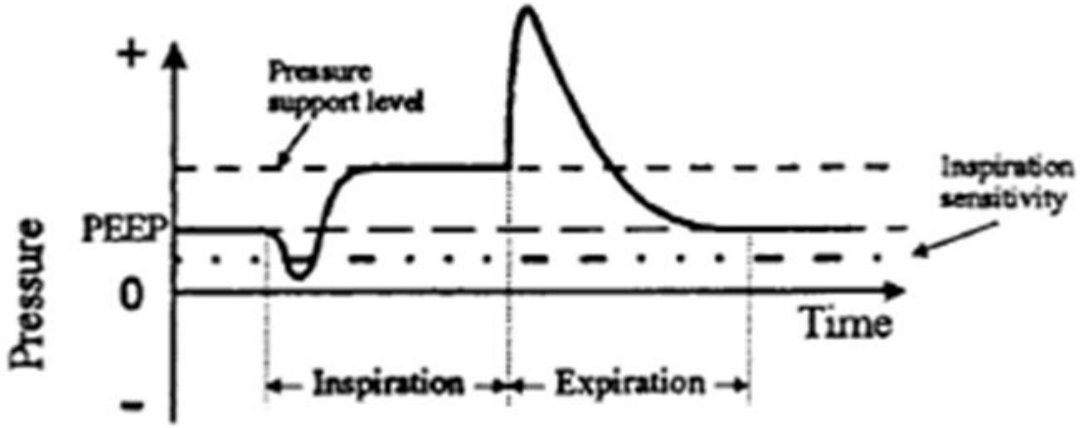


Figure 7, Airway pressure during a pressure support spontaneous breath delivery.

Breathe Delivery Control

- Figure 8 shows a simplified block diagram for delivering mandatory or spontaneous ventilation.
- Compressed air and oxygen are normally stored in high pressure tanks (~=1400 kPa) that are attached to the inlets of the ventilator. In some ventilators, an air compressor is used in place of a compressed air tank. Manufacturers of respirators have designed a variety of blending and metering devices.
- The primary mission of the device is to enrich the inspiratory air flow with the proper level of oxygen and to deliver a tidal volume according to the therapist's specifications. With the introduction of microprocessors for control of metering devices, electromechanical valves have gained popularity.
- In Figure 8, the air and oxygen valves are placed in closed feedback loops with the air and oxygen flow sensors. The microprocessor controls each valves to deliver the desired inspiratory air and oxygen flows for mandatory and spontaneous ventilation. During inhalation, the exhalation valve is closed to direct all the delivered flows to the lungs. When exhalation starts, the microprocessor actuates the exhalation valve to achieve the desired PEEP level.
- The airway pressure sensor, shown on the right side of Figure 8, generates the feedback signal necessary for maintaining the desired PEEP (in both

mandatory and spontaneous modes) and airway pressure support level during spontaneous breath delivery.

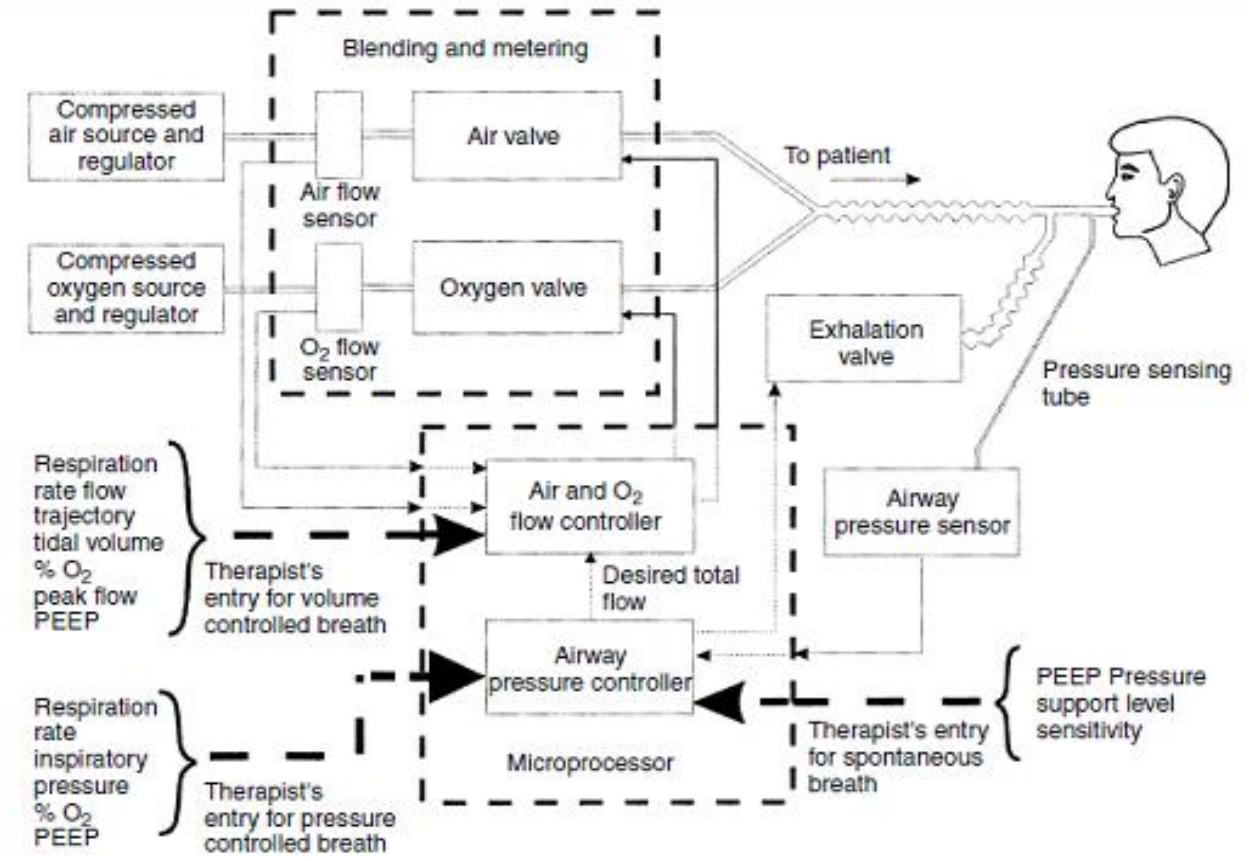


Figure 8, a simplified block diagram of a control structure for mandatory and spontaneous breath delivery

Mandatory Volume Controlled Inspiratory Flow Delivery:

- The electronically actuated valves open from a closed position to allow the flow of blended gases to the patient. The control of flow through each valve depends on the therapist's specification for the mandatory breath.
- That is, the clinician must specify the following parameters for delivery of CMV breaths (1) respiration rate; (2) flow waveform; (3) tidal volume; (4) oxygen concentration (of the delivered breath); (5) peak flow; and (6) PEEP, as shown in Figure 8. It is noted that the PEEP selected by the therapist in the mandatory mode is only used for control of exhalation flow.
- The microprocessor utilizes the first five of the above parameters to compute the total desired inspiratory flow trajectory.

Pressure Controlled Inspiratory Flow Delivery

- The therapist entry for pressure-controlled ventilation is shown in Figure 8. The total desired flow is generated by a closed loop controller labeled as Airway Pressure Controller.
- This controller uses the therapist-selected inspiratory pressure, respiration rate, and the inspiratory- expiratory ratio to compute the desired inspiratory pressure trajectory.
- The trajectory serves as the controller reference input. The controller then computes the flow necessary to make the actual airway pressure track the reference input.

Expiratory Pressure Control in Mandatory Mode

- It is often desirable to keep the patient's lungs inflated at the end of expiration at a pressure greater than atmospheric level. That is, rather than allowing the lungs to deflate during the exhalation, the controller closes the exhalation valve when the airway pressure reaches the PEEP level.
- When expiration starts, the ventilator terminates flow to the lungs; hence, the regulation of the airway pressure is achieved by controlling the flow of patient exhaled gases through the exhalation valve.
- In a microprocessor-based ventilator, an electronically actuated valve can be employed that has adequate response (~= 20 msec rise time) to regulate PEEP. For this purpose, the pressure in the patient breath delivery circuit is measured using a pressure transducer. The microprocessor will initially open the exhalation valve completely to minimize resistance to expiratory flow. At the same time, it will sample the pressure transducer's output and start to close the exhalation valve as the pressure begins to approach the desired PEEP level. Since the patient's exhaled flow is the only source of pressure, if the airway pressure drops below PEEP, it cannot be brought back up until the next inspiratory period.

Spontaneous Breath Delivery Control

- The small diameter (~= 5 mm) pressure sensing tube, shown on the right side of Figure 8, pneumatically transmits the pneumatic pressure signal from the patient airway to a pressure transducer placed in the ventilator.
- The output of the pressure transducer is amplified, filtered, and then sampled by the microprocessor. The controller receives the therapist's inputs regarding the spontaneous breath characteristics such as the PEEP, sensitivity, and oxygen concentration.
- The desired airway pressure is computed from the therapist entries of PEEP, pressure support level, and sensitivity. The multiple-loop control structure shown in Figure 8 is used to deliver a CPAP or a pressure support breath.

- The sensed proximal airway pressure is compared with the desired airway pressure. The airway pressure controller computes the total inspiratory flow level required to raise the airway pressure to the desired level.

- This flow level serves as the reference input or total desired flow for the flow control loop. Hence, in general, the desired total flow trajectory for the spontaneous breath delivery may be different for each inspiratory cycle.
- If the operator has specified oxygen concentration greater than 21.6% (the atmospheric air oxygen concentration of the ventilator air supply), the controller will partition the total required flow into the air and oxygen flow rates. The flow controller then uses the feedback signals from air and oxygen

flow sensors and actuates the air and oxygen valves to deliver the desired flows.

- If a non-zero PEEP level is specified, the same control strategy as the one described for mandatory breath delivery can be used to achieve the desired PEEP.

Summary

- Today's mechanical can be broadly classified into negative-pressure and positive-pressure ventilators. Negative-pressure ventilators do not offer the flexibility and convenience that positive-pressure ventilators provide; hence, they have not been very popular in clinical use. Positive-pressure ventilators have been quite successful in treating patients with pulmonary disorders. These ventilators operate in either mandatory or spontaneous mode.

When delivering mandatory breaths, the ventilator controls all parameters of the breath such as tidal volume, inspiratory flow waveform, respiration rate, and oxygen content of the breath. Mandatory breaths are normally delivered to the patients that are incapable of breathing on their own. In contrast, spontaneous breath delivery refers to the case where the ventilator responds to the patient's effort to breathe independently. Therefore, the patient can control the volume and the rate of the respiration. The therapist selects the

oxygen content and the pressure at which the breath is delivered. Spontaneous breath delivery is typically used for patients who are on their way to full recovery, but are not completely ready to breathe from the atmosphere without mechanical assistance.

Defining Terms

- **Continuous positive airway pressure (CPAP):** 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.
- **Mandatory mode:** A mode of mechanically ventilating the lungs where the ventilator controls all breath delivery parameters such as tidal volume, respiration rate, flow waveform, etc.
- **Patient circuit:** A set of tubes connecting the patient airway to the outlet of a respirator.
- **Positive end expiratory pressure (PEEP):** A therapist-selected pressure level for the patient airway at the end of expiration in either mandatory or spontaneous breathing.
- **Pressure controlled ventilation:** A mandatory mode of ventilation where during the inspiration phase of each breath, a constant pressure is applied to the patient's airway independent of the patient's airway resistance and/or compliance respiratory mechanics.

- **Pressure support:** A spontaneous breath delivery mode during which the ventilator applies a positive pressure greater than PEEP to the patient's airway during inspiration.
- **Pressure support level:** Refers to the pressure level, above PEEP, that the ventilator maintains during the spontaneous inspiration.
- **Spontaneous mode:** A ventilation mode in which the patient initiates and breathes from the ventilator supplied gas at will.
- **Volume controlled ventilation:** A mandatory mode of ventilation where the volume of each breath is set by the therapist and the ventilator delivers that volume to the patient independent of the patient's airway resistance and/or compliance respiratory mechanics.
- **Lung Compliance:** is the ability of the alveoli and lung tissue to expand on inspiration. It is represented by the ration of volume delivered to the pressure rise during the inspiratory phase in the lung, and it is expressed as liters/cm H_2O.
- **Airway Resistance:** relates to the ease with which air flows through the tubular respiratory structures. Higher resistances occur in smaller tubes such as bronchioles and alveoli that have not emptied properly.