ASSIGNMENT 1
ON
FIVE BIOMEDICAL DEVICES

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1 Sphygmomanometer

1.1 Introduction

A sphygmomanometer, also known as a blood pressure monitor, or blood pressure gauge, is a device used to measure blood pressure, composed of an inflatable cuff to collapse and then release the artery under the cuff in a controlled manner and a mercury or aneroid manometer to measure the pressure. Manual sphygmomanometers are used with a stethoscope when using the auscultatory technique.
A sphygmomanometer consists of an inflatable cuff, a measuring unit (the mercury manometer, or aneroid gauge), and a mechanism for inflation which may be a manually operated bulb and valve or a pump operated electrically.

1.2 Types

Both manual and digital meters are currently employed, with different trade-offs in accuracy versus convenience.

1.2.1 Manual

A stethoscope is required for auscultation . Manual meters are best used by trained practitioners, and, while it is possible to obtain a basic reading through palpation alone, this yields only the systolic pressure.
Mercury sphygmomanometers are considered the gold standard. They indicate pressure with a column of mercury, which does not require recalibration. Because of their accuracy, they are often used in clinical trials of drugs and in clinical evaluations of high-risk patients, including pregnant women. A frequently used wall mounted mercury sphygmomanometer is also known as a Baumanometer.
Aneroid sphygmomanometers (mechanical types with a dial) are in common use; they may require calibration checks, unlike mercury manometers. Aneroid sphygmomanometers are considered safer than mercury sphygmomanometers, although inexpensive ones are less accurate. A major cause of departure from calibration is mechanical jarring. Aneroids mounted on walls or stands are not susceptible to this particular problem.

1.2.2 Digital

Digital meters employ oscillometric measurements and electronic calculations rather than auscultation. They may use manual or automatic inflation, but both types are electronic, easy to operate without training, and can be used in noisy environments. They measure systolic and diastolic pressures by oscillometric detection, employing either deformable membranes that are measured using differential capacitance, or differential piezoresistance, and they include a microprocessor. They measure mean blood pressure and pulse rate, while systolic and diastolic pressures are obtained less accurately than with manual

meters, and calibration is also a concern. Digital oscillometric monitors may not be advisable for some patients, such as those suffering from arteriosclerosis, arrhythmia, preeclampsia, pulsus alternans, and pulsus paradoxus, as their calculations may not correct for these conditions, and in these cases, an analog sphygmomanometer is preferable when used by a trained person.
Digital instruments may use a cuff placed, in order of accuracy and inverse order of portability and convenience, around the upper arm, the wrist, or a finger.Recently, a group of researchers at Michigan State University developed a smartphone based device that uses oscillometry to estimate blood pressure. The oscillometric method of detection used gives blood pressure readings that differ from those determined by auscultation, and vary according to many factors, such as pulse pressure, heart rate and arterial stiffness, although some instruments are claimed also to measure arterial stiffness, and some can detect irregular heartbeats.

1.3 Operation

In humans, the cuff is normally placed smoothly and snugly around an upper arm, at roughly the same vertical height as the heart while the subject is seated with the arm supported. Other sites of placement depend on species and may include the flipper or tail. It is essential that the correct size of cuff is selected for the patient. Too small a cuff results in too high a pressure, while too large a cuff results in too low a pressure. For clinical measurements it is usual to measure and record both arms in the initial consultation to determine if the pressure is significantly higher in one arm than the other. A difference of 10 mm Hg may be a sign of coarctation of the aorta. If the arms read differently, the higher reading arm would be used for later readings. The cuff is inflated until the artery is completely occluded.
With a manual instrument, listening with a stethoscope to the brachial artery, the examiner slowly releases the pressure in the cuff at a rate of approximately 2 mm per heart beat. As the pressure in the cuffs falls, a "whooshing" or pounding sound is heard (see Korotkoff sounds) when blood flow first starts again in the artery. The pressure at which this sound began is noted and recorded as the systolic blood pressure. The cuff pressure is further released until the sound can no longer be heard. This is recorded as the diastolic blood pressure. In noisy environments where auscultation is impossible (such as the scenes often encountered in emergency medicine), systolic blood pressure alone may be read by releasing the pressure until a radial pulse is palpated (felt). In veterinary medicine, auscultation is rarely of use, and palpation or visualization of pulse distal to the sphygmomanometer is used to detect systolic pressure.
Digital instruments use a cuff which may be placed, according to the instrument, around the upper arm, wrist, or a finger, in all cases elevated to the same height as the heart. They inflate the cuff and gradually reduce the pressure in the same way as a manual meter, and measure blood pressures by the oscillometric method.

1.4 Significance

By observing the mercury in the column, or the aneroid gauge pointer, while releasing the air pressure with a control valve, the operator notes the values of the blood pressure in mm Hg. The peak pressure in the arteries during the cardiac cycle is the systolic pressure, and the lowest pressure (at the resting phase of the cardiac cycle) is the diastolic pressure. A stethoscope, applied lightly over the artery being measured, is used in the auscultatory method. Systolic pressure (first phase) is identified with the first of the continuous Korotkoff sounds. Diastolic pressure is identified at the moment the Korotkoff sounds disappear (fifth phase).
Measurement of the blood pressure is carried out in the diagnosis and treatment of hypertension (high blood pressure), and in many other healthcare scenarios.

1.5 History

The sphygmomanometer was invented by Samuel Siegfried Karl Ritter von Basch in the year 1881. Scipione Riva-Rocci introduced a more easily used version in 1896. In 1901, pioneering neurosurgeon Dr. Harvey Cushing brought an example of Riva-Rocci's device to the US, modernized it and popularized it within the medical community. Further improvement came in 1905 when Russian physician Nikolai Korotkov included diastolic blood pressure measurement following his discovery of "Korotkoff sounds." William A. Baum invented the Baumanometer brand in 1916, while working for The Life Extension Institute which performed insurance and employment physicals. In 1981 the first fully automated oscillometric blood pressure cuff was invented by Donald Nunn.

Figure 1: Digital Sphygmomanometer

2 Stethoscope

2.1 Introduction

The stethoscope is an acoustic medical device for auscultation, or listening to internal sounds of an animal or human body. It typically has a small disc-shaped resonator that is placed against the skin, and one or two tubes connected to two earpieces. A stethoscope can be used to listen to the sounds made by the heart, lungs or intestines, as well as blood flow in arteries and veins. In combination with a manual sphygmomanometer, it is commonly used when measuring blood pressure.
Less commonly, "mechanic's stethoscopes", equipped with rod shaped chestpieces, are used to listen to internal sounds made by machines (for example, sounds and vibrations emitted by worn ball bearings), such as diagnosing a malfunctioning automobile engine by listening to the sounds of its internal parts. Stethoscopes can also be used to check scientific vacuum chambers for leaks and for various other small-scale acoustic monitoring tasks.

2.2 Current practice

Stethoscopes are a symbol of healthcare professionals. Healthcare providers are often seen or depicted wearing a stethoscope around the neck. A 2012 research paper claimed that the stethoscope, when compared to other medical equipment, had the highest positive impact on the perceived trustworthiness of the practitioner seen with it.
Prevailing opinions on the utility of the stethoscope in current clinical practice vary depending on the medical specialty. Studies have shown that auscultation skill (i.e., the ability to make a diagnosis based on what is heard through a stethoscope) has been in decline for some time, such that some medical educators are working to re-establish it.
In general practice, traditional blood pressure measurement using a mechanical sphygmomanometer with inflatable cuff and stethoscope is gradually being replaced with automated blood pressure monitors.

2.3 History

The stethoscope was invented in France in 1816 by René Laennec at the Necker-Enfants Malades Hospital in Paris. It consisted of a wooden tube and was monaural. Laennec invented the stethoscope because he was not comfortable placing his ear directly onto a woman's chest to listen to her heart.He observed that a rolled piece of paper, placed between the individual's chest and his ear, could amplify heart sounds without requiring physical contact. Laennec's device was similar to the common ear trumpet, a historical form of hearing aid; indeed, his invention was almost indistinguishable in structure and function from the trumpet, which was commonly called a "microphone". Laennec called his device the "stethoscope" (stetho- + -scope, "chest scope"), and he called its use

"mediate auscultation", because it was auscultation with a tool intermediate between the individual's body and the physician's ear. (Today the word auscultation denotes all such listening, mediate or not.) The first flexible stethoscope of any sort may have been a binaural instrument with articulated joints not very clearly described in 1829. In 1840, Golding Bird described a stethoscope he had been using with a flexible tube. Bird was the first to publish a description of such a stethoscope, but he noted in his paper the prior existence of an earlier design (which he thought was of little utility) which he described as the snake ear trumpet. Bird's stethoscope had a single earpiece.
Several other minor refinements were made to stethoscopes until, in the early 1960s, David Littmann, a Harvard Medical School professor, created a new stethoscope that was lighter than previous models and had improved acoustics. In the late 1970s, 3M-Littmann introduced the tunable diaphragm: a very hard (G-10) glass-epoxy resin diaphragm member with an overmolded silicone flexible acoustic surround which permitted increased excursion of the diaphragm member in a Z-axis with respect to the plane of the sound collecting area.The left shift to a lower resonant frequency increases the volume of some low frequency sounds due to the longer waves propagated by the increased excursion of the hard diaphragm member suspended in the concentric accountic surround. Conversely, restricting excursion of the diaphragm by pressing the stethoscope diaphragm surface firmly against the anatomical area overlying the physiological sounds of interest, the acoustic surround could also be used to dampen excursion of the diaphragm in response to "z"-axis pressure against a concentric fret. This raises the frequency bias by shortening the wavelength to auscultate a higher range of physiological sounds.

2.4 Types

2.4.1 Acoustic

Acoustic stethoscopes operate on the transmission of sound from the chest piece, via air-filled hollow tubes, to the listener's ears. The chestpiece usually consists of two sides that can be placed against the patient for sensing sound: a diaphragm (plastic disc) or bell (hollow cup). If the diaphragm is placed on the patient, body sounds vibrate the diaphragm, creating acoustic pressure waves which travel up the tubing to the listener's ears. If the bell is placed on the patient, the vibrations of the skin directly produce acoustic pressure waves traveling up to the listener's ears. The bell transmits low frequency sounds, while the diaphragm transmits higher frequency sounds. To deliver the acoustic energy primarily to either the bell or diaphragm, the tube connecting into the chamber between bell and diaphragm is open on only one side and can rotate. The opening is visible when connected into the bell. Rotating the tube 180 degrees in the head connects it to the diaphragm. This two-sided stethoscope was invented by Rappaport and Sprague in the early part of the 20th century.One problem with acoustic stethoscopes was that the sound level was extremely low. This problem was surmounted in 1999 with the invention of the stratified continuous

(inner) lumen, and the kinetic acoustic mechanism in 2002.

2.4.2 Electronic

An electronic stethoscope (or stethophone) overcomes the low sound levels by electronically amplifying body sounds. However, amplification of stethoscope contact artifacts, and component cutoffs (frequency response thresholds of electronic stethoscope microphones, pre-amps, amps, and speakers) limit electronically amplified stethoscopes' overall utility by amplifying mid-range sounds, while simultaneously attenuating high- and low- frequency range sounds. Currently, a number of companies offer electronic stethoscopes. Electronic stethoscopes require conversion of acoustic sound waves to electrical signals which can then be amplified and processed for optimal listening. Unlike acoustic stethoscopes, which are all based on the same physics, transducers in electronic stethoscopes vary widely. The simplest and least effective method of sound detection is achieved by placing a microphone in the chestpiece. This method suffers from ambient noise interference and has fallen out of favor. Another method, used in Welch-Allyn's Meditron stethoscope, comprises placement of a piezoelectric crystal at the head of a metal shaft, the bottom of the shaft making contact with a diaphragm. 3M also uses a piezo-electric crystal placed within foam behind a thick rubber-like diaphragm. The Thinklabs' Rhythm 32 uses an electromagnetic diaphragm with a conductive inner surface to form a capacitive sensor. This diaphragm responds to sound waves, with changes in an electric field replacing changes in air pressure. The Eko Core enables wireless transmission of heart sounds to a smartphone or tablet.
Because the sounds are transmitted electronically, an electronic stethoscope can be a wireless device, can be a recording device, and can provide noise reduction, signal enhancement, and both visual and audio output. Around 2001, Stethographics introduced PC-based software which enabled a phonocardiograph, graphic representation of cardiologic and pulmonologic sounds to be generated, and interpreted according to related algorithms. All of these features are helpful for purposes of telemedicine (remote diagnosis) and teaching.

Figure 2: Modern stethoscope

3 Thermometer

3.1 Introduction

A thermometer is a device that measures temperature or a temperature gradient (the degree of hotness or coldness of an object). A thermometer has two important elements: (1) a temperature sensor (e.g. the bulb of a mercury-in-glass thermometer or the pyrometric sensor in an infrared thermometer) in which some change occurs with a change in temperature; and (2) some means of converting this change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer or the digital readout on an infrared model). Thermometers are widely used in technology and industry to monitor processes, in meteorology, in medicine, and in scientific research.

3.2 History

While an individual thermometer is able to measure degrees of hotness, the readings on two thermometers cannot be compared unless they conform to an agreed scale. Today there is an absolute thermodynamic temperature scale. Internationally agreed temperature scales are designed to approximate this closely, based on fixed points and interpolating thermometers. The most recent official temperature scale is the International Temperature Scale of 1990. It extends from 0.65 K (272.5 °C; 458.5 °F) to approximately 1,358 K (1,085 °C; 1,985 °F).

3.3 Physical principles of thermometry

Thermometers may be described as empirical or absolute. Absolute thermometers are calibrated numerically by the thermodynamic absolute temperature scale. Empirical thermometers are not in general necessarily in exact agreement with absolute thermometers as to their numerical scale readings, but to qualify as thermometers at all they must agree with absolute thermometers and with each other in the following way: given any two bodies isolated in their separate respective thermodynamic equilibrium states, all thermometers agree as to which of the two has the higher temperature, or that the two have equal temperatures. For any two empirical thermometers, this does not require that the relation between their numerical scale readings be linear, but it does require that relation to be strictly monotonic. This is a fundamental character of temperature and thermometers.
As it is customarily stated in textbooks, taken alone, the so-called "zeroth law of thermodynamics" fails to deliver this information, but the statement of the zeroth law of thermodynamics by James Serrin in 1977, though rather mathematically abstract, is more informative for thermometry:"Zeroth Law – There exists a topological line M which serves as a coordinate manifold of material behaviour. The points L of the manifold M are called 'hotness levels', and M is called the 'universal hotness manifold'." To this information there needs to be added a sense of greater hotness; this sense can be had, independently of

calorimetry, of thermodynamics, and of properties of particular materials, from Wien's displacement law of thermal radiation: the temperature of a bath of thermal radiation is proportional, by a universal constant, to the frequency of the maximum of its frequency spectrum; this frequency is always positive, but can have values that tend to zero. Another way of identifying hotter as opposed to colder conditions is supplied by Planck's principle, that when a process of isochoric adiabatic work is the sole means of change of internal energy of a closed system, the final state of the system is never colder than the initial state; except for phase changes with latent heat, it is hotter than the initial state.
There are several principles on which empirical thermometers are built, as listed in the section of this article entitled "Primary and secondary thermometers". Several such principles are essentially based on the constitutive relation between the state of a suitably selected particular material and its temperature. Only some materials are suitable for this purpose, and they may be considered as "thermometric materials". Radiometric thermometry, in contrast, can be only slightly dependent on the constitutive relations of materials. In a sense then, radiometric thermometry might be thought of as "universal". This is because it rests mainly on a universality character of thermodynamic equilibrium, that it has the universal property of producing blackbody radiation.

3.4 Thermometric materials

There are various kinds of empirical thermometer based on material properties.

Many empirical thermometers rely on the constitutive relation between pressure, volume and temperature of their thermometric material. For example, mercury expands when heated.If it is used for its relation between pressure and volume and temperature, a thermometric material must have three properties:

(1) Its heating and cooling must be rapid. That is to say, when a quantity of heat enters or leaves a body of the material, the material must expand or contract to its final volume or reach its final pressure and must reach its final temperature with practically no delay; some of the heat that enters can be considered to change the volume of the body at constant temperature, and is called the latent heat of expansion at constant temperature; and the rest of it can be considered to change the temperature of the body at constant volume, and is called the specific heat at constant volume. Some materials do not have this property, and take some time to distribute the heat between temperature and volume change.

(2) Its heating and cooling must be reversible. That is to say, the material must be able to be heated and cooled indefinitely often by the same increment and decrement of heat, and still return to its original pressure, volume and temperature every time. Some plastics do not have this property;

(3) Its heating and cooling must be monotonic.That is to say, throughout the range of temperatures for which it is intended to work,

(a) at a given fixed pressure, either (i) the volume increases when the temperature increases, or else (ii) the volume decreases when the temperature increases; but not (i) for some temperatures and (ii) for others; or (b) at a given

fixed volume, either (i) the pressure increases when the temperature increases, or else (ii) the pressure decreases when the temperature increases; but not (i) for some temperatures and (ii) for others. At temperatures around about 4 °C, water does not have the property (3), and is said to behave anomalously in this respect; thus water cannot be used as a material for this kind of thermometry for temperature ranges near 4 °C.

Gases, on the other hand, all have the properties (1), (2), and (3)(a)() and (3)(b)(). Consequently, they are suitable thermometric materials, and that is why they were important in the development of thermometry.

Figure 3: Non-contact Body Infrared Thermometer

Figure 4: Mercury thermometer

4 Pulse oximetry

4.1 Introduction

Pulse oximetry is a noninvasive method for monitoring a person's oxygen saturation. Peripheral oxygen saturation (SpO2) readings are typically within 2percent accuracy (within 4percent accuracy in 95percent of cases) of the more accurate (and invasive) reading of arterial oxygen saturation (SaO2) from arterial blood gas analysis. But the two are correlated well enough that the safe, convenient, noninvasive, inexpensive pulse oximetry method is valuable for measuring oxygen saturation in clinical use.

The most common approach is transmissive pulse oximetry. In this approach, a sensor device is placed on a thin part of the patient's body, usually a fingertip or earlobe, or an infant's foot. Fingertips and earlobes have higher blood flow rates than other tissues, which facilitates heat transfer. The device passes two wavelengths of light through the body part to a photodetector. It measures the changing absorbance at each of the wavelengths, allowing it to determine the absorbances due to the pulsing arterial blood alone, excluding venous blood, skin, bone, muscle, fat, and (in most cases) nail polish.

4.2 Medical uses

A pulse oximeter is a medical device that indirectly monitors the oxygen saturation of a patient's blood (as opposed to measuring oxygen saturation directly through a blood sample) and changes in blood volume in the skin, producing a photoplethysmogram that may be further processed into other measurements. The pulse oximeter may be incorporated into a multiparameter patient monitor. Most monitors also display the pulse rate. Portable, battery-operated pulse oximeters are also available for transport or home blood-oxygen monitoring.

4.3 Advantages

Pulse oximetry is particularly convenient for noninvasive continuous measurement of blood oxygen saturation. In contrast, blood gas levels must otherwise be determined in a laboratory on a drawn blood sample. Pulse oximetry is useful in any setting where a patient's oxygenation is unstable, including intensive care, operating, recovery, emergency and hospital ward settings, pilots in unpressurized aircraft, for assessment of any patient's oxygenation, and determining the effectiveness of or need for supplemental oxygen. Although a pulse oximeter is used to monitor oxygenation, it cannot determine the metabolism of oxygen, or the amount of oxygen being used by a patient. For this purpose, it is necessary to also measure carbon dioxide (CO2) levels. It is possible that it can also be used to detect abnormalities in ventilation. However, the use of a pulse oximeter to detect hypoventilation is impaired with the use of supplemental oxygen, as it is only when patients breathe room air that abnormalities in respiratory function can be detected reliably with its use. Therefore, the routine administration

of supplemental oxygen may be unwarranted if the patient is able to maintain adequate oxygenation in room air, since it can result in hypoventilation going undetected.

4.4 Limitations

Pulse oximetry solely measures hemoglobin saturation, not ventilation and is not a complete measure of respiratory sufficiency. It is not a substitute for blood gases checked in a laboratory, because it gives no indication of base deficit, carbon dioxide levels, blood pH, or bicarbonate (HCO3) concentration. The metabolism of oxygen can be readily measured by monitoring expired CO2, but saturation figures give no information about blood oxygen content. Most of the oxygen in the blood is carried by hemoglobin; in severe anemia, the blood contains less hemoglobin, which despite being saturated cannot carry as much oxygen.

4.5 Mechanism

A blood-oxygen monitor displays the percentage of blood that is loaded with oxygen. More specifically, it measures what percentage of hemoglobin, the protein in blood that carries oxygen, is loaded. Acceptable normal SaO2 ranges for patients without pulmonary pathology are from 95 to 99 percent. For a person breathing room air at or near sea level, an estimate of arterial pO2 can be made from the blood-oxygen monitor "saturation of peripheral oxygen" (SpO2) reading.

4.6 Mode of operation

A typical pulse oximeter uses an electronic processor and a pair of small light-emitting diodes (LEDs) facing a photodiode through a translucent part of the patient's body, usually a fingertip or an earlobe. One LED is red, with wavelength of 660 nm, and the other is infrared with a wavelength of 940 nm. Absorption of light at these wavelengths differs significantly between blood loaded with oxygen and blood lacking oxygen. Oxygenated hemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated hemoglobin allows more infrared light to pass through and absorbs more red light. The LEDs sequence through their cycle of one on, then the other, then both off about thirty times per second which allows the photodiode to respond to the red and infrared light separately and also adjust for the ambient light baseline.
The amount of light that is transmitted (in other words, that is not absorbed) is measured, and separate normalized signals are produced for each wavelength. These signals fluctuate in time because the amount of arterial blood that is present increases (literally pulses) with each heartbeat. By subtracting the minimum transmitted light from the transmitted light in each wavelength, the

effects of other tissues are corrected for, generating a continuous signal for pulsatile arterial blood. The ratio of the red light measurement to the infrared light measurement is then calculated by the processor (which represents the ratio of oxygenated hemoglobin to deoxygenated hemoglobin), and this ratio is then converted to SpO2 by the processor based on the Beer–Lambert law. The signal separation also serves other purposes: a plethysmograph waveform ("pleth wave") representing the pulsatile signal is usually displayed for a visual indication of the pulses as well as signal quality, and a numeric ratio between the pulsatile and baseline absorbance ("perfusion index") can be used to evaluate perfusion

$$SpO_2 = \frac{HbO2}{HbO2 + Hb} SpO_2 = \frac{HbO2}{HbO2 + Hb}$$

4.7 History

The first pulse oximetry was developed in 1972, by Japanese bioengineers, Takuo Aoyagi and Michio Kishi, at a Japanese medical electronic equipment manufacturer, Nihon Kohden, using the ratio of red to infrared light absorption of pulsating components at the measuring site. Nihon Kohden manufactured the first pulse oximeter, Ear Oximeter OLV-5100, and Susumu Nakajima, a surgeon, and his associates first tested the device in patients, reporting it in 1975. However, Nihon Kohden suspended the development of pulse oximetry and didn't apply for a basic patent of pulse oximetry except in Japan. In 1977, Minolta commercialized the first finger pulse oximeter OXIMET MET-1471. In the U.S., it was commercialized by Biox in 1980

Figure 5: Pulse Oximeter

5 Ventilator

5.1 Introduction

A ventilator is a machine that provides mechanical ventilation by moving breathable air into and out of the lungs, to deliver breaths to a patient who is physically unable to breathe, or breathing insufficiently. Ventilators are computerized microprocessor-controlled machines, but patients can also be ventilated with a simple, hand-operated bag valve mask. Ventilators are chiefly used in intensive-care medicine, home care, and emergency medicine (as standalone units) and in anesthesiology (as a component of an anesthesia machine).
Ventilators are sometimes called "respirators", a term commonly used for them in the 1950s (particularly the "Bird respirator"). However, contemporary hospital and medical terminology uses the word "respirator" to refer instead to a face-mask that protects wearers against hazardous airborne substances

5.2 Function

In its simplest form, a modern positive pressure ventilator consists of a compressible air reservoir or turbine, air and oxygen supplies, a set of valves and tubes, and a disposable or reusable "patient circuit". The air reservoir is pneumatically compressed several times a minute to deliver room-air, or in most cases, an air/oxygen mixture to the patient. If a turbine is used, the turbine pushes air through the ventilator, with a flow valve adjusting pressure to meet patient-specific parameters. When over pressure is released, the patient will exhale passively due to the lungs' elasticity, the exhaled air being released usually through a one-way valve within the patient circuit called the patient manifold. Ventilators may also be equipped with monitoring and alarm systems for patient-related parameters (e.g., pressure, volume, and flow) and ventilator function (e.g., air leakage, power failure, mechanical failure), backup batteries, oxygen tanks, and remote control. The pneumatic system is nowadays often replaced by a computer-controlled turbopump.
Modern ventilators are electronically controlled by a small embedded system to allow exact adaptation of pressure and flow characteristics to an individual patient's needs. Fine-tuned ventilator settings also serve to make ventilation more tolerable and comfortable for the patient. In Canada and the United States, respiratory therapists are responsible for tuning these settings, while biomedical technologists are responsible for the maintenance. In the United Kingdom and Europe the management of the patient's interaction with the ventilator is done by critical care nurses.
The patient circuit usually consists of a set of three durable, yet lightweight plastic tubes, separated by function (e.g. inhaled air, patient pressure, exhaled air). Determined by the type of ventilation needed, the patient-end of the circuit may be either noninvasive or invasive.
Noninvasive methods, such as continuous positive airway pressure (CPAP) and non-invasive ventilation, which are adequate for patients who require a ven-

tilator only while sleeping and resting, mainly employ a nasal mask. Invasive methods require intubation, which for long-term ventilator dependence will normally be a tracheotomy cannula, as this is much more comfortable and practical for long-term care than is larynx or nasal intubation.

5.3 Life-critical system

Because failure may result in death, mechanical ventilation systems are classified as life-critical systems, and precautions must be taken to ensure that they are highly reliable, including their power supply. Ventilatory failure is the inability to sustain a sufficient rate of CO2 elimination to maintain a stable pH without mechanical assistance, muscle fatigue, or intolerable dyspnea. Mechanical ventilators are therefore carefully designed so that no single point of failure can endanger the patient. They may have manual backup mechanisms to enable hand-driven respiration in the absence of power (such as the mechanical ventilator integrated into an anaesthetic machine). They may also have safety valves, which open to atmosphere in the absence of power to act as an anti-suffocation valve for spontaneous breathing of the patient. Some systems are also equipped with compressed-gas tanks, air compressors or backup batteries to provide ventilation in case of power failure or defective gas supplies, and methods to operate or call for help if their mechanisms or software fail. Power failures, such as during a natural disaster, can create a life-threatening emergency for people using ventilators in a home care setting.Battery power may be sufficient for a brief loss of electricity, but longer power outages may require going to a hospital.

5.4 History

The 1955 release of Forrest Bird's "Bird Universal Medical Respirator" in the United States changed the way mechanical ventilation was performed, with the small green box becoming a familiar piece of medical equipment. The unit was sold as the Bird Mark 7 Respirator and informally called the "Bird". It was a pneumatic device and therefore required no electrical power source to operate.
In 1965, the Army Emergency Respirator was developed in collaboration with the Harry Diamond Laboratories (now part of the U.S. Army Research Laboratory) and Walter Reed Army Institute of Research. Its design incorporated the principle of fluid amplification in order to govern pneumatic functions. Fluid amplification allowed the respirator to be manufactured entirely without moving parts, yet capable of complex resuscitative functions. Elimination of moving parts increased performance reliability and minimized maintenance.[10] The mask is composed of a poly(methyl methacrylate) (commercially known as Lucite) block, about the size of a pack of cards, with machined channels and a cemented or screwed-in cover plate. The reduction of moving parts cut manufacturing costs and increased durability.
Intensive care environments around the world revolutionized in 1971 by the introduction of the first SERVO 900 ventilator (Elema-Schönander), constructed by Björn Jonson. It was a small, silent and effective electronic ventilator, with

the famous SERVO feedback system controlling what had been set and regulating delivery. For the first time, the machine could deliver the set volume in volume control ventilation.

5.5 COVID-19 pandemic

The COVID-19 pandemic has led to shortages of essential goods and services - from hand sanitizers to masks to beds to ventilators. Countries around the world have experienced shortages of ventilators. Furthermore, fifty-four governments, including many in Europe and Asia, imposed restrictions on medical supply exports in response to the coronavirus pandemic.
The capacities to produce and distribute invasive and non-invasive ventilators vary by country. In the initial phase of the pandemic, China ramped up its production of ventilators, secured large amounts of donations from private firms, and dramatically increased imports of medical devices worldwide. As a result, the country accumulated a reservoir of ventilators throughout the pandemic in Wuhan. Western Europe and the United States, which outrank China in their production capacities, suffered a shortage of supplies due to the sudden and scattered outbreaks throughout the North American and European continents. Finally, Central Asia, Africa, and Latin America, which depend almost entirely on importing ventilators, suffered severe shortages of supplies.
Healthcare policy-makers have met serious challenges to estimate the number of ventilators needed and used during the pandemic. When data is often not available for ventilators specifically, estimates are sometimes made based on the number of intensive care unit beds available, which often contain ventilators.

Figure 6: ventilator