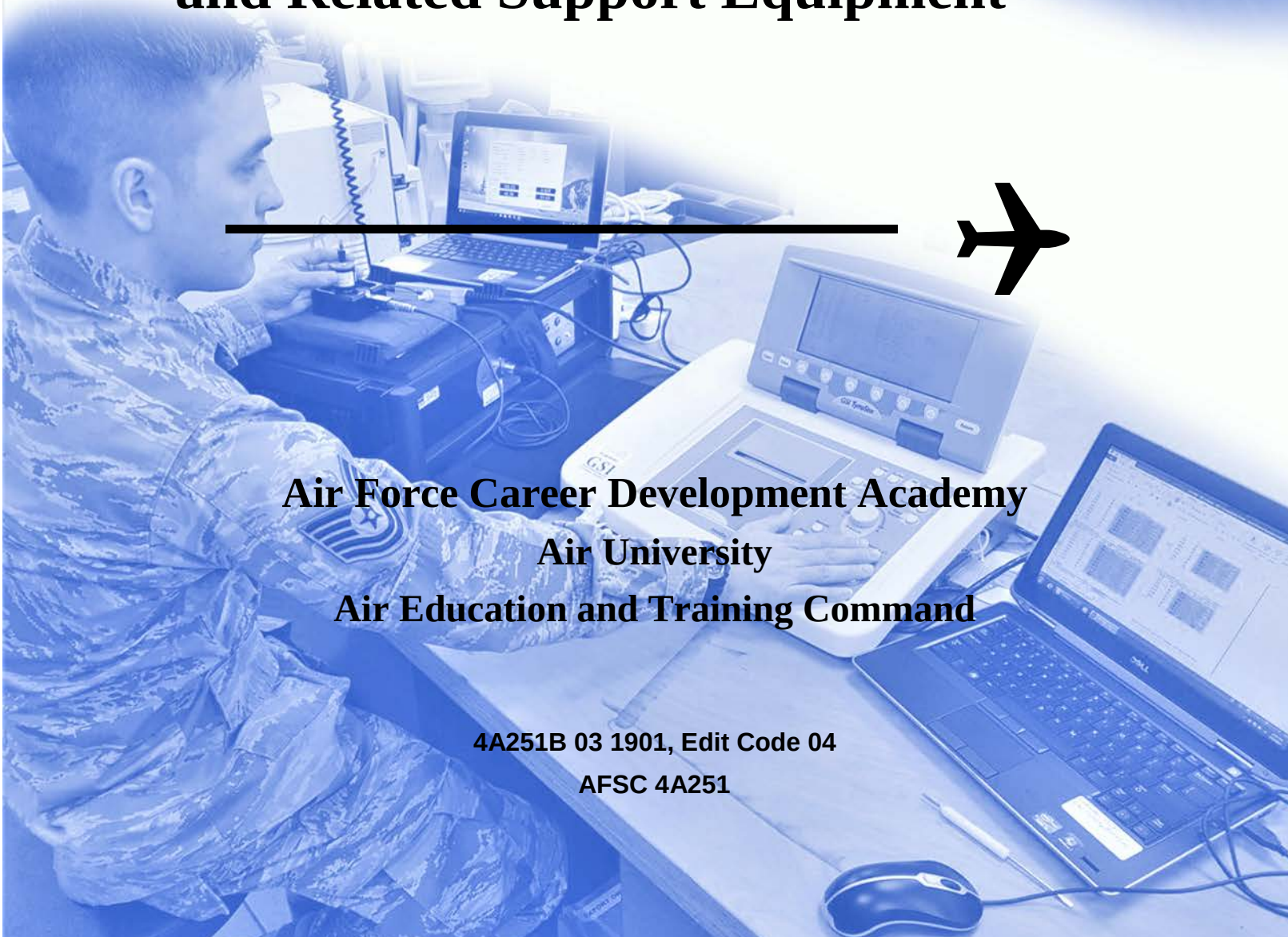
CDC 4A251B

Biomedical Equipment Journeyman

Volume 3. Diagnostic (Non-Imaging) and Related Support Equipment



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Air University

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Author: MSgt Matthew J. Colica, CBET, Sec+
MSgt Jason E. Johnson, CBET, Sec+
382d Training Squadron
59th Training Group (AETC)
382 TRS/TRR
3068 William Hardee Road, MIF 1 Building 899
JBSA Ft. Sam Houston, TX 78234
DSN: 420-1775
E-mail address: matthew.j.colica.mil@mail.mil
jason.e.johnson1.mil@mail.mil

Instructional Systems Specialist: Dr. Kenith Isreal

Editor: Sandra F. Glenn

Air Force Career Development Academy (AFCDA)
Air University (AETC)
Maxwell AFB-Gunter Annex, Alabama

THIS IS THE third volume of CDC 4A251B. This volume of the Biomedical Equipment Journeyman course will take us into the world of diagnostic equipment; the material contained within this volume is extremely important and should garner your full attention. The journey through this volume will take you through three units. The information in the volume begins with the fundamentals of applied physics, and anatomy and physiology, and concludes with diagnostic support equipment.

Unit 1 of this volume covers anatomy and physiology of the eye, ear, and blood. The unit also covers material on the principles of optics and acoustics, as they relate to the medical equipment that follows.

Unit 2 moves on to the non-imaging side of diagnostic equipment and will familiarize you with units including audiometers, tympanometers, optometric/ophthalmic equipment, electrocardiographs, and pulmonary function testers. This unit concludes with inpatient, and labor and delivery monitoring equipment such as physiological monitors, central patient monitoring systems, multiparameter patient simulators, and finally fetal heart monitors.

The volume concludes with Unit 3, which contains information on various diagnostic support equipment. The unit begins with surgical optics, where you will learn about fiberoptic scopes and scope towers, as well as scope washers needed for disinfection. We then move onto the clinical laboratory, which includes units such as tissue processors, centrifuges, electronic particle counters, blood gas analyzers, chemistry analyzers, electrolyte analyzers, deoxyribonucleic acid (DNA) analyzers, and various microscopes. The volume wraps up with miscellaneous support equipment, to include stress test systems and treadmills along with fume hoods.

A glossary is included for your use.

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For Guard and Reserve personnel, this volume is valued at 16 hours and 4 points.

Acknowledgment

PREPARATION of this volume was aided through the cooperation and courtesy of several industry partners. Advanced Analytical Technologies, Inc., Fluke Biomedical, Richard Wolf Medical Instrumentation Corporation, Spacelabs Medical, and Wikimedia Commons provided graphical and literature support. Permission to use this information is gratefully acknowledged.

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Company	Literature	CDC Figure Number
Advanced Analytical Technologies, Inc.	AATI - ZAG™ DNA Analyzer	3-13
Fluke Biomedical Corporation	ProSim™ 8, Vital Signs Simulator Users Manual January 2011, Rev. 3, 3/16	3-36 to 3-39
Richard Wolf Medical Instrumentation Corporation	www.corexcel.com/courses2/body.flexible.endoscopes.title.htm and www.corexcel.com/courses2/rigid.endoscopes.title.htm	3-1 to 3-4
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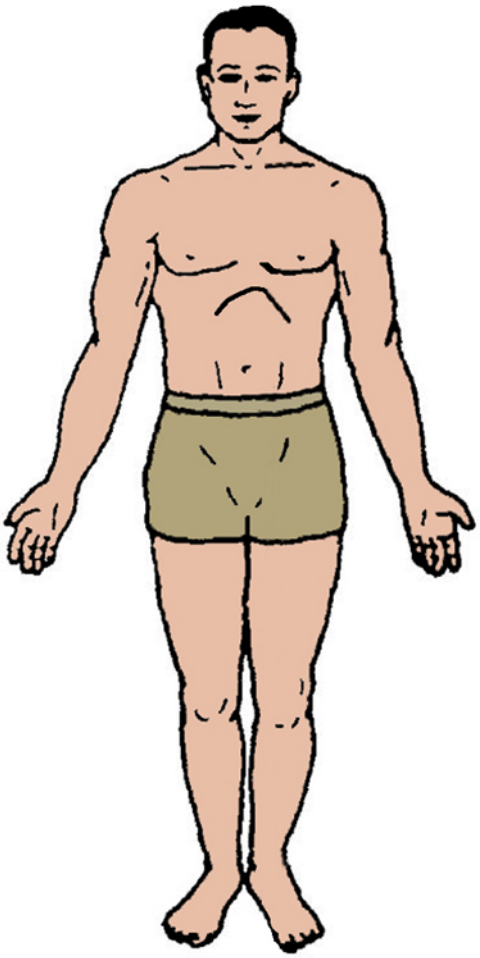
NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Page

Anatomy, Physiology, and Applied Physics



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Unit 1. Anatomy, Physiology, and Applied Physics

MUCH OF THE MEDICAL equipment you work on is used to diagnose a patient (either their illness or level of health). Often when we think of diagnostic equipment, we think of X-ray or imaging equipment; however, a vast majority of diagnostic equipment in the medical treatment facility (MTF) is the non-imaging type. This career development course (CDC) volume will cover many of these "non-imaging" diagnostic equipment items.

Before we get into specific equipment and its uses, it is necessary for you to understand some basic principles that make this particular equipment operate. In this unit, we will explore some anatomy and physiology related to the equipment covered in other units of this volume. We will also discuss two important physics principles involved in this equipment: optics and acoustics. The information in this unit is not designed to make you an expert in the fields of anatomy, physiology, and physics; however, a certain depth must be reached to prepare you to understand the equipment and its function. That being said, let's get started with some anatomy and physiology.

1–1. Related Anatomy and Physiology

The human body is a marvelous thing with many different parts which function together as a team. We often do not think about the internal workings of our bodies (until something goes wrong!), but we do use the sensing ability of our body on a continual basis. Two of those sensory organs are the ear and the eye, which we will cover in this section. We will also cover the blood, which works to keep all parts of our body alive and well. Let's begin with the sense of hearing and the human ear.

401. The human ear

In a later unit of this volume, we will cover the audiometer; however, to understand the purpose of an audiometer, you must understand the system the audiometer evaluates—the auditory system of the human body.

Structure and function of the ear

The ear is a three-part structure composed of an outer ear, middle ear, and inner ear. It acts as a receptor for the sense of hearing and for equilibrium. Most of the structures that make up the ear are involved in the sense of hearing. It is capable of collecting sound waves from the air, changing those waves to vibrations, amplifying the vibrations, and transferring them through bone, fluid, and various tissues. The ear stimulates the auditory receptors to convert those vibrations into nerve impulses, and then sends those impulses to the brain for interpretation. That, in a nutshell, is what hearing is all about. Now, let's explore just how that system works.

Outer ear

The outer ear closely resembles a funnel in shape and function. It consists of the auricle or pinna (fig. 1–1), and the external auditory canal. The auricle is the cartilaginous framework that collects sound waves and directs them through the external auditory canal to the tympanic membrane (eardrum). The canal is a slightly curved tube, approximately 1-inch long. It passes into the cranium through the temporal bone. Protective hairs surround the external opening, and the canal itself is a thin layer of skin containing numerous modified sweat glands called ceruminous glands. These glands secrete a

waxy substance called cerumen or “ear wax” that helps keep the canal moist. The glands also trap dust and foreign particles that might otherwise enter the ear. As sound waves pass through the canal, they cause changes in the air pressure around the membrane. These changes cause the tympanic membrane to vibrate.

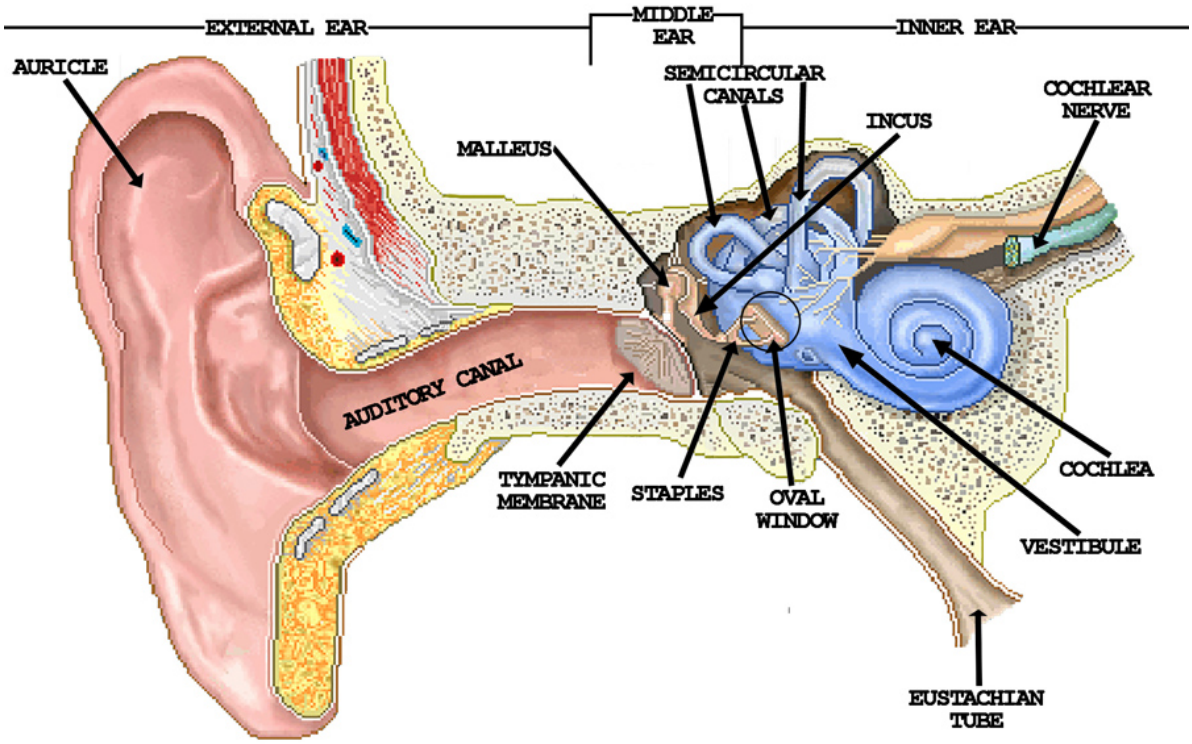

Figure 1–1. The ear.

Middle ear

The middle ear is located within a cavity of the temporal bone called the tympanic cavity. This cavity is lined with mucous membrane, and contains the tympanic membrane and three tiny ear bones called auditory ossicles.

The tympanic membrane stretches across the ear canal and separates the external ear from the middle ear. It is a thin, tough, almost transparent membrane, lined externally with skin and internally with mucous membrane. This membrane has an oval, somewhat concave, shape with the curve directed inward. At the point, or apex, of the curve, it attaches to one of the ossicles. In addition to receiving sound waves, the membrane protects the middle and inner ear from foreign particles.

As we mentioned, the tympanic membrane vibrates in response to sound waves. These vibrations then transfer through the ossicles to the inner ear. These ossicles are the smallest bones in the body and get their name according to their shape. The ossicle attached to the tympanic membrane is called the malleus or hammer. The “handle” of the malleus attaches to the tympanic membrane, and the “head” attaches to the second ossicle. The name of the second bone is the incus, because its shape roughly resembles an anvil. It connects the malleus to the third ossicle, the stapes. The stapes resembles a stirrup with the arch connecting to the incus and the oval-shaped base connecting to the inner ear.

The ossicles secure into position using ligaments that attach to the wall of the tympanic cavity. Ligaments also attach the malleus to the tympanic membrane, and the stapes to the inner ear. One muscle, the tensor tympanic, connects to the medial aspect of the malleus and acts to pull the malleus toward the inner ear. The other muscle, the stapedius, connects to the posterior aspect of the stapes and acts to pull the stapes toward the outer ear. The combined effect of these muscles is to tighten the

connection between the ossicles. This, in turn, reduces or dampens the vibrations. This combined action, called the tympanic reflex, is a protective reaction to loud noises. The tensor tympana maintain a constant tension on the malleus, except when the reflex activates. This pulls on the membrane and helps to keep the “drum” tight.

There are a number of openings into the middle ear. The tympanic membrane covers the opening to the external canal. The base of the stapes covers one opening into the inner ear, the oval window. A similar opening, the round window, also opens into the inner ear. There are a number of air spaces (mastoid spaces) that open into the middle ear. There is also an opening called the Eustachian tube that connects the middle ear to the pharynx.

The function of the Eustachian tube is to equalize the air pressure in the middle ear with that of the atmosphere. This pressure adjustment is especially important during air flight and under water. Unless the pressure can equalize, the eardrum may rupture. Flaps of skin cover the pharyngeal openings. Chewing, swallowing, or yawning causes these flaps to open so air can enter and equalize the pressure.

As the vibrations pass through the ossicles into the middle ear, they are amplified and concentrated. The arrangement of the ossicles produces a leverage effect, which amplifies the vibrations. By the time they reach the window, the vibrations are about 20 times stronger than they were at the eardrum.

Inner ear

The inner ear, or labyrinth, contains the receptors for hearing and equilibrium. It consists of a series of complicated canals located in a hollow portion of the temporal bone. The receptor for hearing is the organ of Corti, contained inside a fluid-filled, shell-like structure called the cochlea. The semi-circular canals are involved in determining equilibrium. Vibrations reach the cochlea from the external ear by way of the ossicles through the oval window. Their vibrations cause movement of the fluid within the cochlea, which stimulates the sensory nerve ending in the organ of Corti. The acoustic nerve relays impulses from the organ of Corti to the hearing center in the temporal lobe of the brain.

Sound properties

Pressure changes are what cause sound. A vibrating tuning fork sets up pressure waves much like how a stone thrown in a pond sets up circular waves that move outward. The ear converts these pressure waves to nervous impulses, which relay to the brain. The brain interprets these impulses as sound. This is, of course, a simple interpretation; but the ear and its associated neural pathways are more complex than any electrical system developed by humans.

For maximum effect, the ear operates within the limits of the rest of the body. For example, the ear responds much less to frequencies of 100 Hertz (Hz) than it does for frequencies of 1,000 Hz. The reason for this is most of the noises made by the human body (e.g., muscle movements and organ noises) fall below the 100-Hz level. Since these noises would cloud our senses, the ear does not respond to them. This response window is known as the audible frequency range. This range does extend from a very low limit with some individuals of 16 Hz to a high limit of approximately 20 kilohertz (kHz).

402. The human eye

The eye consists of various structures controlled by a small network of muscles. The eye is the organ of vision, a highly specialized sense organ. It is in a cone-shaped, bony cavity called the orbit. Seven cranial bones form the orbit and, along with the eyelashes, eyelids, and eyebrows, protect this delicate organ.

Layers of the eye

As you can see in figure 1–2, the eyeball has three coats or layers: the sclera, choroid, and retina.

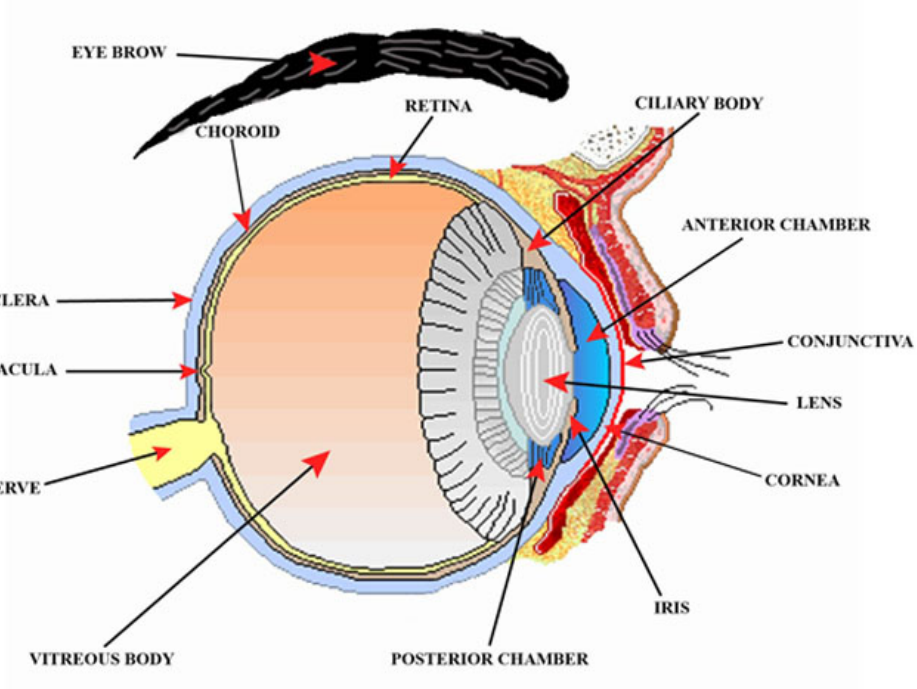

Figure 1–2. The eye.

Outer layer

The outer layer of the eye is the sclera. The front part of the sclera is the cornea, which is transparent. The cornea is merely a small area of the anterior sclera and has five layers. The sclera is resistant to stretching and tearing, and provides strength to the fluid-filled eyeball. If something cuts or penetrates the outer layer, it is possible for the fluid content of the eye to leak out. You could compare this to letting the air out of a tire; a tire with a hole in it will eventually collapse—so can the eye.

Middle layer

The middle layer of the eye consists of the choroid, which includes the iris, and ciliary body. The choroid is a highly vascular layer suppling the eye with nutrition and lines its posterior portion. The iris is a thin, circular-shaped membrane that gives the eye its color. It resembles the shutter of a camera and surrounds the pupil, which is the opening the light rays pass through. The iris has a hole in it that regulates the opening (dilation) and closing (contraction) of the pupil. This action of the iris helps the eye adjust to existing brightness and, thus, prevents injury. At night or on a cloudy day, the pupil dilates and lets in more light.

The ciliary body suspends the iris and crystalline lens, and contains the ciliary muscles, which make movement of the lens possible. The lens is a transparent body just behind the pupil that focuses light upon the retina. It automatically changes its shape to accommodate near or distant vision and assures the image we see focuses on the retina. The older we become the lenses of our eyes lose their transparency, which can develop into a cataract. Well-developed cataracts are gray opacities in the lens. Unless surgically removed, they can cause a gradual loss of vision.

Inner layer

The innermost layer of the eye is the retina, a delicate membrane that receives the images. It is a complex network of nerve cells and fibers, called rods and cones, which convert light rays and images to nerve impulses. These impulses transmit to the brain by way of the optic nerve.

Look again at figure 1–2 and notice the eye contains two cavities. The anterior cavity contains the anterior chamber, located in front of the lens, and the posterior chamber, located behind the iris. These two chambers contain a clear, watery fluid called aqueous humor. This fluid bathes the lens

and helps refract light rays. The posterior cavity, located behind the lens, is the vitreous body. The vitreous body contains a gelatin-like substance, called the vitreous humor, which maintains the shape of the eye.

The fluid or aqueous solution is constantly forming and diffusing out of the eye into the blood. It is the lymph of the eye. This fluid normally maintains a balance between the amount formed and the amount diffused out of the eye. This balance is necessary to maintain normal intraocular pressure. An increase in the intraocular pressure causes a condition called glaucoma, which is the result of an obstruction of the flow of aqueous humor between the posterior and anterior chambers of the eye.

Eye muscles

The muscles of the eye are of two muscle groups—intrinsic and extrinsic. The intrinsic muscles are inside the globe or eyeball and include the iris muscles and ciliary body muscles. The iris muscles function in light. In bright light, they reduce the size of the pupil; in dim light, they enlarge the pupil. The pupil contracts to view near objects and dilates to view far objects. The ciliary body muscles control the shape of the lens.

A total of seven muscles make up the extrinsic muscles, which are outside the globe. One end of each muscle attaches to the orbit, and the other end attaches to the sclera. The levator palpebrae superioris is a muscle that attaches to the eyelid and is responsible for superior eyelid movement. The other six ocular extrinsic muscles attach to the eye and control the different movements made by the eyes. The six muscles and their functions are:

1. Medial rectus – adducts the eyeball on one axis.
2. Lateral rectus – abducts the eyeball on one axis.
3. Superior rectus – elevates, adducts, and rotates the eyeball medially.
4. Inferior rectus – depresses, adducts, and rotates the eyeball laterally.
5. Superior oblique – depresses, abducts, and rotates the eyeball medially.
6. Inferior oblique – elevates, abducts, and rotates the eyeball laterally.

Figure 1–3 shows the six ocular muscles from a lateral view of the eyeball. Under normal circumstances, the ocular muscles finely balance and automatically coordinate the movement of both eyes, so they look in the same direction at the same time. When one or more of them becomes paralyzed or weak, a condition called strabismus results (a deviation of the eye the patient cannot overcome).

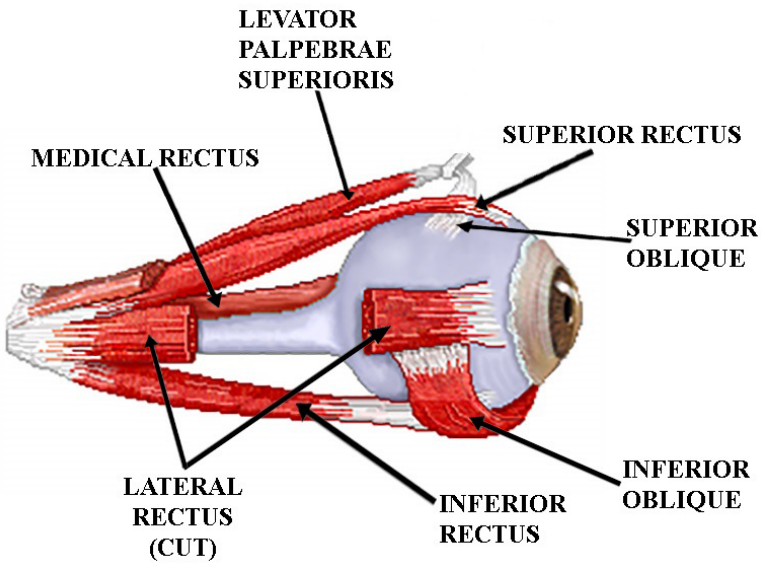

Figure 1–3. Eye muscles—lateral view.

Optical nerves

The second cranial nerve, called the optic nerve, connects to the eye directly behind the optic disc. These nerves carry visual impulses received by the rods and cones to the brain for interpretation and terminate in the occipital lobe of the brain.

Accessory structures

The accessory structures of the eye include the eyebrows, eyelids, and lachrymal apparatus. Each of these structures has a distinct and specialized function. The eyebrow overhangs the orbit to shade the eye from light and break the force of blows coming head-on. The eyelids are folds of connective tissue that protect the eye from foreign objects and excessive light. Contained within the eyelid are small sebaceous glands (Meibomian glands). Their tubes extend toward the edge of the lid and secrete a lubricant that serves to grease the lid margin and hold back tears from running down the face. The lachrymal apparatus consists of a lachrymal gland about the size and shape of an almond. Its function is to produce tears when we cry or when our eye is irritated. Smaller accessory glands secrete most of the tears that keep the front of the eye always moist.

403. Blood physiology

This lesson first covers the physiology of blood, so you may better understand the clinical uses of selected lab equipment. After blood physiology, we will explore how the blood performs external and internal respiration functions.

Hematology

Hematology is the study of blood and derives its name from two Greek words aima, meaning blood, and logos meaning study. Blood is a tissue in which the cells are suspended in a liquid medium. In this respect, it differs from other tissues of the body, which also are groups of specialized cells identified with a common function. The prime function of the blood is to maintain oxygen (O_2) and food supply for the body cells, and prevent accumulation of waste products. However, these are by no means the only functions of blood. Immunologic mechanisms, as well as other physical and chemical activities, involve the blood in many ways.

In practicing hematology, laboratory specialists are concerned more with measurable evidence of dysfunction than with the final result of blood functions. They observe blood cells, measure chemical constituents, and perform serological tests to identify problem areas. These are, as we stated, tasks performed by the laboratory technician. We seldom reflect on the many complicated tasks the blood must perform while we support the medical lab, but it is important you understand the functions of blood to enable you to become more familiar with the variety of specialized equipment found in today's hospital labs.

Note, in this lesson, we will be describing functions of the blood with reference to other body tissues supported by the blood. We are not especially concerned with the ways blood maintains itself. If its only function were to sustain itself, there would be no justification for its existence. Although you're not expected to arrive at clinical conclusions, you need to appreciate the interrelationships existing among the mechanisms the lab technician is attempting to measure in the laboratory.

Since blood has a variety of complex functions, the composition of blood must also be complex. The average circulating total blood volume in a healthy male is 73 milliliters (mL) per kilogram of body weight; in a healthy female, 63 mL per kilogram. Formed elements account for nearly 45 percent of the blood volume; 90 percent of the remaining 55 percent is water (H_2O), but the portion of liquid that is not H_2O includes an uncalculated number of organic and inorganic materials.

The following information on blood components includes the cells and the medium in which they are suspended. We will consider the functions of blood in terms of the cellular and noncellular components.

Blood constituents

The cellular components of blood are erythrocytes (red blood cells [RBC]), leukocytes (white blood cells [WBC]), and platelets or thrombocytes. Where do these cellular elements come from and what are their functions? First, let's look at the RBCs.

Erythrocytes

The RBC is a living, metabolically active cell and not merely a small globule of protein that transports hemoglobin. RBCs perform the most important blood duty—they constantly travel through the body delivering O_2 and removing waste.

RBCs are red because they contain a protein chemical called hemoglobin, which is bright red in color. Hemoglobin contains the element iron, which makes it an excellent vehicle for transporting O_2 and carbon dioxide (CO_2). As blood passes through the lungs, O_2 molecules attach to the hemoglobin. As the blood passes through the body's tissue, the hemoglobin releases the O_2 to the cells. The empty hemoglobin molecules then bond with the tissue's CO_2 or other waste gases, transporting it away.

Over time, the RBCs wear out and die. The average life cycle of an RBC is 120 days. Following birth, the red marrow of the spongy bones starts producing RBCs. In an adult, this is restricted to the ribs, sternum, vertebrae, certain skull bones, and the epiphyses (ends) of the femur and humerus. Your body does not remake blood all of the time; however, it continually recirculates the blood throughout your body.

Leukocytes

The purpose of WBCs is to fight infection or disease in the body. When a germ appears, WBCs have a variety of ways by which they can attack. Some will produce protective antibodies that overpower the germ, while others will surround and devour the bacteria. There are five main types of leukocytes and each has a distinct purpose:

1. Neutrophils – Contain granules of bacteria-killing enzymes.
2. Eosinophils – Attack protozoa that cause infection.
3. Basophils – Regulate allergic reactions, such as asthma, hives, hay fever, and adverse reactions to drugs. They also contain heparin, which helps prevent blood clotting.
4. Monocytes – Engulf and destroy invading bacteria and fungi, and clean up debris once other WBCs destroy foreign organisms.
5. Lymphocytes – Fight viral infections and assist in the destruction of other parasites, bacteria, and fungi.

WBCs have a rather short life span, living from a few days to a few weeks. A drop of blood can contain anywhere from 7,000 to 25,000 leukocytes at a time; however, if an invading infection fights back or persists, that number will significantly increase to help combat the infection.

Thrombocytes

Platelets, the smallest cell elements in blood, are irregularly shaped, colorless bodies present in the blood. They have a sticky surface that allows them, along with other substances, to form clots to stop bleeding. When bleeding from a wound starts, platelets gather at the wound and attempt to block the blood flow. The mineral calcium (Ca), vitamin K, and a protein called fibrinogen work in concert with the platelets to form a clot.

A clot begins to form when the blood receives air exposure. The platelets sense the presence of air and begin to break apart. They react with the fibrinogen to begin forming fibrin, which resembles tiny threads. The fibrin threads then begin to form a web-like mesh that traps the blood cells within it. This mesh of blood cells hardens as it dries, forming a clot, or "scab."

Plasma

Plasma is what remains after removing the cells from the blood. In addition to proteins, plasma contains certain metabolic components required by cells. Glucose is probably the single-most important food substance found in blood. Various ions present in plasma are also nutrients for body cells, as well as blood cells. All products of cells may also be found in the blood, including enzymes, antibodies, and hormones. Cellular waste products include urea, uric acid, and like compounds. In addition to dissolved solids, we find dissolved and combined gases. Foremost among these are O_2, CO_2, and nitrogen (N).

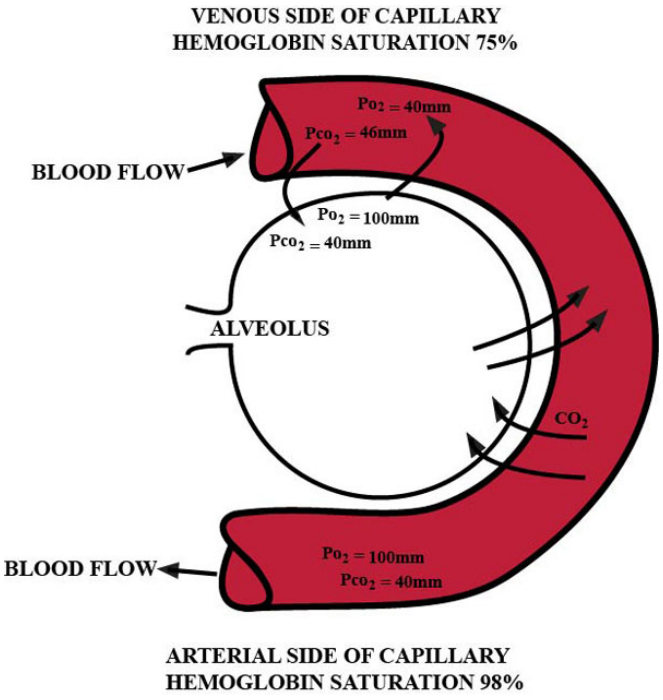

Figure 1–4. External respiration.

Respiration

External respiration is the exchange of gases between the alveoli of the lungs and the bloodstream (fig. 1–4). And conversely, internal respiration is the exchange of gases between the blood and tissue cells. Because respiration is a principal function of blood, we need to examine this process more closely. Please note we are not using the term "respiration" in the popular context of "breathing."

External respiration

The gases we are concerned with in the lungs, blood, and cells are N, O_2, CO_2, and H_2O vapor. It is convenient to discuss these gases in terms of their pressures or tensions. By doing so, the gas exchange mechanism—pressure gradients—can be more easily understood. Through experimentation, the average gas pressure values were determined. The knowledge of these gas pressures is important to the four places previously mentioned. The following table shows the average values in the alveoli, arterial blood, venous blood, and tissue cells:

Gas	Alveolus (millimeters of mercury [mmHg])	Arterial blood (mmHg)	Venous blood (mmHg)	Cell (mmHg)
O_2	100	100	40	1–60*
N	573	573	573	573
CO_2	40	40	46	46
H_2O vapor	47	47	47	47

* Tissue activity controls this value.

NOTE: The value for N is constant; therefore, there is no exchange of this gas during the respiratory phases.

When breathing air at a normal sea level pressure of 760 mmHg, important changes begin to occur as the air enters the conducting passages and progresses toward the alveoli. Since the passageways contain H_2O vapor at a pressure of 47 mmHg, the air is diluted by the H_2O vapor; consequently, the total air pressure is reduced by that amount (760 - 47 = 713). The moist air, now at a pressure of 713 mmHg, enters the bronchial tree, and then the alveoli. The alveoli, however, contain CO_2 at an average pressure of 40 mmHg and N at its constant pressure of 573 mmHg. The O_2 in the inspired air

just prior to entering the alveoli has a pressure of approximately 150 mmHg (21 percent of 713). The CO_2 present further penalizes this O_2 pressure until it has a value of 110 mmHg. The "calculated "alveolar partial pressure is the sum of oxygen (PO_2). Experimentation proved that this calculated value is slightly high. The alveolar PO_2 most frequently used is 100 mmHg. The slight difference is probably because neither the atmospheric composition nor the action of CO_2 and O_2 in the alveoli is static, as well as due to other slight physiological variances.

We consider the inflation of the alveoli to be static at a given point; figure 1–4 shows the relationship of the various gas pressures within the alveoli and bloodstream. The exchange of O_2 between the alveoli and capillary is due to the great difference between the pressures. Since, according to the law of gaseous diffusion, gases flow from a high-pressure area to one of lower pressure, O_2 diffuses through the walls of the alveoli and into the bloodstream. The pressure gradient is 60 mmHg. O_2 is constantly diffusing into the capillaries around the alveoli, and the exchange continues until reaching a value of 100 mmHg within each capillary. At this point, the hemoglobin of the RBCs saturates to approximately 98 percent of its capacity (fig. 1–4). Note the O_2 pressure in the venous side of the capillary is 40 mmHg. The percent saturation of the hemoglobin in this part of the capillary is, therefore, 75 percent. This process is one of oxygenation (not oxidation).

At the same time the exchange of O_2 is occurring, there is a similar transfer of the waste gas, CO_2. The pressure of CO_2 in venous blood is 46 mmHg; in the alveoli, it is 40 mmHg. The exchange proceeds from the capillary blood into the alveoli. Although the CO_2 pressure gradient is only 6 mmHg, a large quantity of gas flows across into the alveoli. This is because CO_2 has a greater coefficient of diffusion than does O_2. As this exchange continues throughout the course of the capillary, the pressure of CO_2 in the blood falls until it reaches its normal value of 40 mmHg.

As the two gases flow in and out of the alveoli, they oxygenate the blood. The O_2 content is high, and the CO_2 content is low. The blood then returns to the left side of the heart for pumping throughout the body to all tissue cells. At this level, the second phase of respiration—internal respiration—occurs.

Internal respiration

We now turn our attention to the exchange of gas between the blood and the tissue cells. The "pure" highly oxygenated blood with a low content of CO_2 leaves the left side of the heart with each contraction and travels throughout the arterial system to all of the capillaries.

The cells of all types of tissues are in contact with capillaries. As blood enters the arterial side of the capillary, the arterial blood gas tensions are O_2 – 100 mmHg and CO_2 – 40 mmHg (fig. 1–5). In the cell, oxidation is constantly occurring and, consequently, the O_2 content is at a low level. It varies in value, depending upon the activity of the cell at the time. A muscle cell, for example, during exercise has a lower O_2 pressure than during a period of rest. The O_2 tension can vary from about 1 mmHg to about 66 mmHg. Since the O_2 pressure in the blood on the arterial side of the capillary is always higher than in the tissue cell, a large pressure gradient exists

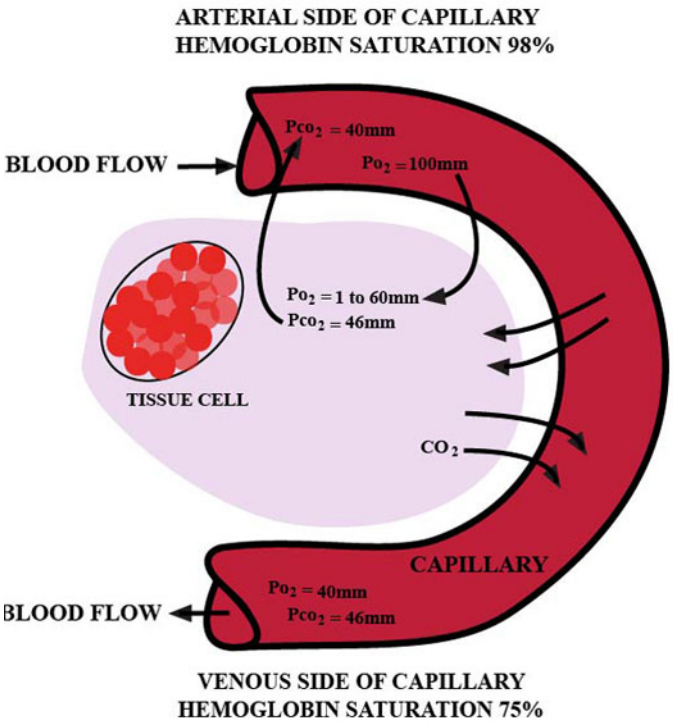

Figure 1–5. Internal respiration.

and there is a flow of O_2 to the lower pressure—in this case, from the blood into the cell. This transfer of O_2 is actually occurring throughout the length of the capillary until the pressure of O_2 in the blood gains equilibrium with the O_2 pressure in the cell.

While the transfer of O_2 is occurring, there is also a transfer of CO_2. The constant metabolic activity of the cell results in a high production of CO_2. The tension of CO_2 reaches 46 mmHg. In the arterial blood in the capillary, the tension of CO_2 is about 40 mmHg. Even though a much smaller pressure gradient exists for this gas than for O_2, the cell forces a larger amount of CO_2 into the blood, due to the diffusion characteristics of CO_2. As this transfer continues, the CO_2 tension in the blood increases to a level of about 46 mmHg. Some of the CO_2 combines with hemoglobin; some carry on in the plasma. The total exchange completes as the arterial blood passes the cell and enters the venous system. The blood returns to the heart for pumping to the lungs via the pulmonary artery for another cycle of gaseous exchange. External respiration then repeats.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. The human ear

1. Where is the auricle located?

2. What is the function of the auricle?

3. Exactly where is the middle ear located?

4. Name the function of the tympanic membrane.

5. Which part of the middle ear serves the function of transmitting vibrations from the tympanic membrane to the inner ear?

6. Which part of the middle ear connects the middle ear cavity with the pharynx?

7. Where is the organ of Corti contained?

8. Why is the ear relatively insensitive to frequencies below 100 Hz?

402. The human eye

1. What is the name of the outermost layer of the eye?

2. What is the function of the sclera?

3. What is the name of the segment of the middle layer of the eye responsible for supplying the eye with nutrition?

4. What regulatory function does the iris have?

5. Which segment of the eye automatically changes its shape to accommodate near or distant vision?

6. Which segment, located in the innermost layer of the eye, receives images and transmits them to the brain?

7. Match each term in column B with its description or function in column A. Select the items in column B only once.

Column A	*Column B*
____ (1) Abducts the eyeball on one axis.	a. Medial rectus.
____ (2) Elevates, abducts, and rotates the eyeball laterally.	b. Lateral rectus.
____ (3) Depresses, adducts, and rotates the eyeball laterally.	c. Superior rectus.
____ (4) Adducts the eyeball on one axis.	d. Inferior rectus.
____ (5) Elevates, adducts, and rotates the eyeball medially.	e. Superior oblique.
____ (6) Depresses, abducts, and rotates the eyeball medially.	f. Inferior oblique.
____ (7) Protects the eye from foreign objects and excessive light.	g. Eyebrow.
____ (8) Secretes a lubricant to grease the lid margin.	h. Eyelid.
____ (9) Breaks the force of blows coming head-on.	i. Meibomian glands.
____ (10) Produces tears because of crying or irritation of the eye.	j. Lachrymal apparatus.

403. Blood physiology

1. What word describes the study of blood and where did it come from?

2. What is the average circulating total blood volume for a healthy male? For a healthy female?

3. List the cellular components of blood.

4. What is contained within hemoglobin that makes it an excellent vehicle for transporting O_2 and CO_2?

5. What is the average life cycle for an RBC?

6. List the five main types of leukocytes.

7. What purpose do thrombocytes serve?

8. What is left from blood after all cells have been removed?

9. List the gases discussed in the external respiration process.

10. What is the normal pressure of air at sea level?

11. Describe the law of gaseous diffusion.

12. What is the pressure of CO_2 in venous blood?

1–2. Related Physics Principles

The following principles will prepare you for the equipment you will see in the remainder of this volume. The two principles we will focus on are optics and acoustics. Obviously, optics relates to the optometric and ophthalmic instruments, as well as the fiber-optic systems we will cover; while acoustics relates to the audiometric equipment we will also discuss. Let's begin with the principle of optics.

404. Optics

Every object you view either emits or reflects light. Optics is the part of science that deals with light, including how it originates and how we manipulate it. These are the concepts that we will explore in this lesson. As with other areas of physics, you don't need to be an expert, but a thorough understanding of optic principles will help you to better understand the equipment you are tasked to work on. So, let's get started with some important principles about optics.

Principles

We will focus on some of the basic, and most important, principles of optics, to include reflection, refraction, diffraction, and interference.

Reflection

Early scientists working with light discovered it always travels in a straight line. While this was a truth, these same scientists also found they could change the direction of light by aiming it at a mirror.

They found the light would bounce off at an equal angle. This discovery, known as reflection, is a fundamental rule of optics.

At the beginning of this lesson, we stated all visible objects either emit or reflect light. If an object does not emit light (which accounts for most objects in the world), it must reflect light to be seen. The walls in the room where you are sitting do not emit light; rather, they reflect the light from the ceiling lights in the room.

Reflection involves two rays:

1. An incoming or incident ray.
2. An outgoing or reflected ray.

Figure 1–6 illustrates the principle of reflection and its related law, known as Snell's Law. The law states the angle of incidence (striking) and the angle of reflection are always equal. In figure 1–6, you can see the angles on either side of the imaginary perpendicular centerline (dashed) are equal. This shows the angles of incidence (i) and reflection (i') are equal.

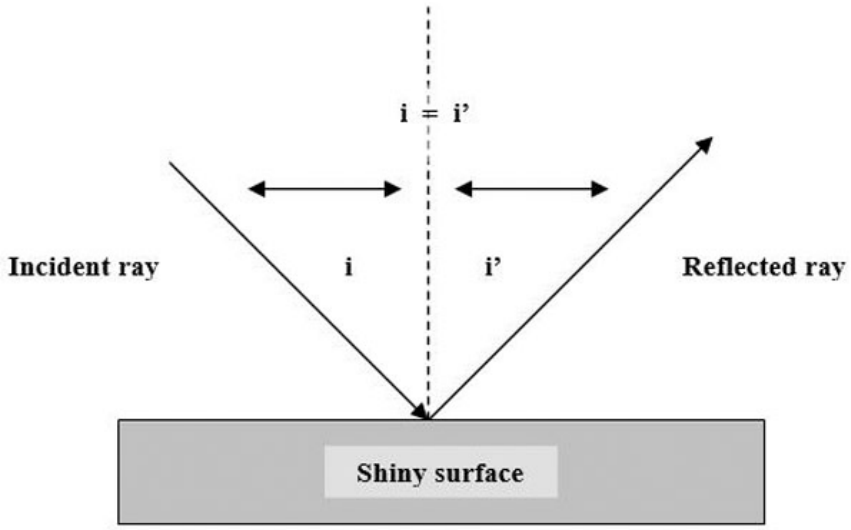

Figure 1–6. Light reflection.

This law is a constant, but it involves two different types of reflection. The first, known as specular reflection, occurs when light reflects off a smooth, shiny surface. The second, known as diffuse reflection, occurs when light reflects off a rough surface. You can easily understand these two types of reflection by thinking of sunlight reflecting off water. If the water is smooth, the light will reflect off it smoothly; however, if the water has ripples in it, the light will still obey Snell's law and reflect off it at the same angle it struck, but there will be different regions of the water to strike causing the light to reflect in different directions (fig. 1–7).

Refraction

Earlier, we stated light always travels in a straight line; however, have you ever noticed how an object sitting in water (a fishing line in a pond for instance) seems to bend? This is an example of refraction. Simply put, light does travel in a straight line; however, it may deflect when it enters a new medium. This is why the appearance of the fishing line seems to bend. After the deflection, it will continue to travel in a straight line (fig. 1–8). Of course, the amount of deflection depends on the medium that deflects it. Each transparent substance, which refracts light, has a corresponding numeric value called a material refractive index. Later research in the field of optics found that the speed at which light travels through a material determines its refractive index. In short, the higher a material's refractive index, the slower light travels through it; so, refraction is changing the speed of light.

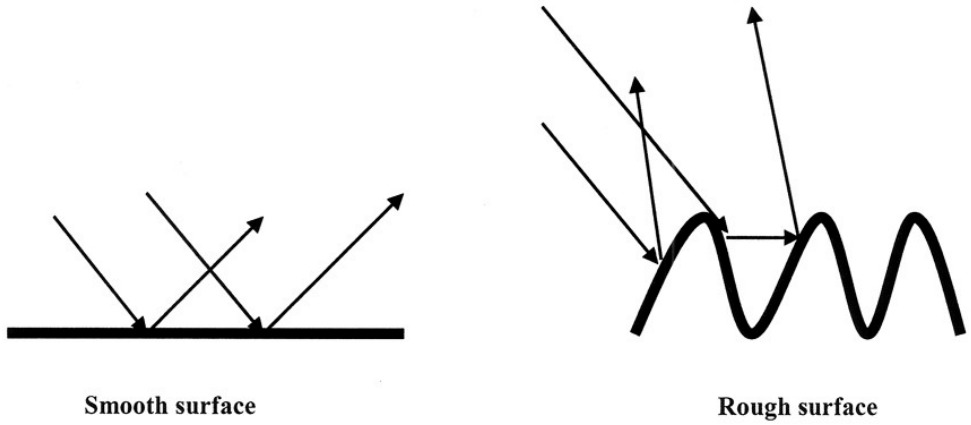

Figure 1–7. Specular vs. diffuse reflection.

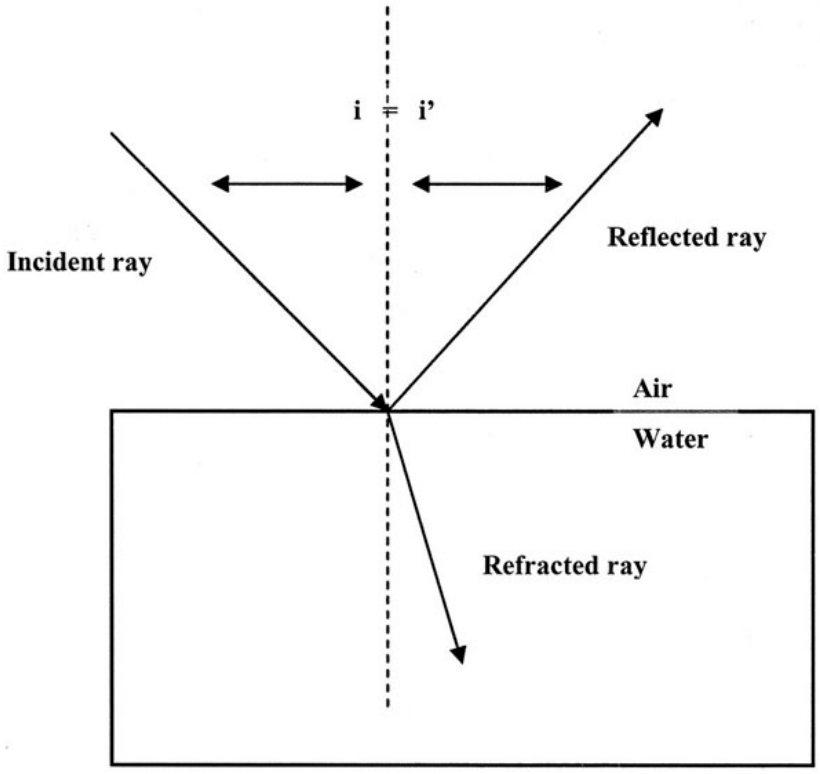

Figure 1–8. Refraction.

One important discovery about refraction we haven't touched on yet is the phenomenon known as total internal reflection. This occurs when a propagated wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal surface. If the refractive index of one substance is lower on the other side of the boundary (i.e., as it is between air and glass) and the incident angle is greater than the critical angle, the wave cannot pass through and is entirely reflected. When this happens, the light bends so much that all of it reflects and none escapes.

As you can see in figure 1–9, when light first strikes the glass, its direction changes. The medical field takes advantage of this phenomenon in fiber optic scopes. Fiber optic cables are made from glass rods; when light enters the end of a glass rod, it doesn't shine through the sides but is reflected back to the inside (internal reflection). The internal reflection repeats, all the way down the length of the rod until the light comes out the other side. The glass rods in fiber optic cable even allow the light to continue around corners when the cable is bent.

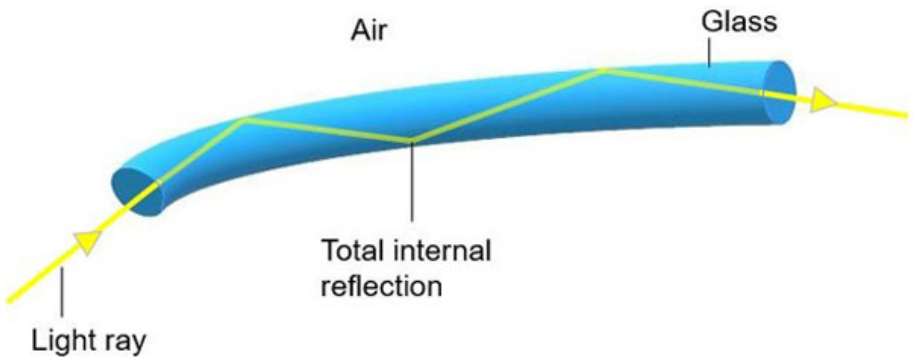

Figure 1–9. The principle of total internal reflection.

Here is another noteworthy fact about refraction. The degree light bends not depends only on the substance it is passing through, but also the color of the light, which leads us to the spectrum. Sir Isaac Newton found when he passed light through a prism in a dark room, it emerged out the other side as a series of brilliant colors, otherwise known as the light spectrum (actually a small part of the electromagnetic spectrum, fig. 1–10). The light spectrum starts with the color red at one end and goes through orange, yellow, green, blue, indigo, and violet at the other end. Newton further found if the spectrum were directed through another prism, it would recombine to form white light again (that is how we know white light is actually a combination of all colors).

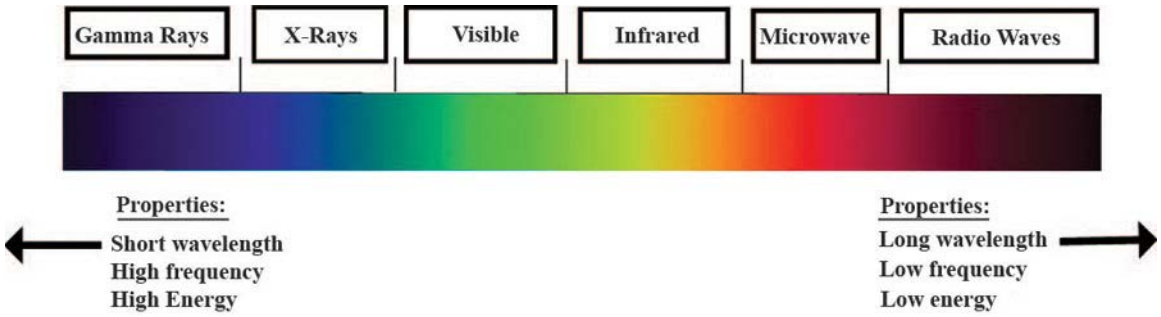

Figure 1–10. The electromagnetic spectrum.

Diffraction

The phenomenon of diffraction takes place when light waves bend as they pass around an object. The amount a waveform bends depends upon the wavelength of the light and the size of the object. Diffracted light can produce many different effects, such as dark or colored bands. Diffracted light is also what causes shadows to appear fuzzy. These optical effects are caused by our next phenomenon—interference.

Interference

Interference describes the overlapping of light waves, which results in either amplification or cancellation of the waves. The best way to explain this phenomenon is by thinking of light waves as ripples in a lake. If you were in a boat on the lake, ripples on the water would cause the boat to bob up and down, which would produce more ripples. The new ripples would either combine with the existing ripples to form bigger ripples, or crash into the existing ripples, thus canceling them out. When a light wave amplifies another light wave, this is known as constructive interference (fig. 1–11, A). Conversely, if a light wave cancels another light wave, it creates destructive interference (fig. 1–11, B).

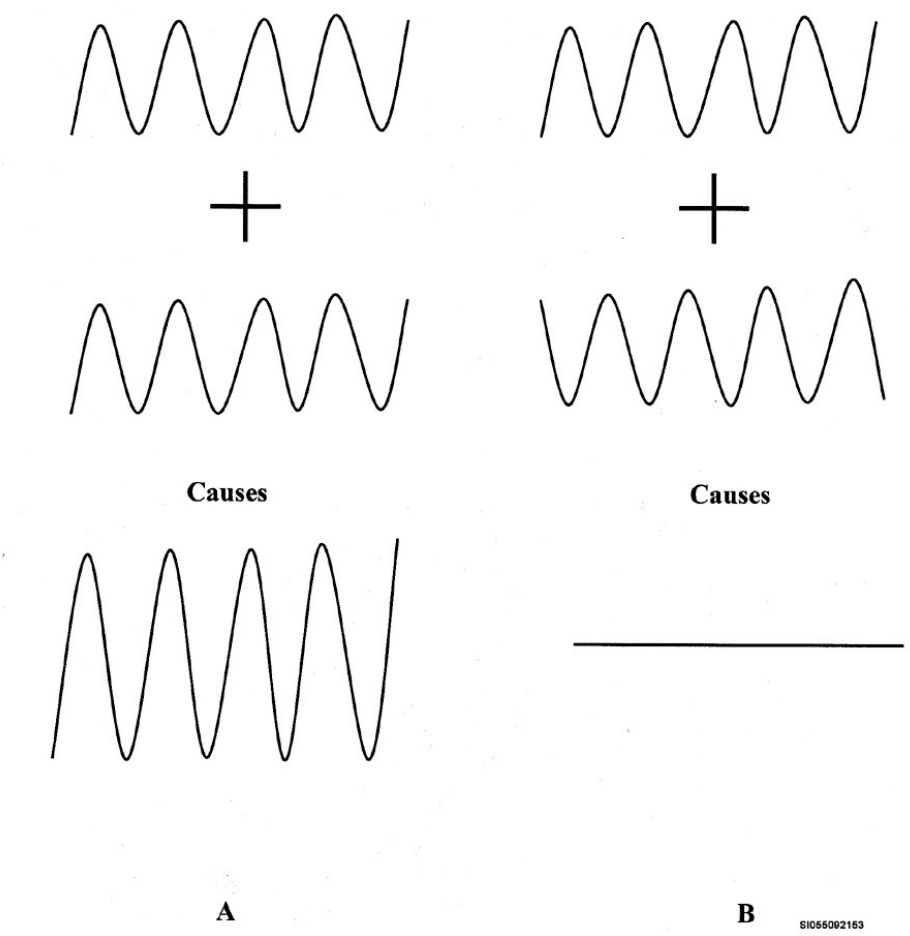

Figure 1–11. The phenomenon of interference.

Lenses

The discoveries of these principles allowed early pioneers of optics to develop and refine optical instruments, such as the telescope. While you won't likely be working on any telescopes in your biomedical equipment technician (BMET) career, telescopes do contain lenses, which are common to many of the medical instruments you will see. The lenses in optical equipment all work on the same principle we just learned—light bends as it goes from one medium to the next. One important point to make about optical instruments is the lenses within them can either have a concave or convex shape.

Convex lens

If a lens is convex (thin at the edge and thick in the middle), parallel rays of light that reach the lens are bent into a pattern of converging rays and focused on a single spot. The convex lens bends the light rays inward and creates an inverted image on the other side of the lens (fig. 1–12).

Concave lens

If a lens is concave (thick at the edge and thin in the middle), light rays are spread and an effect opposite that of a convex lens occurs. With the concave lens, light rays diverge so they do not actually meet to create an image. The way we see the image is when some of the diverging rays enter the eye, they seem to produce an image. We perceive the refracted rays as if they had traveled in straight lines; therefore, the eye sees an image closer to the lens and smaller than the object (fig. 1–13). Because of the way we see the image with a concave lens, the image is known as a virtual image (only a convex lens will produce a "real" image).

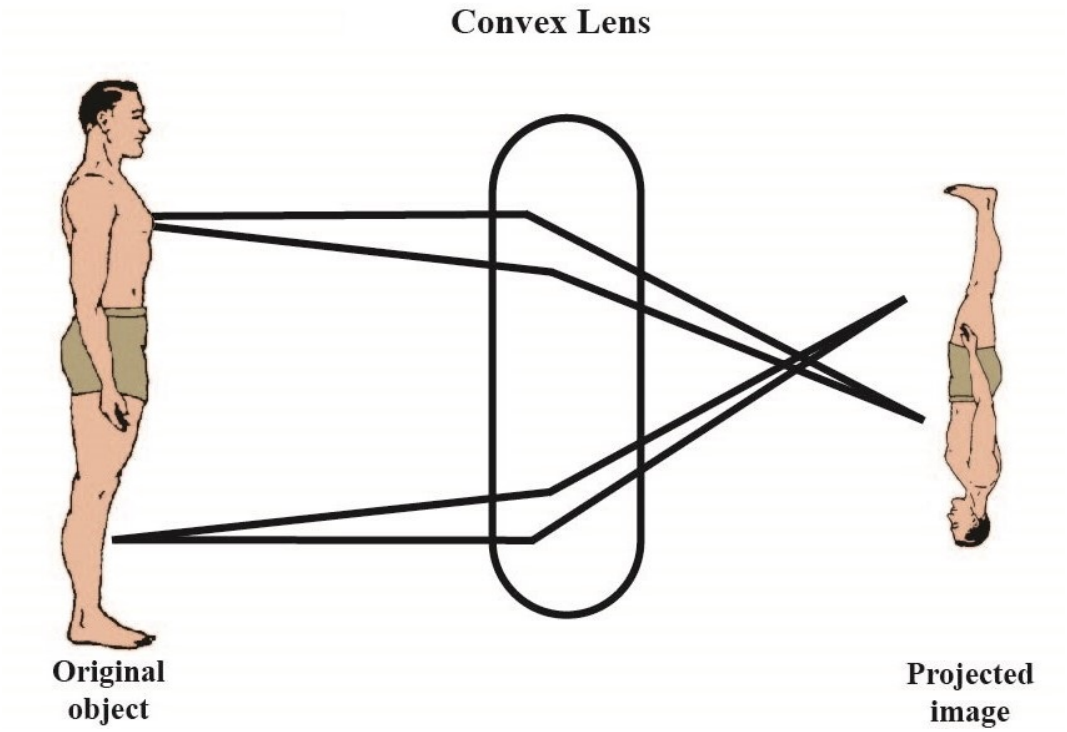

Figure 1–12. Convex lens.

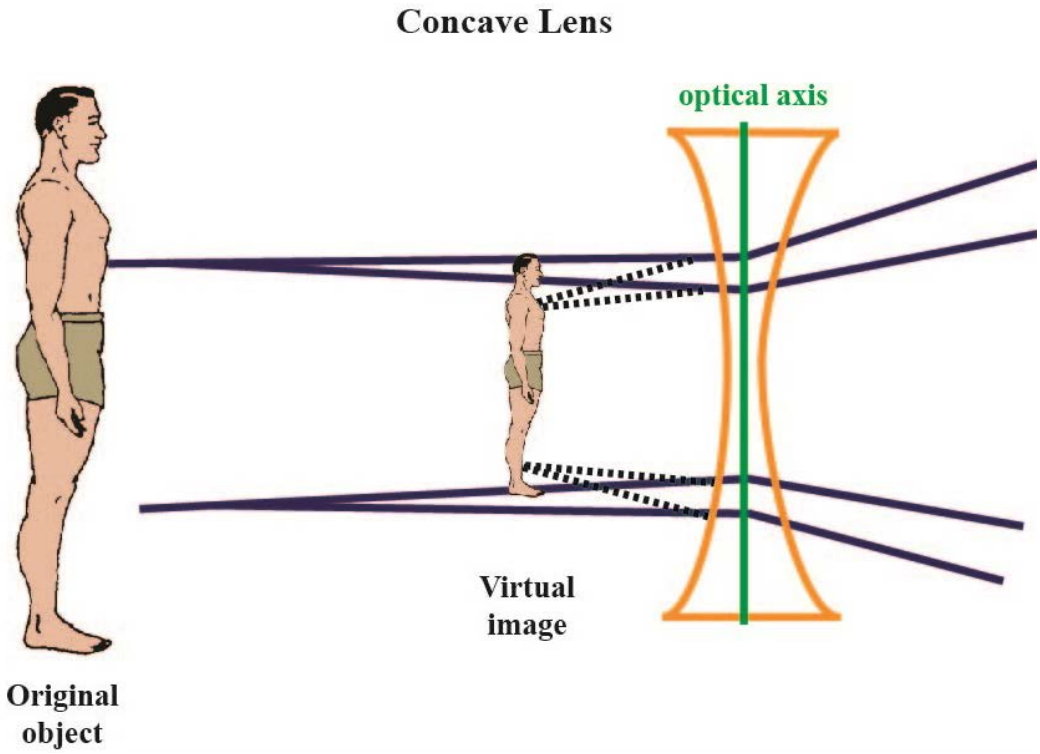

Figure 1–13. Concave lens.

Focal length

Most lenses can be described by one characteristic—their focal length. To understand the focal length, you must first know about the focal point. The focal point is the point at which light rays converge after they leave a lens. The focal length of a lens is the distance from the lens to the focal point (fig. 1–14); all lenses have unique focal lengths.

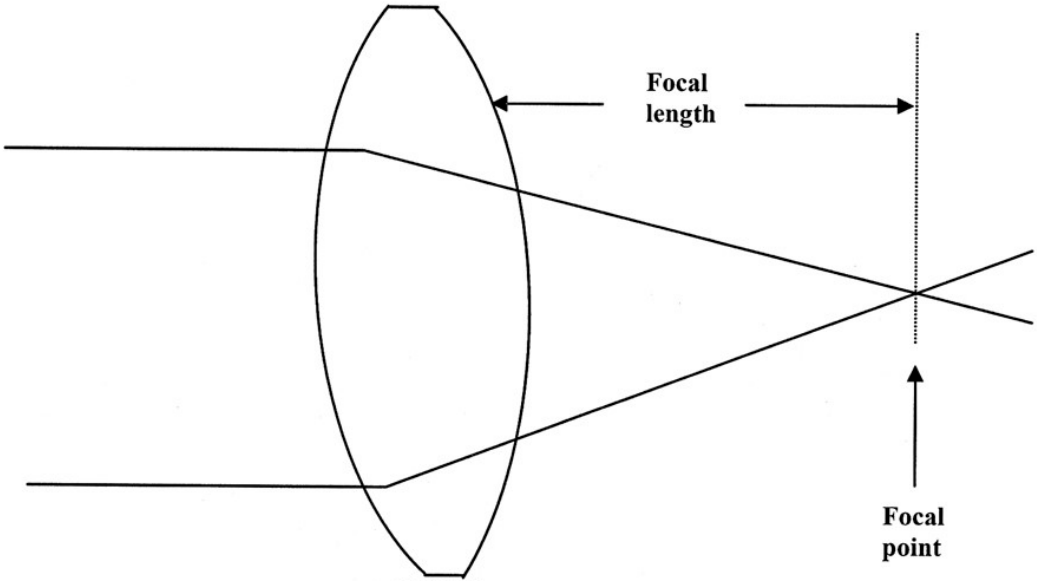

Figure 1–14. Focal point and focal length.

There are two different types of focal length—negative and positive. Negative focal length means the focal point is on the same side of the lens as where the original object is placed (concave lens); positive focal length means the focal point is on the side opposite of where the original object is placed (convex lens).

405. Acoustics

Now that you have a thorough understanding of optical principles, it's time to move on to some principles of sound, known as acoustics. One thing sound and light have in common is they are waveforms. This is where we will start with our discussion of acoustics.

Characteristics of sound waves

As already stated, sound and light are waveforms. More specifically, sound is a compression waveform that moves through the air or some other material. Sound waves are caused by the vibration of an object and are detected when they cause a sensor (such as your eardrum) to vibrate. While the characteristics of a sound wave are similar to a light wave, there are some wave characteristics that weren't covered in our discussion of light, which are important for you to better understand sound.

Amplitude

This characteristic should be familiar to you since we covered it in the 4A251A CDC throughout the lessons about electronics. The only difference here is we are talking about a sound wave, rather than an electronic signal. The amplitude of a sound wave determines how loud a sound is. The image in figure 1–15 demonstrates how to measure the amplitude of a sound wave.

Tone

There are several interrelated characteristics that determine the tone, or pitch, of a sound wave: period, frequency, and wavelength. Let's take a quick look at each of these individually.

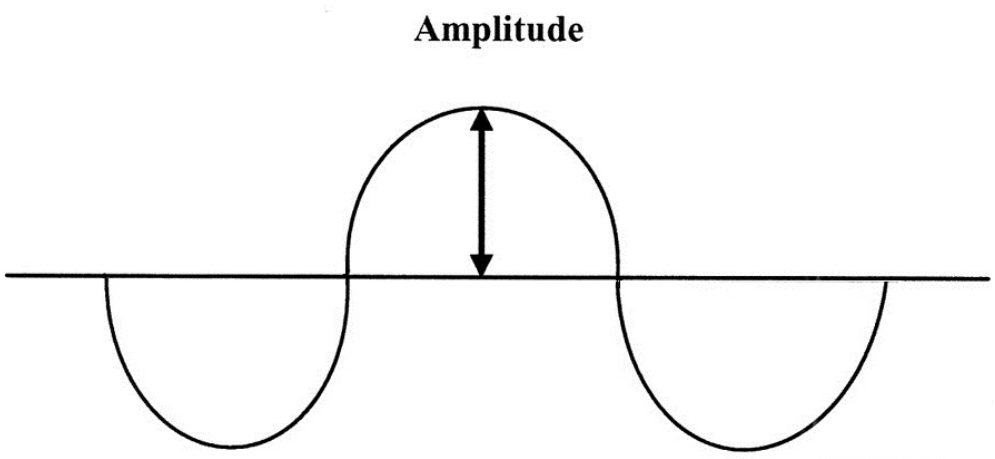

Figure 1–15. Amplitude of a sound wave.

Period

Figure 1–16 indicates one cycle of a sound wave. The time it takes to complete one cycle is the period of a sound wave.

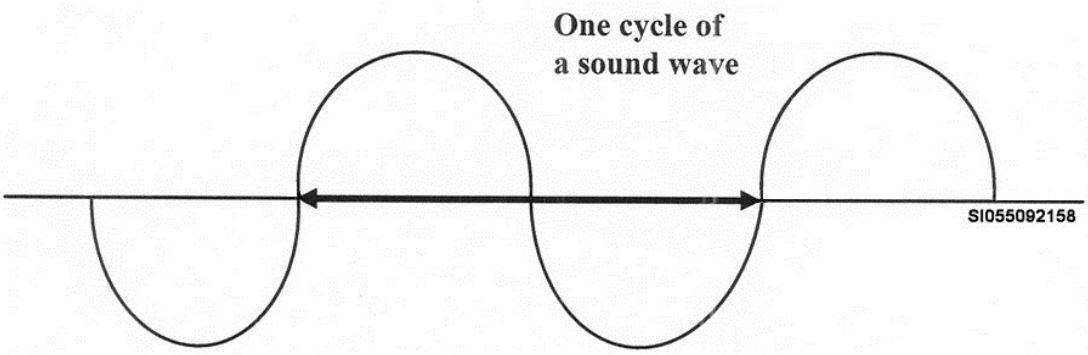

Figure 1–16. Cycle of a sound wave.

Frequency

Frequency is the inverse of the period, or the number of cycles per second. Of course, frequency is measure in Hz.

Wavelength

The distance a sound wave travels during one period is the wavelength and is annotated by the symbol λ.

The relationship between these three characteristics is seen in the two mathematical equations below:

$$P = \frac{1}{f}.$$

In this equation, P equals period and f equals frequency.

$$\lambda = \frac{s}{f}.$$

In this equation, λ equals wavelength, s equals speed, and f equals frequency.

The reason these characteristics are important is they determine how a sound wave will “sound” to the human ear. For example, a sound wave with a low frequency (i.e., 60 Hz) has a very low hum to the human ear. A sound wave with a high frequency (i.e., 20,000 Hz) has a very shrill sound to the

human ear. It is important for you to remember our ears are very sensitive to frequency and will detect the slightest variation in a sound (i.e., the tone of an audiometer); therefore, when you deal with a tone-producing piece of equipment, it is imperative you are accurate with your calibrations.

Velocity

In simple terms, the velocity of a sound wave is how fast it travels. At sea level, sound travels through air at 1,000 feet per second, but the speed of sound will vary depending upon the density of the substance through which it travels. The denser a material is the faster sound will travel. For example, sound will travel faster through steel than it will through air.

Principles of sound waves

Because sound is a wave, it reacts to the same principles that affect light waves, such as reflection and refraction. Let's talk about some acoustic principles and how they affect sound waves.

Reflection

Whenever a sound wave strikes an object, it bounces back, or reflects. The reflection of the sound wave can be analyzed in terms of momentum and energy conservation. If the collision between the sound wave and the object is elastic (as with a hard object), all of the energy and momentum is reflected, and the sound wave bounces back with the same speed. If the collision is inelastic, the object absorbs all of the energy and momentum of the sound wave. When a sound wave collides with an object that is neither hard nor soft, the object absorbs some of the sound wave, while other portions of the wave bounce back with a lower momentum and energy.

Refraction

The speed of a sound wave depends on the properties of the medium through which it is traveling. When a sound wave is traveling and changes mediums, it will usually change directions (just like a light wave)—this is refraction. When we covered refraction in our discussion of optics, we saw how light would strike a boundary and change directions rather abruptly. Refraction of sound waves doesn't normally happen in this manner. With sound waves, refraction normally occurs over a longer time period. For example, the speed of a sound wave depends upon the temperature of the medium (we'll just keep it simple and say air) it is traveling through. As the temperature of the air gradually changes, the speed of the sound wave gradually changes.

Interference

Sound waves react to the principle of interference, just like light waves. Of course, just like light waves, sound waves can have constructive and destructive interferences. Constructive interference occurs when two sound waves are traveling in phase with each other; they combine to form a wave twice the amplitude of the original wave. Destructive interference occurs when two waves are traveling in opposite phases; they interfere with each other, thus canceling each other out.

Measurement of sound

Sound pressure is a measure of the intensity of sound. Oscillating air movement (or pressure waves) produces sound waves and the intensity, or volume, of the sound is proportional to the pressure of the air movement. To measure the pressure of the sound objectively, a sound pressure meter (or sound level meter) is used. Sound pressure is measured as a ratio of an unknown sound pressure to a referenced sound pressure, instead of pounds per square inch (psi). The logarithm of this ratio is defined as a bel (named after Alexander Graham Bell). It is more convenient to measure this ratio in decibels (dB) rather than bels. Mathematically, a dB (decibel, or $^1/_{10}$ of a bel) is shown as:

$$dB = 10[\log(\frac{P^2}{P^1})].$$

In this equation, dB equals decibel, P^1 equals the reference sound pressure level, and P^2 equals the unknown sound pressure level.

However, there are two things you must know about this equation:

1. 0 dB is not a complete absence of sound but is a referenced level of sound (many people can hear 0 dB noise).
2. The relationship between different dB levels is not linear; rather, it is logarithmic. That is, 20 dB is not twice as loud as 10 dB but is 10 times as loud.

Figure 1–17 is a listing of common sounds and the sound pressure levels in dB to give you an idea of sound intensity and some sources of noise.

SPEECH AND HEARING	DECIBELS	FAMILIAR SOURCES OF NOISE
Threshold of pain	140	Largest air raid siren at 100ft.
Average threshhold of discomfort	120	Airplane engine (close by)
Loud shout at 1 foot	110	
	90	Noisy factory
Loud speech	80	Very loud radio
	70	Busy street, noisy office
Average conversation	60	Average car, noisy office
	50	Quite car, average office
Faint speech	40	Very quiet radio
Whisper	30	Average dwelling
Faint whisper	20	Very quiet dwelling outdoor

Figure 1–17. Hearing thresholds and noises that are close

An individual with normal hearing can hear one dB of loudness at 1,000 Hz. With a 10-dB hearing loss, they would miss the rustle of leaves; a 20-dB loss causes them to miss a faint whisper. An individual with a 40-dB loss would miss a conversation at 12 feet; with a 60-dB loss, the individual might not hear thunder.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

404. Optics

1. Briefly describe the principle of reflection.

2. What are the two rays involved in reflection?

3. Briefly describe Snell’s law.

4. What are the two types of reflection?

5. Briefly explain the principle of refraction.

6. Briefly explain total internal refraction and give an example of its use within the medical field.

7. What determines how much a waveform bends during diffraction?

8. Briefly explain the difference between constructive and destructive interference.

9. Which type of lens produces a virtual image?

10. What are the two types of focal lengths? What is the difference?

405. Acoustics

1. What causes sound waves?

2. What does the amplitude of a sound wave determine?

3. What three characteristics determine the pitch of a sound wave?

4. Will a sound wave travel faster in air or in steel? Why?

5. Briefly describe the difference between elastic reflection and inelastic reflection.

6. What is the intensity of a sound wave proportional to?

Answers to Self-Test Questions

401

1. The outer ear.
2. It collects sound waves and directs them through the external auditory canal to the tympanic membrane.
3. Within a cavity of the temporal bone called the temporal cavity.
4. It receives sound waves and protects the middle and inner ear from foreign particles.
5. The ossicles.

6. The Eustachian tube.
7. The inner ear, inside a fluid-filled, shell-like structure called the cochlea.
8. So that we don't hear muscle movement and organ noises.

402

1. The sclera.
2. It resists scratching and tearing, and provides strength to the fluid-filled eyeball.
3. The choroid.
4. It regulates the opening and closing of the pupil.
5. The lens.
6. The retina.
7. (1) b.
   (2) f.
   (3) d.
   (4) a.
   (5) c.
   (6) e.
   (7) h.
   (8) i.
   (9) g.
   (10) j.

403

1. Hematology; from the Greek words aima (meaning blood) and logos (meaning study).
2. 73 mL per kilogram of body weight; 63 mL per kilogram of body weight.
3. Erythrocytes (RBCs), leukocytes (WBCs), and thrombocytes (platelets).
4. The element iron.
5. 120 days.
6. (1) Neutrophils.
   (2) Eosinophils.
   (3) Basophils.
   (4) Monocytes.
   (5) Lymphocytes.
7. They help to form clots to stop bleeding.
8. Plasma.
9. N, O_2, CO_2, and H_2O vapor.
10. 760 mmHg.
11. Gases always flow from an area of high pressure to an area of lower pressure.
12. 46 mmHg.

404

1. Light will always travel in a straight line until it strikes an object, which causes it to bounce off resulting in a change in direction.
2. (1) An incoming, or incident, ray.
   (2) An outgoing, or reflected, ray.
3. During reflection, the angle of incidence and the angle of reflection are always equal.
4. (1) Specular reflection, which occurs when light bounces off a shiny surface.
   (2) Diffuse reflection, which occurs when light bounces off a rough surface.
5. Light travels in a straight line until it enters a new medium, which causes it to bend or deflect.

6. This phenomenon occurs when a propagated wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal surface. If the refractive index of one substance is lower on the other side of the boundary (i.e., as it is between air and glass) and the incident angle is greater than the critical angle, the wave cannot pass through and is entirely reflected. When this happens, the light bends so much that all of it reflects and none escapes. It is used in various types of fiber optic scopes.
7. The wavelength of the light and the size of the object.
8. Constructive interference occurs when two light waves combine to form a larger wave; destructive interference occurs when two light waves cancel each other out.
9. A concave lens.
10. (1) Negative – a lens with a negative focal length has a focal point on the same side as the original image.
    (2) Positive – a lens with a positive focal length has a focal point on the opposite side as the original image.

405

1. The vibration of an object.
2. How loud that a particular sound is.
3. (1) Period.
   (2) Frequency.
   (3) Wavelength.
4. Steel; the denser an object, the faster sound will travel through it.
5. If the collision between a sound wave and an object is elastic, all of the energy and momentum is reflected and a sound wave bounces back with the same speed; if the collision between a sound wave and an object is inelastic, the object absorbs all of the energy and momentum of the sound wave.
6. The pressure of the air movement caused by the sound wave.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) What part of the ear separates the external ear from the middle ear?
   a. Tympanic membrane.
   b. Malleus.
   c. Stirrup.
   d. Incus.

2. (401) Air pressure in the middle ear is equalized by the
   a. Eustachian tube.
   b. organ of Corti.
   c. labyrinth.
   d. ossicles.

3. (401) What is the *approximate* high frequency limit of human hearing?
   a. 1 kilohertz (kHz).
   b. 2 kHz.
   c. 10 kHz.
   d. 20 kHz.

4. (402) What is the outer layer of the eye?
   a. Sclera.
   b. Retina.
   c. Cornea.
   d. Choroid.

5. (402) The color of the eye comes from the
   a. iris.
   b. retina.
   c. cornea.
   d. ciliary body.

6. (402) Images are converted to nerve impulses and sent to the brain by way of the
   a. corneal passageway.
   b. pupillary nerve.
   c. aqueous humor.
   d. optic nerve.

7. (402) How many muscles control the movements of the eye?
   a. Four.
   b. Six.
   c. Eight.
   d. Ten.

8. (403) What blood constituent transports oxygen and carbon dioxide through the body?
   a. Thrombocytes.
   b. Erythrocytes.
   c. Leukocytes.
   d. Platelets.

9. (403) What portion of the blood remains after removing *all* cells from the blood?
   a. Fibrin.
   b. Plasma.
   c. Platelets.
   d. Basophils.

10. (403) External respiration is the exchange of gases between the bloodstream and the
   a. tissue cells.
   b. arteries.
   c. alveoli.
   d. heart.

11. (404) According to Snell's Law, when light is reflected, the angle of reflection is always equal to the angle of
   a. occurrence.
   b. dissipation.
   c. absorption.
   d. incidence.

12. (404) What type of reflection occurs when light strikes a *smooth*, *shiny* surface?
   a. Concurrent.
   b. Specular.
   c. Brilliant.
   d. Diffuse.

13. (404) The refractive index of a material is determined by the
   a. speed at which light travels through it.
   b. angle at which light travels through it.
   c. amount of light that will pass through it.
   d. amount of light that is reflected off of it.

14. (404) What phenomenon occurs when light waves *bend* as they pass *around* an object?
   a. Refraction.
   b. Diffraction.
   c. Interference.
   d. Total internal reflection.

15. (404) Which type of lens produces a virtual image rather than an actual image?
   a. Dark.
   b. Convex.
   c. Concave.
   d. Diffraction.

16. (404) The point at which light rays *converge* after they leave a lens is known as the
   a. diffractive point.
   b. cross point.
   c. focal point.
   d. exit point.

17. (405) The tone, or pitch, of a sound wave is *not* determined by
   a. period.
   b. velocity.
   c. frequency.
   d. wavelength.

18. (405) Which type of interference occurs when two sound waves are traveling *in* phase and combine to form a larger wave?
    a. Combined.
    b. Developed.
    c. Destructive.
    d. Constructive.

19. (405) The relationship between different decibel levels is
    a. logarithmic.
    b. volumetric.
    c. residual.
    d. linear.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Diagnostic Equipment

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Unit 2. Diagnostic Equipment

IN THIS UNIT, we will begin exploring specific pieces of medical equipment used throughout the MTF to diagnose a patient's condition. These equipment items are very important because their outputs help guide the medical staff in determining diagnosis and medical decisions. We will begin in the audiology and optometry clinic, move on to the cardiopulmonary section, and end our trek with inpatient care and labor and delivery.

2–1. Audiology and Optometry Clinic

These two clinics are generally very busy and use the equipment on a constant basis. Therefore, your proper and timely maintenance will be vital to keeping their operations running smoothly. Some of the equipment used in these sections are quite costly and require specialized maintenance; we will not focus on these items. We will, however, look at a few of the equipment items you will likely maintain more often.

406. Audiometer and tympanometer

In this lesson, we will discuss two of the most commonly used equipment items in the audiology clinic: the audiometer and tympanometer.

Audiometer

The first item we will cover is the audiometer. More than likely, you have seen this piece of equipment in the audiology clinic of your MTF. It is the single most important piece of equipment to an audiologist, and its proper maintenance and calibration are extremely important.

Audiometer classifications

There are four classifications of audiometers: pure tone, speech, high frequency, and free-field equivalent. An audiometer's classification derives from its features, including the transducer type, maximum hearing level, test frequency, test signal switching, reference tones, speech inputs, and masking types. Each classification can be further broken down into types but for the purpose of this introductory lesson, we will stop here and simply cover the basics.

Clinical applications

We will focus on pure tone audiometry since this is the classification you are most likely to deal with. Normally, we use pure tone audiometry to determine the type, degree, and configuration of hearing loss, and ultimately measure hearing sensitivity. The test involves the peripheral and central auditory systems.

In a typical hearing test, the patient sits in a soundproof booth with headphones that deliver the tones from the audiometer. The patient holds a push-button response switch as instructed, and the test begins. A 250-Hz tone is introduced into the left ear at 0 dB and increased in dB until the patient can hear the tone—known as the pure tone threshold (PTT). PTTs indicate the softest sound audible to a patient at least 50 percent of the time. We use the recording chart paper to record the PTT for that specific frequency. The same procedure then continues for all remaining frequencies on the left ear and finishes by repeating the tests on the right ear. The resulting test culminates in what we refer to as an audiogram.

An audiogram (fig. 2–1) is a graph that visualizes a patient's hearing sensitivity, with frequency charted on the horizontal axis and intensity charted on the vertical axis. Intensity is the level of sound power measured in dBs—in simple terms, the loudness of a tone. For threshold testing intensity, dBs are measured in hearing levels (HL), which is based on the standardized average of individuals with normal hearing sensitivity. During a usual test, we use frequencies of 250-8,000 Hz because this range represents most of the speech spectrum. Let's take a look at some specific tests performed using pure tone audiometry.

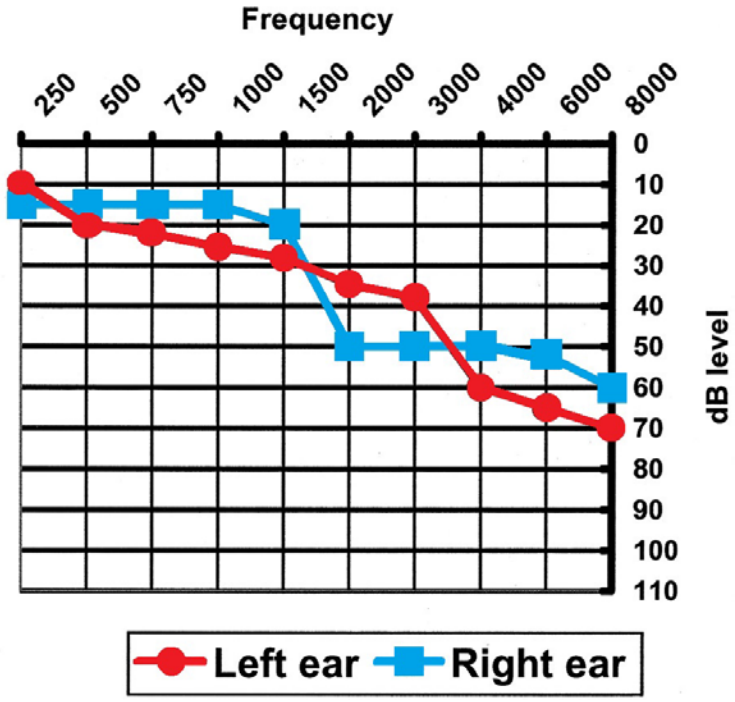


Figure 2–1. Sample audiogram.

Air conduction testing

This particular test assesses hearing sensitivity when a signal is transmitted through the outer, middle, and inner ear, and then through the brain to the cortex. When performing this test, a variety of methods can produce the required sounds, including headphones, insert earphones, or sound fields.

- Headphones – When using headphones, they generally rest over the outer ear. Circumaural headphones have a large cushion that fits around the ear contacting the head. These headphones help to reduce ambient noise. Supra-aural headphones are more common and rest on the ear or auricle, but they typically provide no ambient noise reduction (this emphasizes the importance of a quiet sound booth).
- Insert headphones – These are transducers housed in a small box. Test signals transmit down a tube to foam tips, which fit in the patient's ear canal. These earphones help reduce

collapsing ear canals, and they reduce some ambient noise and crossover of test signals to the ear not under test through skull transmission.

- Sound field – This particular method of testing is most appropriate when testing infants or other patients with special needs that cannot use headphones. Sound field testing presents tones using speakers normally placed at a 45-degree (°) angle in front of the patient's face. During the test, an individual sits in the center of the room, facing forward, halfway between each speaker. Typically, there is some type of visual reinforcement (i.e., toys that light and animate when the child responds to a sound) used during the test to reinforce the responses and make the test more interesting to the child.

Bone conduction testing

This test assesses hearing sensitivity when a signal is transmitted through the bones of the skull to the cochlea, and then through the auditory pathways of the brain. This type of testing bypasses the outer and middle ear, and can rule out, or confirm, problems with the middle or outer ear. A bone conduction test places a small oscillator on the forehead or on the bone behind the ear, which stimulates the bones of the skull, in turn, stimulating both cochleae.

Audiometer operational principles

Pure tone audiometers, in general, produce tones of discrete frequencies at octave or half-octave intervals. A standard oscillator circuit electronically generates these tones; most units have a frequency control switch, which allows the operator to control the oscillation frequency through a range of standard frequencies. The number of standard frequencies available depends on the design of the unit. The frequency ranges for standard state-of-the-art diagnostic testing are 250; 500; 750; 1,000; 1,500; 2,000; 3,000; 4,000; 6,000; and 8,000 Hz. An attenuator dial controls the signal strength at each of these frequencies, which you can generally calibrate in 5-dB steps from –110 dB audiometer zero to +100 dB.

One of the most important circuits in an audiometer is the interrupter circuit. The purpose of the interrupter circuit is to connect or disconnect the patient's earphones from the output of the audiometer without turning the unit on or off. The design of the interrupter circuit allows it to perform without clicks, scratches, or other extraneous noises that might interfere with the signal tone. The operator can then make changes in the frequency setting and in the attenuator setting without these extraneous sounds reaching the patient. Another important circuit is the masking circuit. The purpose of this circuit is to block out, or mask, extraneous noises in one ear while the other is under test.

Audiometers have an earphone circuit to deliver the test signals to the patient and a hand push-button circuit for the patient to signify to the operator when they hear the test signal. A signal light alerts the operator when the patient pushes the hand push-button.

Also incorporated into the design is a live voice test capability that enables two-way speech communication between the patient and operator. This uses a standard audio amplifier circuit, which includes an operator volume indicator meter, so output levels can be monitored. This capability is also helpful if the operator needs to give the patient specific instructions while the patient is still in the soundproof audiometer booth.

Tympanometer

The second piece of equipment we will look at is the tympanometer. It is not as common or well known as the audiometer; however, it still plays a key role in acoustic diagnosis. Let's take a look at some of its uses.

Clinical applications

A tympanometer measures the movement (compliance) of a patient's tympanic membrane (eardrum) and the condition of the middle ear. This test inserts a probe into the ear canal. The probe emits a test signal, while also applying various pressures to the ear. The compliance of a patient's tympanic

membrane is measured in cubic centimeters (cc), while the pressure in the ear canal measures in decapascals (daPa), or tenths of a pascal. The tympanometer then measures the energy of the signal reflected by the tympanic membrane at the different pressures.

As stated previously, we frequently use a tympanometer to check the condition of a patient's eardrum. If the ear contains fluid, most of the test sound reflect back to the probe because the tympanic membrane is stiff; this will produce what is known as a "flat" tympanogram. If the middle ear contains no fluid, the tympanic membrane will absorb most of the sound and the returning signal will be very weak. The tympanogram will indicate this action as a normal tympanogram. There are two main tests performed with a tympanometer: the static acoustic compliance test and a tympanogram.

Static acoustic test

This test measures the mobility of a patient's eardrum and estimates the functional size of the middle ear. During this test, a tone around 220 Hz at 80–90 dB is introduced into a patient's ear. The test uses air pressures of +200 daPa (used to immobilize the ear) and 0 daPa (used to make the eardrum mobile). The result of this test is called the ear's static acoustic compliance. Abnormal readings can stem from a problem with the tympanic membrane, or, in patients with pressure equalizing tubes (children with "tubes" in their ears), may indicate the tubes are not working.

Tympanogram

This test produces a visual graph of how stiff a patient's eardrum is at various pressures. As the pressure varies within the ear, the tympanometer presents a test sound and records the reflection. This test is similar to the static acoustic test; however, it uses a wider range of pressures to test the ear. The principle behind this test is that an eardrum moves best when the pressure on both sides is equal (0 daPa in a normal ear), and ear pressure will vary in a patient with some type of ear problem.

Just as with the static acoustic test, the tympanometer produces test tones, but the pressure is swept across a broad range from –400 daPa to +200 daPa. The results of the test are known as a tympanogram, which is essentially a plot of the eardrum's reaction to the test. There are three main plot types:

1. Type A plot – Indicates a normal tympanogram.
2. Type B plot – Indicates there is fluid in the middle ear or a torn eardrum.
3. Type C plot – Indicates the Eustachian tube is not functioning correctly.

There are also subcategories to these types, but it is not necessary for you to be that familiar with the results to understand the clinical applications of the equipment.

Operating principles

A tympanometer contains a manometer to produce and measure the pressure within a patient's ear. A tympanometer also has a probe, which inserts into the patient's ear. Most units have probes of various sizes to accommodate different ear canal sizes. The tip of the probe contains a pressure transducer, which applies the varying pressures to the ear. The probe also contains a speaker to produce the test tone and a microphone to pick up the returning signal. Think of the concept of a sonar ping being sent out and reflected back. Once the tympanometer receives a reflected tone, the internal circuitry measures the signal strength.

One important point to remember is a tympanometer automatically calculates the volume of a patient's ear canal. However, if there is an excessive amount of cerumen (ear wax), the volume may read abnormally low causing an erroneous tympanogram. Remember this if a user complains of false readings especially if the unit in question produced a faulty reading after only one or two patients.

407. Optometric and ophthalmic equipment

In this lesson, we will cover two of the more common equipment items found in most optometry and ophthalmology clinics. This lesson will not attempt to teach you how to repair or maintain the

equipment, but it will familiarize you with it so if you have a work order for this section of the MTF, you won't be quite so apprehensive. One word of caution before we begin—always be very careful with this equipment because it is very sensitive and often requires special tools and training to maintain. If you are in doubt as to whether you should work on something—don't! Ask your supervisor or trainer for assistance. Although there are many pieces of equipment in the eye clinic, in this lesson we will cover the clinical applications of slit lamps and tonometers.

Slit lamp

This is a very important piece of equipment in the eye clinic. The slit lamp is basically a microscope with a light attached that allows the doctor to examine a patient's eyes under high magnification (fig. 2–2). The primary purpose of this instrument is to view the anterior structures of the eye, such as the cornea, iris, and lens; however, with special lenses, it is possible to examine the vitreous and the back of the eye as well. The instrument's name is derived from its adjustable light beam. By changing the width of the beam, the doctor can gather important details about each eye structure.

Figure 2–2. Slit lamp in use.

Slip lamps use either a light-emitting diode (LED) or tungsten-halogen bulb light source to provide the light for the illumination system; most also have a dial to adjust the brightness. The slit is adjustable in width and length and can rotate from a vertical position to a 90-degree position in either direction. Slit lamps also have filters for the illuminating system—normally green and cobalt blue. The filters are used to block certain colors of light (green blocks red light, which makes the blood vessels clearer; blue is used in conjunction with the contact tonometer) allowing the doctor to see different parts of the eye. The slit lamp also has various lenses to change magnification, depending on which structure of the eye requires examination.

Let's take a moment to look at the various parts of a slit lamp. Although slit lamps vary considerably from one manufacturer to another, the major components in all of them are similar (fig. 2–3).

Illumination arm

The illumination arm contains the illumination system. From the straight-ahead position, the angle of the arm can be varied 0° to 90°. The illumination arm has three main components:

1. Slit controls – Control the vertical and horizontal adjustment of the slit, as well as the orientation of the light beam.
2. Click stop – Alters the position of the reflecting mirror to adjust the angle of the beam with respect to the viewing system.
3. Filters – Used to alter the appearance of the slit beam as mentioned earlier.

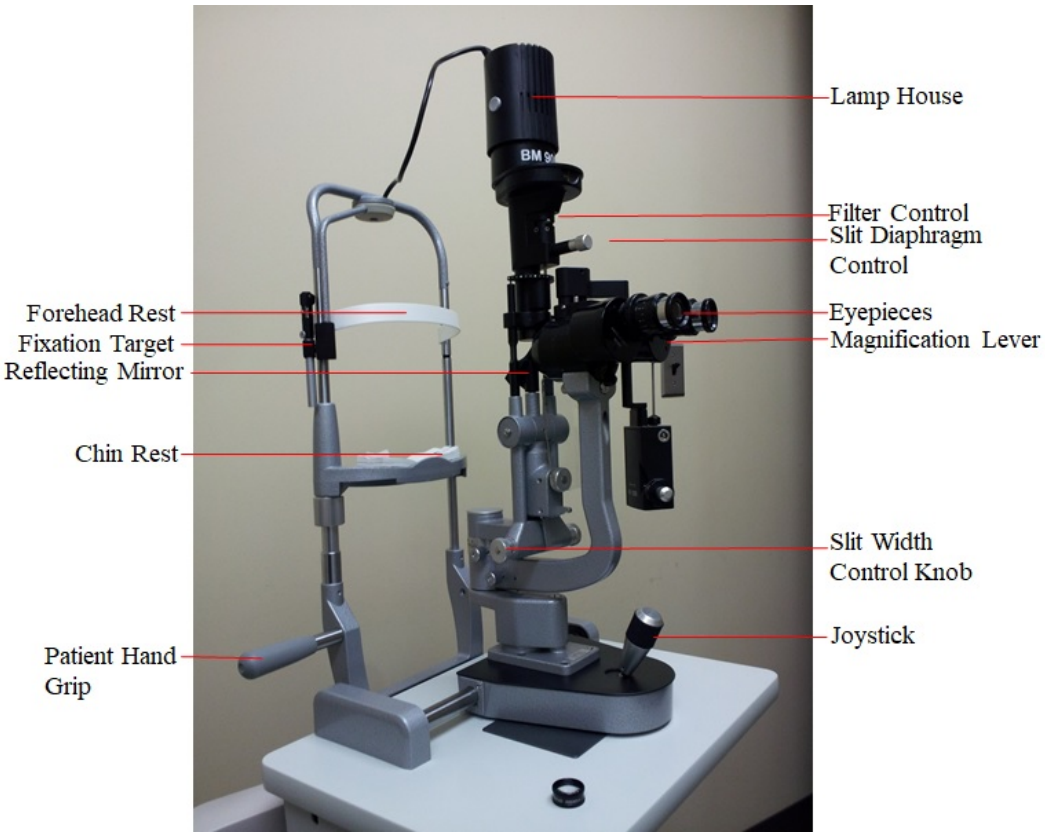


Figure 2–3. Retina Group slit lamp.
(Licensed by CC BY-SA 3.0.)

Microscope arm

The microscope arm contains the viewing system. The viewing system consists of the objective and ocular lenses. Although the microscope arm is normally kept in the straight-ahead position, the angle of the arm can be varied.

Slit lamp position controls

There are two primary controls to a slit lamp: a joystick and elevation controls. These may be a single control or two separate controls.

1. Joystick – Controls the forward and back movement of the slit lamp and controls focus. In addition, it directs the left-to-right movement of the slit lamp. On some instruments, the joystick also acts as the elevation knob.
2. Elevation knob – Controls the vertical alignment of the microscope.

Tonometers

The tonometer is one of the most commonly used equipment items. Tonometry is the measurement of the pressure exerted by the fluids inside the eye. This fluid pressure maintains the eye's shape. Tonometry is comparable to checking the air pressure in the tire of your car—too much or too little pressure will damage it. Just as the correct range of pressure varies according to the type of car you drive and model of tire used, so does the normal range for eye pressure vary with each individual. The most common use of this test is to screen for glaucoma; a disease characterized by increased pressure within the eyeball. If undiagnosed and untreated, glaucoma may lead to optic nerve damage, loss of visual field, gradual vision impairment, and, sometimes, blindness. There are two types of tonometers: contact and non-contact.

Contact tonometer

A contact tonometer (also known as an applanation-tonometer) is part of the slip lamp. When using the contact tonometer, the operator places the slit lamp in front of the patient, who rests his or her chin and forehead on a support that keeps the head steady. The lamp moves forward until the tonometer touches the cornea. A light then shines into the patient's eye, which is usually a blue circle. Finally, the doctor looks through the eyepiece on the slit lamp and adjusts the tension on the tonometer to obtain a pressure reading.

Contact tonometer measurements are also available using a small mobile pen-style instrument. Its chief advantage over other tonometers is its portability. This versatility allows for intraocular pressure (IOP) measurements on wheelchair or bedridden patients. It's compact, lightweight, and battery operated, making it useful in field conditions or on humanitarian missions. The mobile pen-style unit measures the amount of pressure required to push the plunger-like tip back into the instrument's sleeve. The IOP converts into an electrical signal displayed as mmHg.

Non-contact tonometer

The most commonly performed type of tonometry in the Air Force (AF) and civilian world is non-contact tonometry (NCT). Performing NCT is a quick and painless way to screen patients for elevated IOP. An NCT has one major advantage over other types of tonometry. There is no contact with the eye, therefore, no need for a topical anesthetic. This significantly decreases testing time and reduces the possibility of an eye injury or infection as compared to conventional applanation tonometry. If you have had this test performed, you probably remember it well. The test is not painful, although it is rather unpleasant. The non-contact tonometer (fig. 2–4) shoots a gentle puff of air at the eye (the unpleasant part!), and then computes the time it takes the air pulse to flatten the cornea.

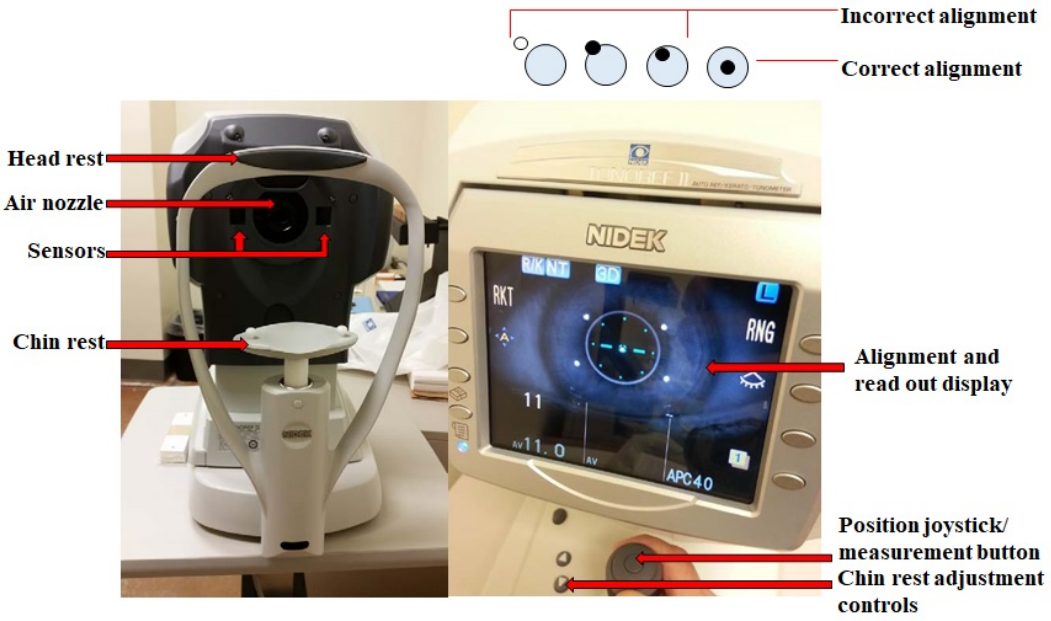


Figure 2–4. Non-contact tonometer.

Look at figure 2–4 and find the chin rest. This is where the patient places his or her chin. The patient's head presses against the headrest, which tells the machine a patient is in place. Next, the air nozzle must align perfectly to get a correct reading. For this, the vertical and horizontal adjustments align using the chin rest adjustment controls and the alignment joystick.

The top of the figure shows what the light looks like to the operator as he or she tries to align it. The fourth circle is a correct alignment. Once this is set, the air button on the joystick is pressed and air gently puffs forward into the patient's eye. The air flattens the cornea causing the light to reflect back

at the machine. After that, sensors located on each side of the air nozzle pick up the reflected light. These sensors pick up the edge of the light reflection as soon as the cornea flattens enough, thus telling the tonometer that time is up. This time converts into mmHg representing the IOP. A digital reading of the IOP instantly displays for the operator to read. There is also an adjustable safety stop, which prevents the operator from coming too close or touching the patient's eye with the air nozzle.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

406. Audiometer and tympanometer

1. What are the four classifications of audiometers?

2. What is pure tone audiometry used for?

3. Briefly describe a typical hearing test.

4. What is an audiogram?

5. What is air conduction testing?

6. Why is bone conduction testing performed?

7. What are the standard frequency ranges for state-of-the-art diagnostic testing?

8. What is the purpose of the interrupter circuit in an audiometer?

9. What is a tympanometer used for?

10. What is a "flat" tympanogram?

11. What are the three main tympanogram plot types and what does each indicate?

407. Optometric and ophthalmic equipment

1. What is the primary use of a slit lamp?

2. What are the three main components on the illumination arm of a slit lamp and what are they used for?

3. What is tonometry?

4. What is the most commonly performed type of tonometry in the AF and civilian world?

5. Briefly describe how a non-contact tonometer works.

2–2. Cardiopulmonary

We will now progress into the cardiopulmonary department of the MTF. This particular section provides a variety of cardiopulmonary services. The department is responsible for administering cardiac diagnostic tests, as well as, providing treatments on a daily basis for the prevention or improvement of respiratory conditions. In this section, we'll learn about the electrocardiograph and pulmonary function testers. We'll begin with the electrocardiograph.

408. Electrocardiograph

The electrocardiograph (often called an ECG or EKG) is a machine that assists in detecting and diagnosing heart abnormalities. It is second in importance only to the stethoscope as a primary diagnostic tool in identifying heart problems. It measures electrical potentials on the body surface and produces a record of the electrical currents associated with heart muscle activity, called an electrocardiogram (also abbreviated ECG or EKG). This equipment item is very common throughout an MTF, and you may have already had some experience with it. Let's go ahead and dig a little deeper into what this important piece of diagnostic equipment is all about.

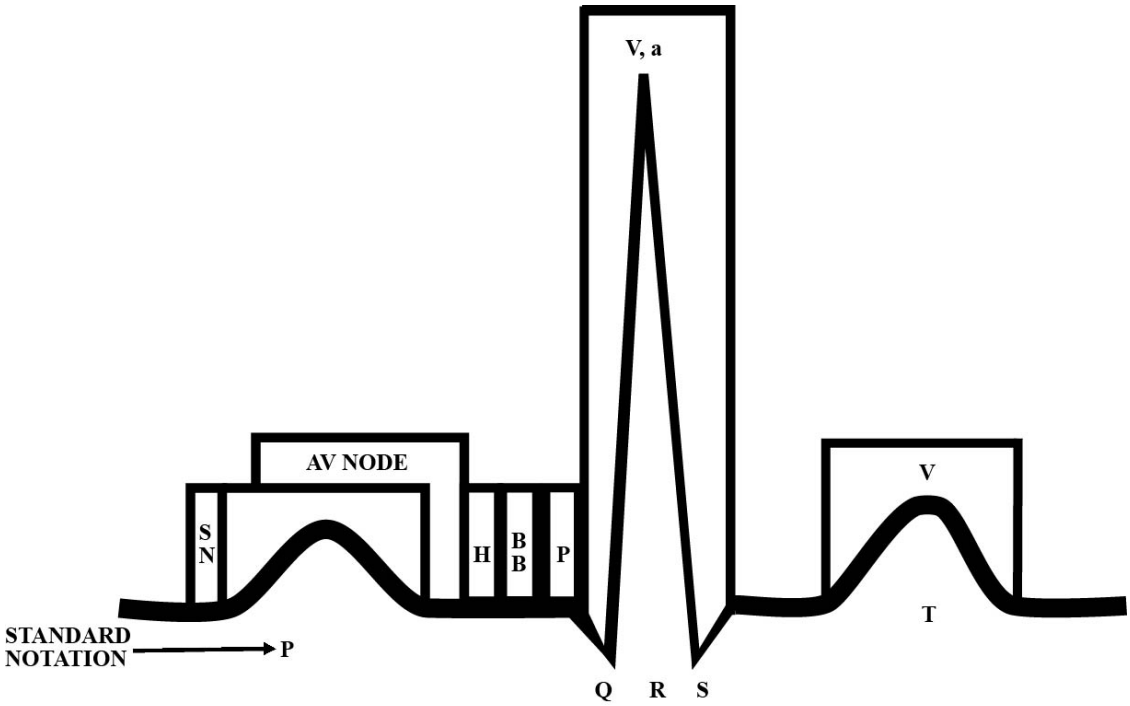
Principles of operation

If you have forgotten about the heart, now would be a good time to review the anatomy and physiology portion of Volume 2 from this CDC. The ECG is a recording of the depolarizations and repolarizations of the heart. A typical ECG waveform is shown in figure 2–5.

An ECG waveform contains three important pulses for each beat of the heart:

1. P-wave.
2. Q-wave, R-wave, and S-wave (QRS) complex.
3. T-wave.

The P-wave is the small, rounded pulse generated by the atrial depolarization (contraction) at the start of each cycle of heart operation. Next comes a short pause while the atrioventricular (AV) node depolarizes, and the impulse is sent to the ventricles. The QRS complex is the fast, high-amplitude, triangular pulse associated with the contraction of the ventricles. The T-wave occurs after a brief interval. It represents the relaxation and repolarization of the ventricles. The repolarization of the atria is not seen because it occurs at the same time as the QRS complex.



DEPOLARIZATIONS IN:

SN	SINOATRIAL NODE
ATRIA	RIGHT ATRIUM AND LEFT ATRIUM
AV NODE	ATRIOVENTRICULAR NODE
H	BUNDLE OF HIS
BB	BUNDLE BRANCHES
P	PURKINJE NETWORK
V	RIGHT VENTRICLE AND LEFT VENTRICLE

REPOLARIZATIONS IN:

a	RIGHT ATRIUM AND LEFT ATRIUM
v	RIGHT VENTRICLE AND LEFT VENTRICLE

Figure 2–5. Typical ECG waveform.

By recording voltage variations at the body surface, caused by the depolarization and repolarization of the cardiac muscle, the electrocardiograph produces an electrocardiogram. The ECG is simply a graphic representation of the recorded voltage variations plotted with time on the horizontal (X) axis and voltage on the vertical (Y) axis. Analysis of the ECG waveform provides the physician valuable information to use for detection of such factors as heart size, wall thickness, variations in the normal beat rhythm (arrhythmia), premature ventricular contractions (PVC), high blood pressure (hypertension), and “heart attack” damage (myocardial infarctions). The science of

electrocardiography is indeed extensive and complex, but from the point of view of the BMET journeyman, about all you need to know are some of the basics. This will allow you to communicate with the professional staff; however, even the basics are quite involved.

Simply speaking, an ECG uses the potentials recorded on two body surface electrodes as the input to a differential amplifier. As you learned in electronic principles, the differential amplifier produces a single output based on the difference of the two input voltages. The output of the differential amplifier feeds into a galvanometer, which deflects in proportion to the difference of the two input signals. A recording system, driven by the galvanometer, records the event on chart paper. In patient monitors, a video display replaces the recording system, although most monitors also have the option of printing the ECG onto chart paper if a cardiac event occurs.

The P-wave, T-wave, and QRS complex representations recorded by an ECG represent electrical vectors (magnitude and direction) generated within the muscle of the heart. The direction (up or down) of the recorder deflection or video trace is determined by whether the net or resultant electrical vector is directed toward or away from the electrode from which the signal is being recorded. The recording of an ECG signal at the body surface, however, is significantly more complicated because the sensing electrodes are not in direct contact with the source of the charging potential.

When done in a laboratory, measuring an action potential, such as a heart contraction, is essentially a simple one-dimensional problem, much like applying voltmeter leads to a battery. However, since the heart is a solid object with three dimensions, it develops different potentials across its surface at different times during depolarization (contraction). Furthermore, those complex potentials must transmit through the body mass to the skin surface before being able to record them.

Applying electrodes to certain portions of the body enables the ECG to make measurements. To simplify the process of measuring the three-dimensional electrical activity, we consider each dimensional plane separately. The three planes are the frontal, sagittal, and transverse. We will only concern ourselves with the frontal and transverse plane, because these two form the standard twelve-lead ECG. Also, we seldom use the sagittal plane measurement, because in order to do so we must place a lead into the esophagus.

The standard ECG looks at the heart from different angles (fig. 2–6) and is known as the twelve-lead ECG. Three different sets of leads come together to form the twelve-lead ECG. Let’s take a look at each lead set and their purpose.

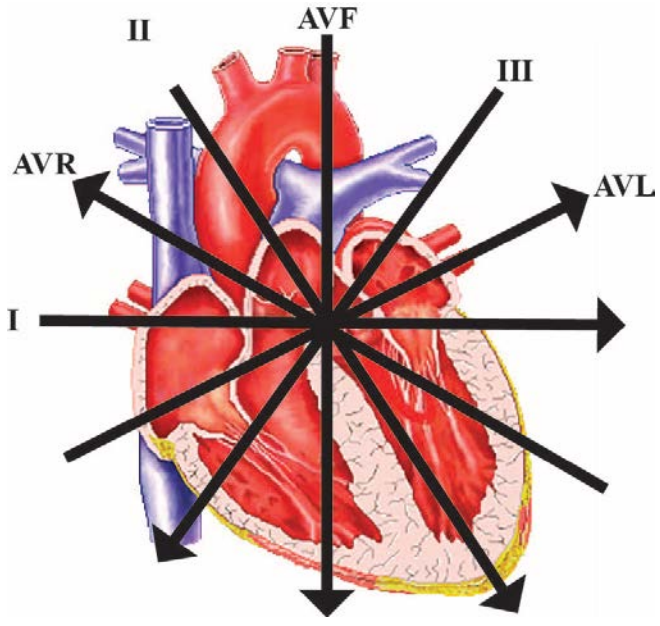


Figure 2–6. Heart measurement angles.

Standard leads

The standard leads are the most basic ECG leads and are also called the bipolar limb leads (bipolar means they detect a change in potential between two points). The standard leads detect a change in potential in the frontal plane and are normally designated leads I, II, and III. The measurements taken by the leads are:

- Lead I – The potential between the right arm and left arm.
- Lead II – The potential between the right arm and left leg.
- Lead III – The potential between the left arm and left leg.

Figure 2–7 shows the standard lead measurement. This is also known as the Einthoven triangle (fig. 2–8), named after the Dutch doctor who first described this relationship.

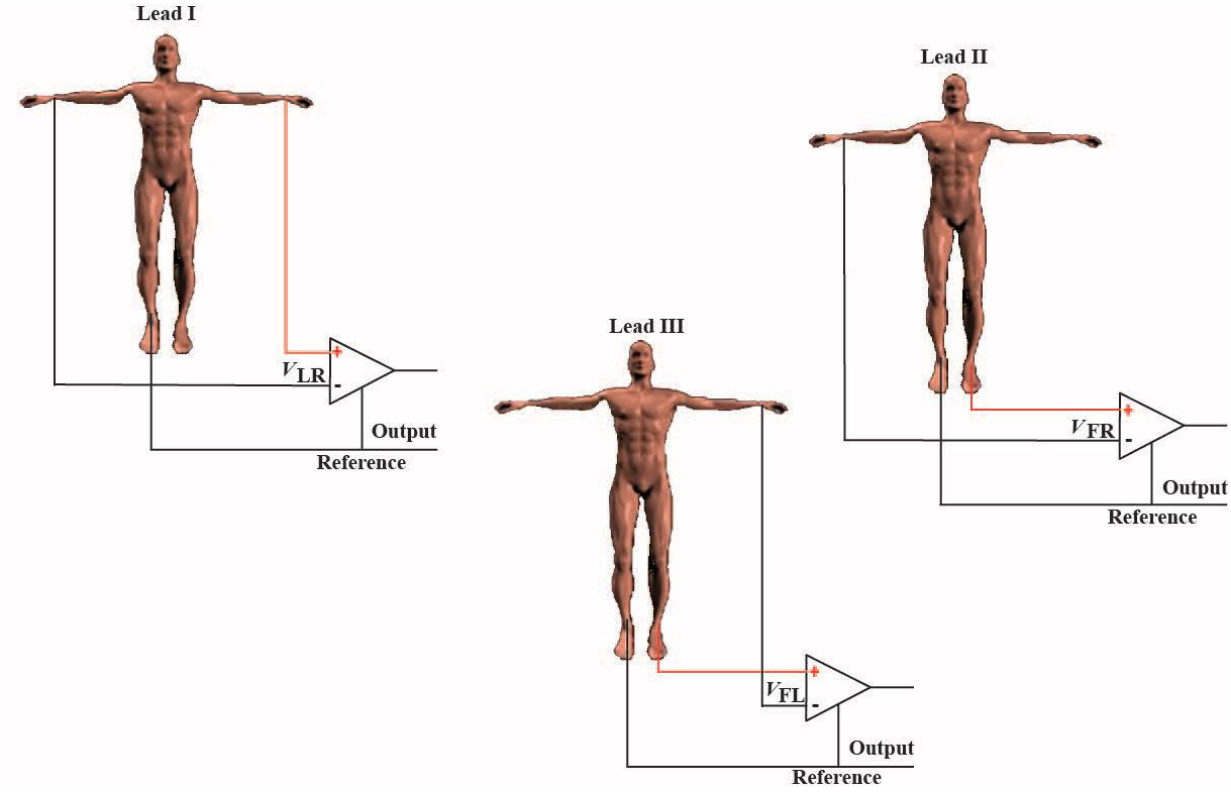


Figure 2–7. Connections for the bipolar limb leads.

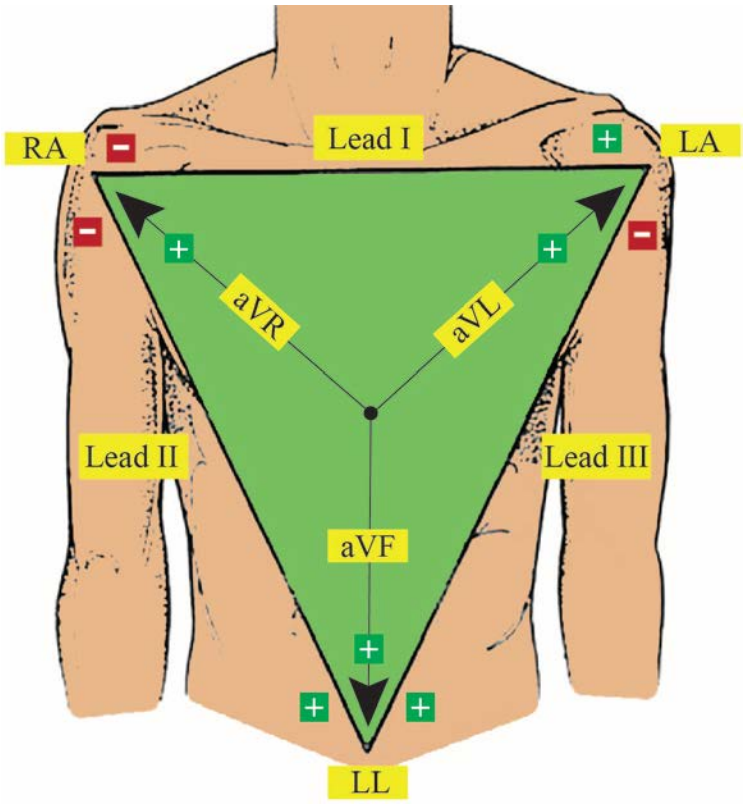


Figure 2–8. Einthoven's triangle.

Augmented limb leads

The same three leads that form the standard leads also form the augmented limb leads. These leads, however, are known as unipolar leads because they measure the electrical potential at one point with respect to a null point (a point that doesn't register any significant variation in electric potential during the contraction of the heart). The null point is obtainable for each lead by adding the potential from the other two leads. For example, an augmented voltage right arm (aVR) lead compares the electric potential of the right arm to a null point, obtained by adding together the potential of leads augmented voltage left arm (aVL) and augmented voltage foot (aVF). These leads also measure potential in the frontal plane; the measurements are:

- aVR – The potential at the right arm using the left arm and left leg to form an indifferent electrode.
- aVL – The potential at the left arm using the right arm and left leg to form the indifferent electrode.
- aVF – The potential at the left leg using both arms to form the indifferent electrode.

Figure 2–9 is a graphical representation of the augmented limb leads.

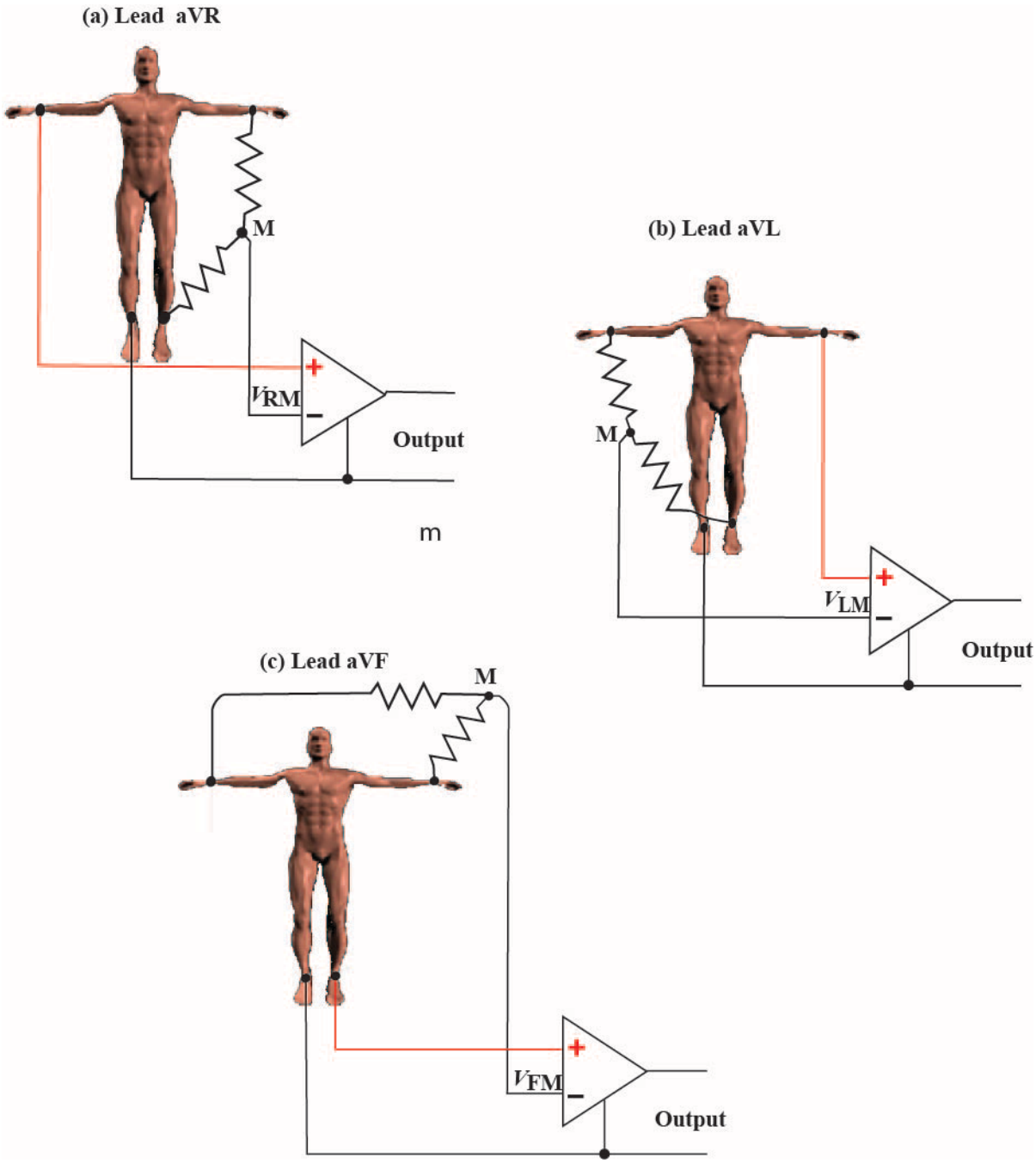


Figure 2–9. Augmented limb leads.

Precordial leads

These leads are unipolar leads, and they record electrical activity in the transverse plane of the heart. You can think of the transverse plane as looking at the heart in a cross-sectional view. First, the potential at the right arm, left arm, and right leg add together to form an indifferent electrode. Then, the measurement records the potential between this indifferent electrode and chest electrodes placed at different positions on the chest (fig. 2–10). The transverse plane measurements are also called the V lead measurements due to their designations (V1, V2, V3, V4, V5, and V6). The numbers refer to the position on the chest (fig. 2–11).

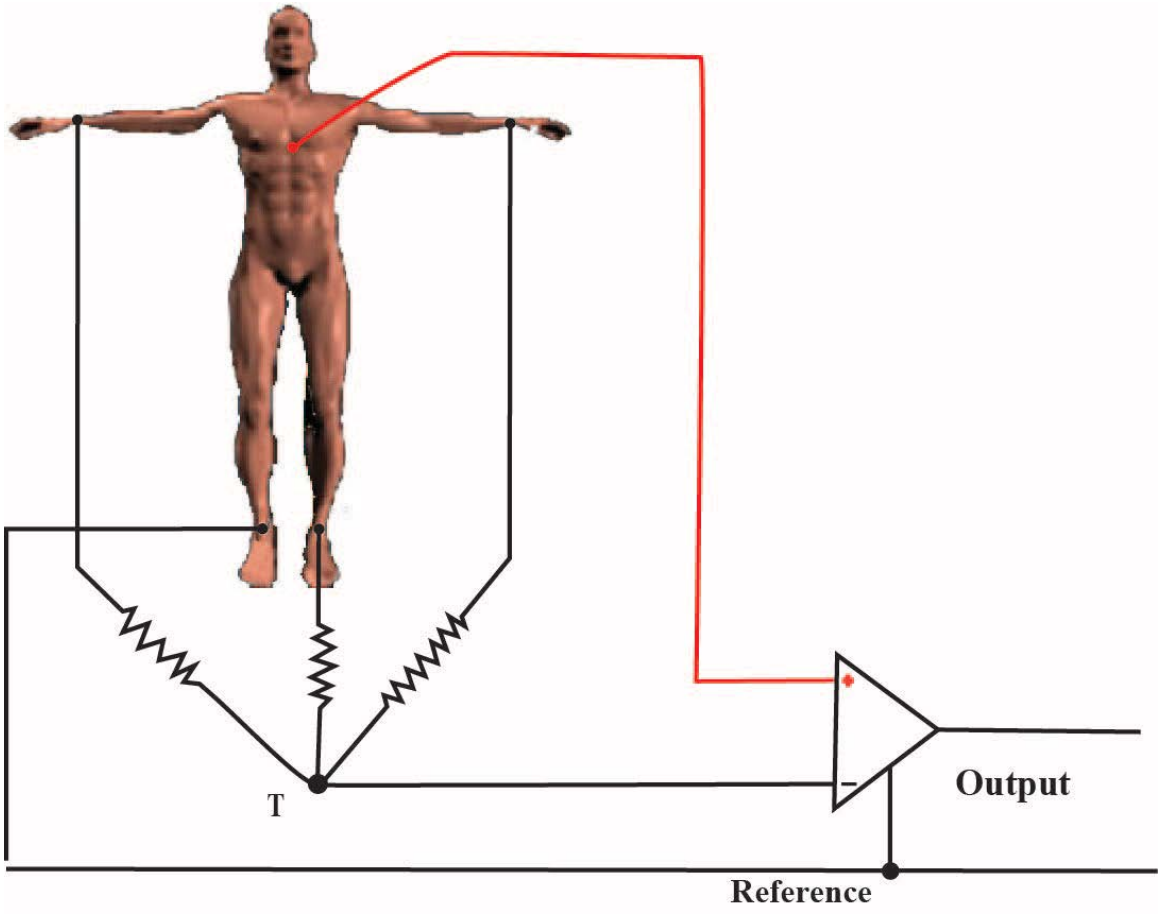


Figure 2–10. Precordial leads.

V1 - At fourth intercostal space, at right margin of sternum
V2 - At fourth intercostal space, at left margin of sternum
V3 - Midway between sites of V2 and V4
V4 - At fifth intercostal space, at midclavicular line
V5 - At same level as site of V4, at interior axillary line
V6 - At same level as site of V4, at midaxillary line

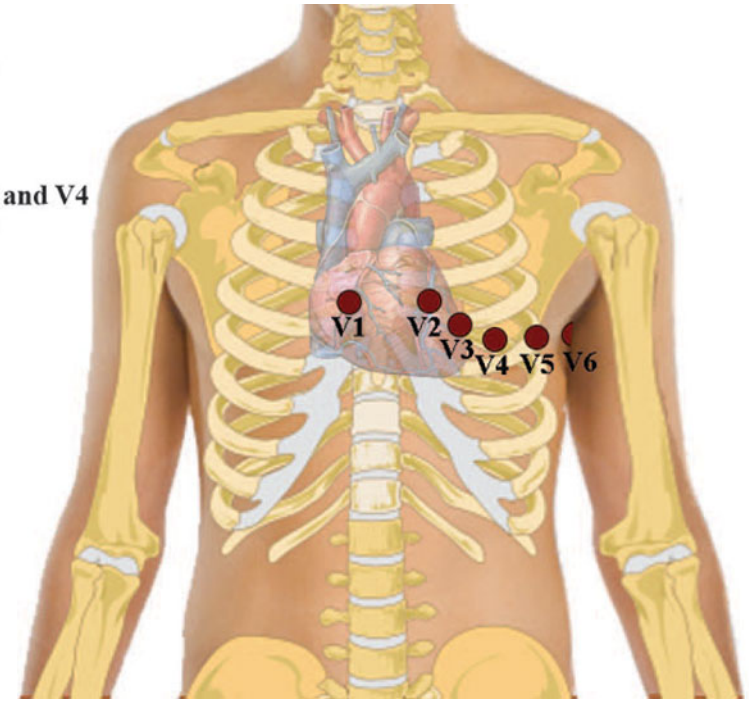


Figure 2–11. V leads placement.

We use these three lead sets simultaneously to form the twelve-lead ECG. Although the lead positions derive from mathematical summations, the interpretation of ECG recordings is a comparison against a "normal" reading. The "normal" ECG (fig. 2–12) came about by observing thousands of recordings from healthy individuals.

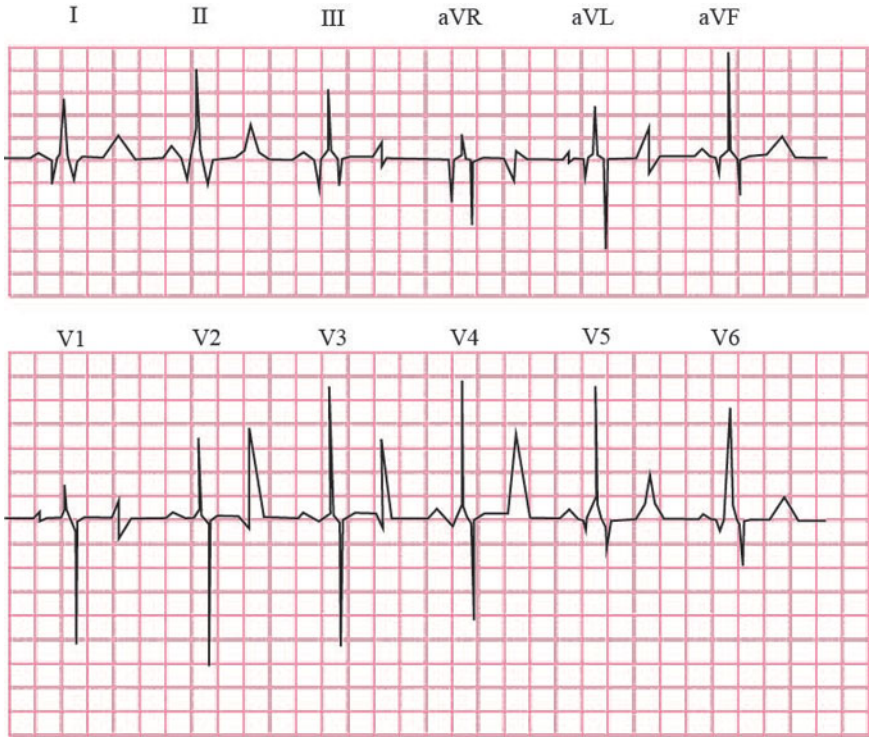


Figure 2–12. Normal twelve-channel ECG.

These units are also called three-channel automatic recorders (the three channels being the different lead sets) and are the industry standard. These units are special because they record the three lead configurations simultaneously on a single sheet of paper. They also switch automatically to the next group of leads during the run. Therefore, an ECG with the 12-standard lead configuration can record automatically as a sequence of four groups of three traces. The average time required for the actual recording is approximately 10 seconds. The groups of leads recorded and the time at which the switching occurs receive automatic identification by code markings at the margin of the recording paper. Standardization pulses appear in all three channels at the end of the recording.

Clinical applications

Clinicians generally use an ECG during periodic medical evaluations, such as part of a routine physical. It also serves as a valuable diagnostic tool when a patient complains of chest pains, shortness of breath, dizziness, or fainting. It also operates in conjunction with stress testing when a resting ECG appears normal, and the patient complains of problems during activity. The following are some common items that an ECG can measure or detect:

- The underlying rate and rhythm mechanism of the heart.
- The orientation of the heart (how it is placed) in the chest cavity.
- Evidence of increased thickness (hypertrophy) of the heart muscle.
- Evidence of damage to the various parts of the heart muscle.
- Evidence of severely impaired blood flow to the heart muscle.
- Patterns of abnormal electric activity that may predispose the patient to abnormal cardiac rhythm disturbances.

You have probably realized by now the interpretation of ECG recordings is extremely complicated. While ECG recordings can render a lot of exceptionally valuable information about the heart, it takes specialized training and practice to accurately interpret the many possible ECG tracings. Fortunately, you don't need to worry about that, but let's take a moment to look at some specific conditions that can be diagnosed with the ECG.

- Abnormally fast, slow, or irregular heart rhythms.
- Abnormal conduction of cardiac impulses, which may suggest underlying cardiac or metabolic disorders.
- Evidence of a prior heart attack (myocardial infarction).
- Evidence of an evolving, acute heart attack.
- Evidence of impaired blood flow to the heart muscle (angina). Adverse effects on the heart from various heart diseases or systemic diseases, such as high blood pressure, thyroid conditions, and so forth.
- Adverse effects on the heart from certain lung conditions, such as emphysema or pulmonary embolus (blood clots to lung).
- Certain congenital heart abnormalities.
- Evidence of abnormal blood electrolytes (potassium, calcium, or magnesium).
- Evidence of inflammation of the heart or its lining.

409. Pulmonary function testers

A pulmonary function analyzer or pulmonary function tester (PFT) is found not only in the cardiopulmonary department but also the flight surgeon's office, respiratory therapy, and family practice. It can be as simple as a peak flow meter used to measure the output volume of the lungs; as complex as a computer used to calculate input volume, output volume, and length of breath; or as unique as a full body analyzer. This lesson will cover the clinical applications of PFTs, but before you can fully appreciate the clinical applications, we need to review lung volumes and capacities; that is where we'll start.

Lung volumes and capacities

Many tests can determine pulmonary efficiency and volume. To understand the purposes and functions of the tests, you must understand lung volumes. There are four standard lung volumes:

1. Tidal volume (TV) – The volume of air inhaled or exhaled from the lungs during normal breathing.
2. Inspiratory reserve volume (IRV) – The maximum volume of air that you can inhale following a normal quiet inspiration.
3. Expiratory reserve volume (ERV) – The amount of gas that you can exhale from the lungs following a quiet exhalation.
4. Residual volume (RV) – The volume of gas remaining in the lungs after a maximum exhalation. A person can never voluntarily expel his or her RV.

Two or more of these lung volumes can be grouped together to form a lung capacity. There are four standard lung capacities:

1. Inspiratory capacity – The maximum amount of gas that you can inhale following a normal quiet exhalation. It is the sum of the TV and IRV.
2. Vital capacity – The maximum amount of gas that you can exhale following a maximum inhalation, or the maximum amount of gas that you can inhale following a maximum exhalation. It is the sum of the IRV, TV, and ERV.

3. Functional residual capacity (FRC) – The amount of gas left in the lungs following a normal quiet exhalation. The sum of the RV and ERV.
4. Total lung capacity (TLC) – The maximum volume of gas in the lungs at the end of a maximum inhalation. The sum of the TV, IRV, ERV, and RV.

Figure 2–13 is a picture designed to simplify the lung volumes and capacities for you. The center picture shows the four volumes—residual, inspiratory reserve, tidal, and expiratory reserve. The outside lungs show the four capacities—total lung, vital, inspiratory, and functional residual. The shaded areas of the capacity lungs show which volumes determine the capacity. Look at vital capacity. It is composed of the ERV, TV, and IRV. Look at each of the other capacities so you can better understand their interrelationships.

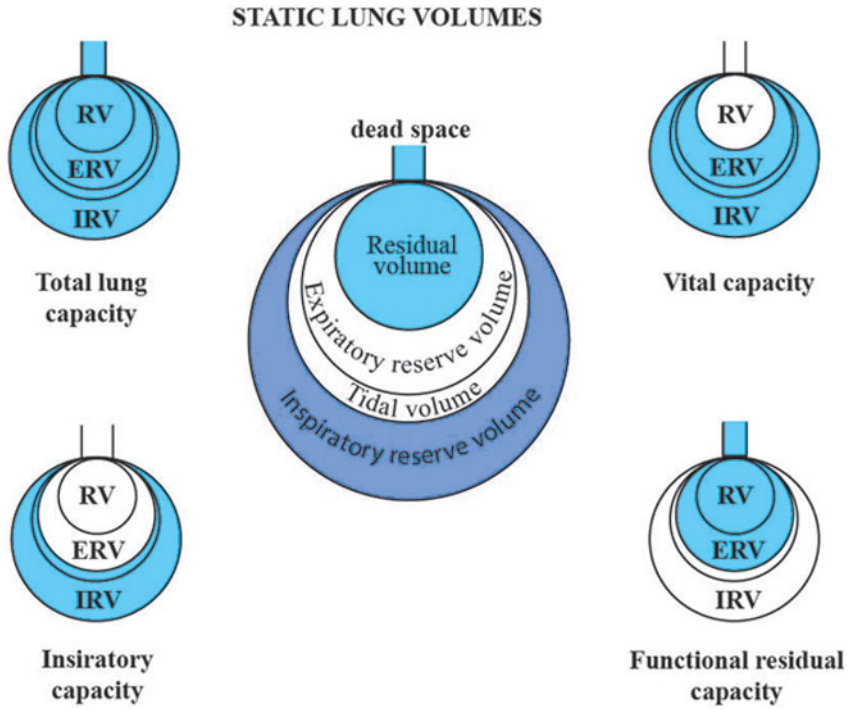


Figure 2–13. Lung volumes and capacities.

Pulmonary function testing equipment

There are several pieces of equipment used to test pulmonary function. We'll start with the most basic item—the spirometer.

Spirometer

The primary piece of equipment used to test pulmonary function is the spirometer. This piece of equipment measures how well the lungs exhale and has been around for many years. There are several types of spirometers, with the primary types being water-sealed, dry rolling-sealed, bellows-type, and flow-sensing. Let's take a moment to briefly examine each type.

Water-sealed

This is the oldest type of spirometer, and the one you are least likely to see. This type consists of a large bell suspended in a container of water. The unit suspends the open end of the bell below the surface of the water and the breathing tubes go into the interior of the bell. When a patient breathes into the tube, the bell moves a proportional distance. The bell, in turn, moves a pen across a rotating drum with a chart on it (kymograph) to chart the patient's breathing. This unit can also use a potentiometer in place of the kymograph, which produces a voltage used to drive a mechanical recorder.

Dry rolling-seal

This type of spirometer consists of a lightweight piston mounted horizontally in a cylinder. A rod that rests on frictionless bearings supports the piston, which is coupled to the cylinder wall by a flexible plastic seal. The seal simply rolls on itself, rather than sliding as the piston moves. As the patient breathes into the unit, the piston moves. Finally, the attached rod connects to a potentiometer, which, as in the water-sealed type, produces a voltage to drive a recorder. Figure 2–14 is an illustration of this type of spirometer.

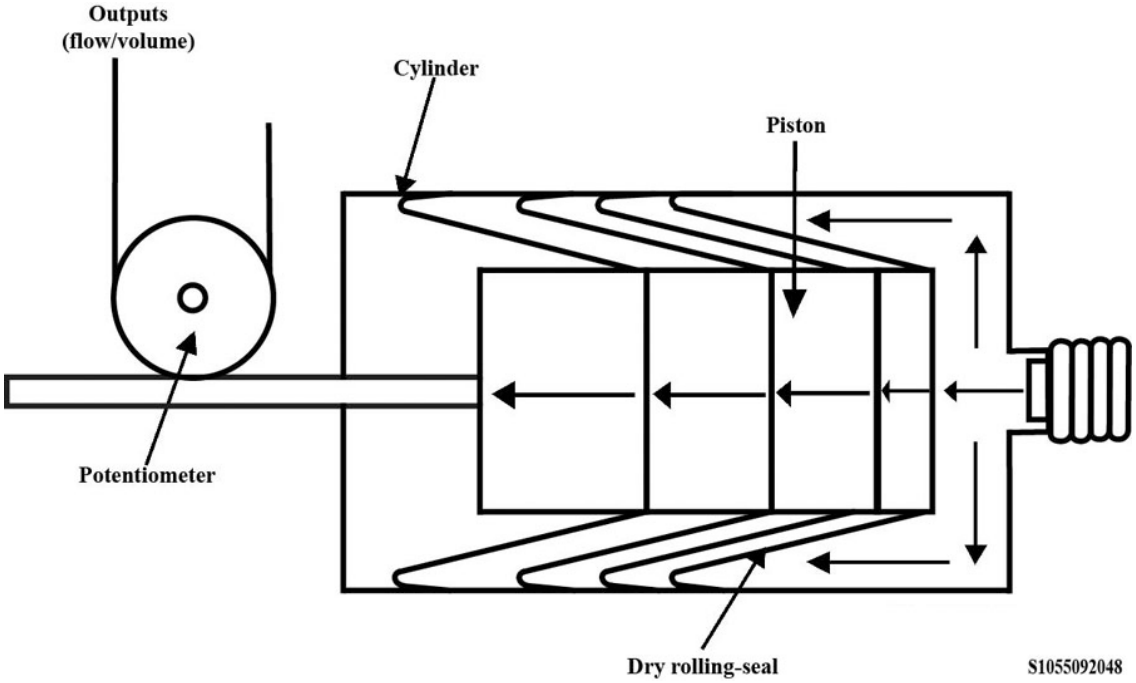


Figure 2–14. Dry rolling-seal spirometer.

Bellows-type

There are two types under this heading—the standard bellows and wedge. They both consist of a collapsible bellows that fold or unfold in response to a patient's breathing. A standard bellows looks similar to an accordion. One end of the bellows remains stationary, while the other end moves in proportion to the amount of expired or inspired air. The wedge type (fig. 2–15) resembles the bellows type, except it expands and contracts like a fan. In this type of spirometer, the movement may be transformed into a voltage by a potentiometer and recorded on a mechanical recorder, or the voltage may be converted into a digital signal and used by a computer for tracking. Using the mechanical recorder, the stylus will rise and fall with the bellows and chart the responses on paper.

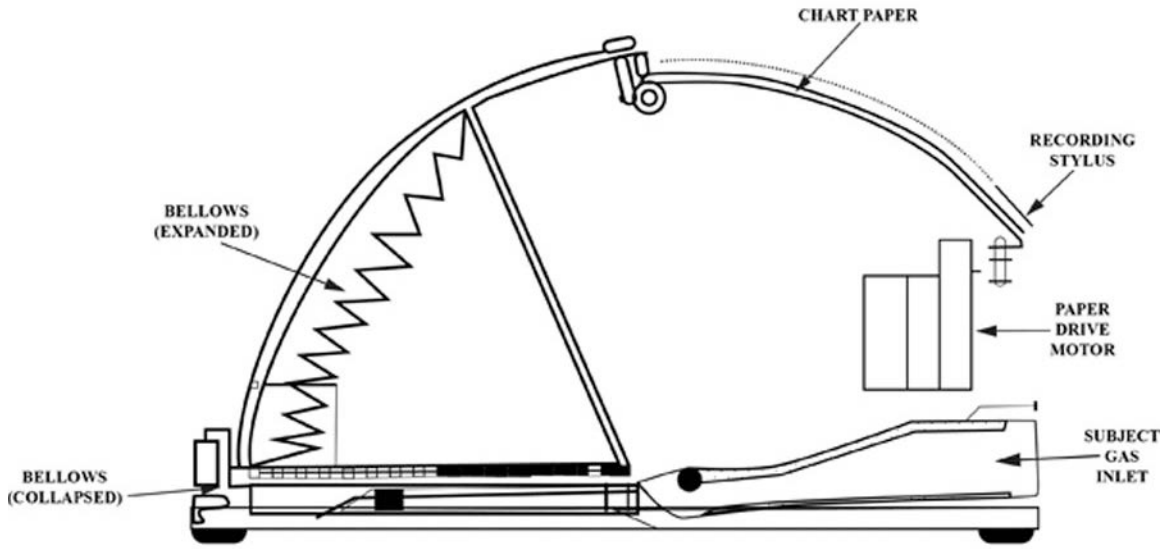


Figure 2–15. Wedge type bellows spirometer.

Flow-sensing

This type is known as a pneumotachometer (a device that measures flow). There are numerous methods used to measure flow in this particular type or spirometer. The following are the primary types:

- Turbine – This is the simplest type and consists of a vane connected to a series of precision gears (fig. 2–16). As gas flows through the unit, it moves the vane, which then registers a volume.

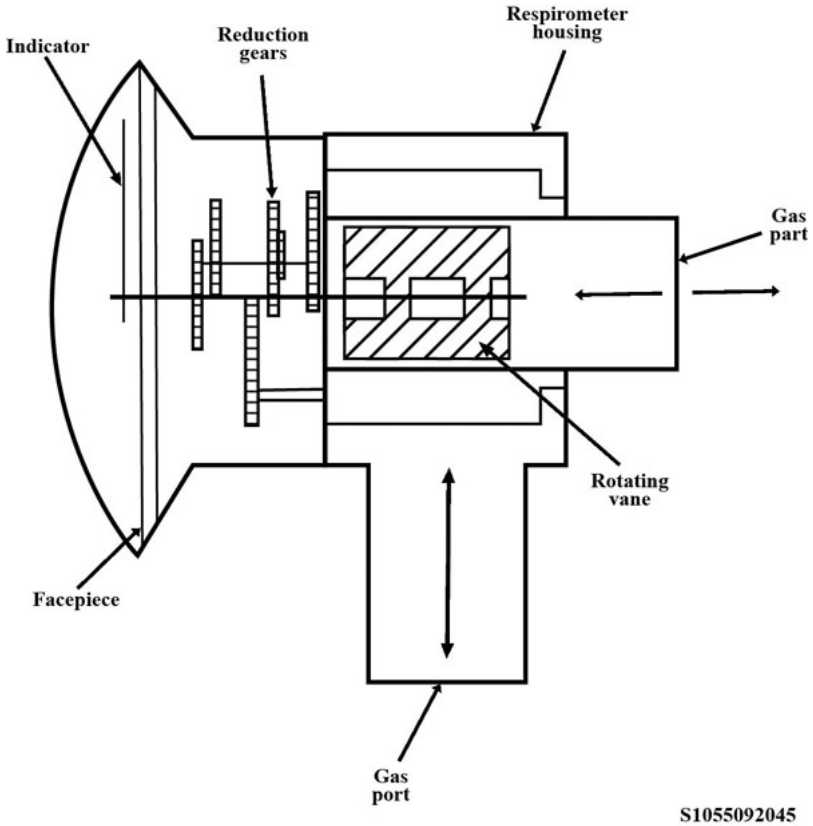


Figure 2–16. Turbine type flow sensor.

- Pressure-differential – This type is comprised of a tube containing a resistive element (fig. 2–17). The resistive element allows gas to flow through it but causes a pressure drop. A transducer, with taps on either side of the element, then measures the difference in pressure across the resistive element. The pressure differential is proportional to the gas flow.

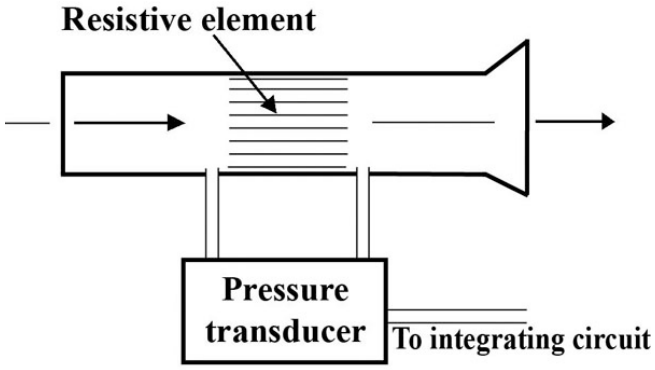


Figure 2–17. Pressure-differential flow sensor.

- Heated-wire – This type is made up of a tube containing a heated wire (thermistor) with a preset temperature (fig. 2–18). As gas flows past the thermistor, the temperature drops, thus, causing the unit to supply more current to the wire in order to maintain the preset temperature. The amount of current needed to maintain the temperature of the wire is proportional to the amount of gas flow.

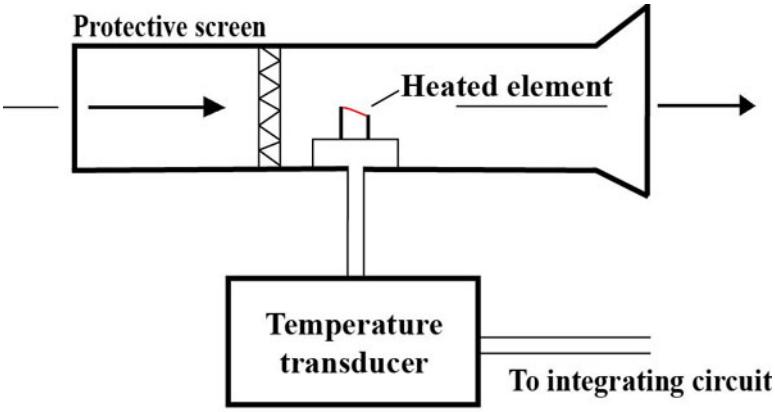


Figure 2–18. Heated-wire flow sensor.

- Ultrasonic – This type uses a principle called vortex shredding. It is a tube with struts, which look like airplane wings, placed within the path of flow. As gas flows over the struts, it is disturbed and broken up into waves called vortices. An ultrasonic crystal downstream of the strut transmits high-frequency sound waves across the gas flow to a receiving crystal on the opposite side of the tube (fig. 2–19). Each vortex passing through the ultrasonic beam produces a pulse. Each pulse is proportional to specific volume. The unit counts and sums the pulses electronically providing a measurement of volume.

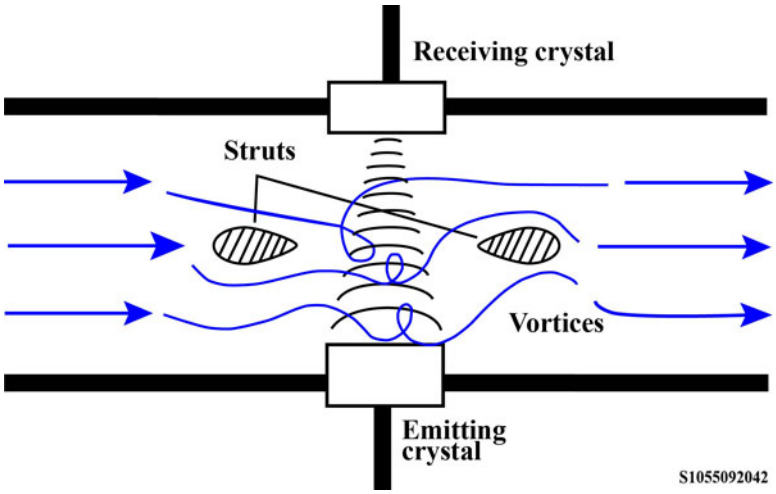


Figure 2–19. Ultrasonic flow sensor.

Spirometry is very common and quite useful in determining pulmonary function; however, it cannot make many required measurements, such as residual volume. For this reason, lung capacities that include the residual volume (FRC and TLC) are also not obtainable with spirometry. For this type of measurement, more complicated equipment is needed.

Body plethysmograph

This equipment item is the most accurate way to measure the lung volumes and capacities. It looks much like a clear telephone booth (fig. 2–20) that the patient sits inside of. There are two types of body plethysmographs—constant volume and flow (or variable-volume).

Figure 2–20. Body plethysmograph system.
(Licensed by CC BY-SA 3.0.)

Constant volume

The constant-volume plethysmograph is based on the principle that volume changes in a closed container can be determined from measured pressure changes as long as the temperature is constant. A sensitive pressure transducer monitors box pressure changes related to volume changes by

calibration. Pressure fluctuations result from the compression and decompression of gas within the subject's thorax and the box, as well as thermal changes. If the temperature is constant, each unit of pressure change equals a specific volume change. For example, in many systems, 15 mL of volume change results in a pressure change of 1 centimeter (cm) H_2O.

The pressure plethysmograph must be relatively free from leaks. A valving mechanism allows the technologist to vent pressure to maintain thermal equilibrium. Making measurements at rapid breathing rates (panting) can minimize pressure changes resulting from thermal drift, leaks, or background noise. Some pressure systems use a "slow" leak to facilitate thermal equilibrium. You can create a leak to allow thermal equilibration by connecting a long length of small-bore tubing to the box. Similarly, connecting the atmospheric side of the box pressure transducer to a glass bottle within the box dampens the effects of thermal drift. Both methods reduce the effect of temperature changes within the box while maintaining good frequency response. Pressure plethysmographs are best suited to maneuvers that measure small volume changes (100 mL or less).

Flow

The flow plethysmograph employs a flow transducer in the box wall to measure volume changes in the box. As gas in the box compresses or decompresses, the transducer measures pressure changes as gas flows out of the box through the flow opening. Flow through the wall is integrated, corrections applied, and the volume change recorded as the sum of the volume passing through the wall and volume compresses. In one implementation, the subject breathes through a pneumotachometer connected to the room (transmural breathing). The transmural pneumotachometer allows measurement of larger gas volumes while the subject is enclosed in the plethysmograph. The transmural flow redirects to the plethysmograph for airway resistance measurements in order to plot the ratio of flow-to-box volume. For measurements, you would block the flow transducer in the wall so the device works as a pressure box. The flow-type plethysmograph requires computerization to measure pressure, volume, and flow signals in phase. Although thermal changes must be accounted for, the flow plethysmograph does not need to be absolutely airtight. Figure 2–21 is a block diagram of a flow plethysmograph.

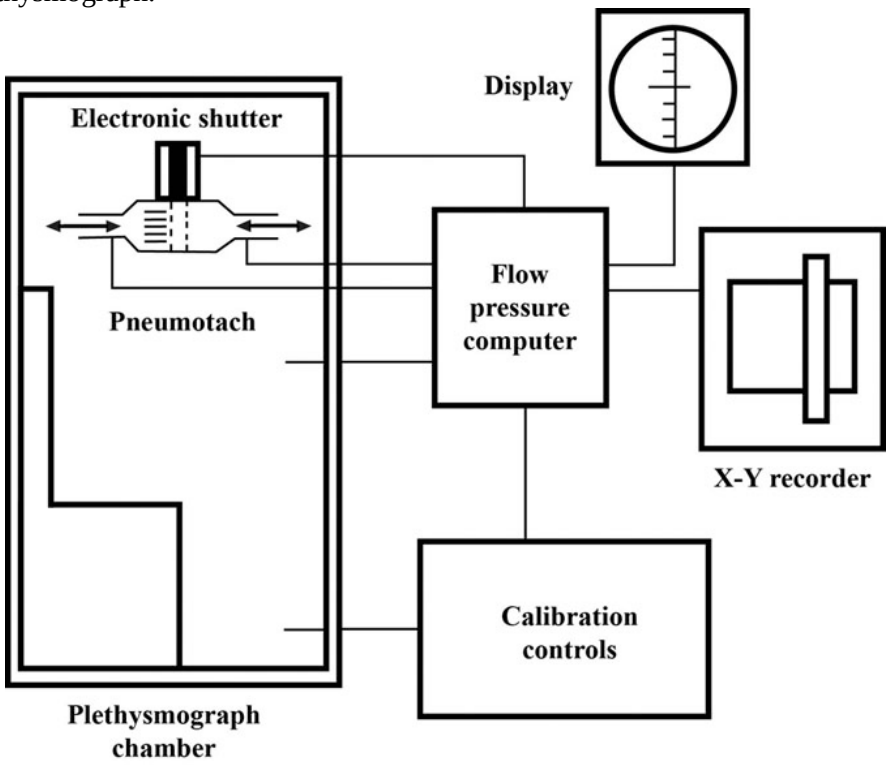


Figure 2–21. Flow plethysmograph block diagram.

With either unit, the test procedure is the same. During the test, the patient sits inside the airtight chamber, and inhales or exhales to a particular volume (usually FRC); a shutter then drops across the breathing tube. The patient then makes respiratory efforts against the closed shutter causing his or her chest volume to expand and decompressing the air in the lungs. The increase in chest volume slightly reduces the box's volume, thus, slightly increasing the pressure inside the box.

Clinical applications

Physicians use pulmonary function testing as a basic tool for evaluating a patient's respiratory status. In patients with suspected pulmonary disease, it is often the first diagnostic test used. PFTs can also help evaluate the condition of a patient's lungs before or after surgery, after they no longer require the use of a ventilator, to track and document the progression of lung disease, as well as in quantifying the amount of pulmonary disability a patient has.

Some other diagnostic uses of spirometry include evaluation of certain symptoms such as dyspnea, wheezing, cough, or chest pain. Certain signs displayed by a patient that indicate a need for testing include diminished breath sounds, slow exhalation, chest deformity, or unexplained crackling sounds. Also, certain patients may require testing, to include smokers and individuals who work in hazardous environments.

As stated earlier, the primary instrument used in pulmonary function testing is the spirometer. Its main purpose is to measure changes in volume and can only measure lung volumes or capacities that exchange gas with the atmosphere (i.e., nothing with RV in it). Some spirometers contain pneumotachs, or electronic signal detectors, used to measure flow (volume per unit of time). A device, known as a spirograph, is usually attached to the spirometer and measures the movement of gas in and out of the chest. Sometimes a printer may replace the spirograph, which produces a tracing called a spirogram. Many computerized systems have complex spirographs or printouts that show the predicted or "normal" values next to the observed values (the values actually measured). Of course, computerized units will have memory that can store prediction (or "normal") tables for males and females across all age groups. More sophisticated spirometers may even store more specialized tables, such as those for specific ethnic groups or for children.

This leaves us with the clinical applications of the body plethysmograph. As we have already discussed, we use this unit when we require the measurement of RV or any lung capacity containing RV. These measurements are most often required when a patient has suspected obstructive or restrictive lung disease. An obstructive disease normally will cause an increased TLC, an increased RV, and a decreased flow rate. A restrictive disease will cause a decreased TLC.

When limited airflow in the lungs develops over time, it is known as obstructive lung disease, also referred to as chronic obstructive pulmonary disease (COPD). The two major diseases in this category are emphysema and chronic bronchitis. Emphysema is a disease marked by destruction in the alveoli. Bronchitis is an inflammation of the bronchial tubes, or bronchi (the air passages that extend from the windpipe into the lungs). Other diseases that fit into this category are asthma and cystic fibrosis. Obstructive lung diseases make it difficult for the patient to breathe out.

Restrictive lung disease is any respiratory condition where the patient is unable to take in a full, deep breath. It can be due to lung, chest cage, or nervous system disease. All of these conditions are issues in which we would use pulmonary diagnostic equipment to detect.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

408. Electrocardiograph

1. What does the EKG measure?

2. What is an ECG?

3. Briefly describe the three primary pulses in an ECG waveform.

4. What are the three planes of electrical heart activity?

5. Briefly describe what the three standard leads measure.

6. Why are the augmented limb leads known as unipolar leads?

7. In which plane do the precordial leads measure?

8. List at least four items that can be detected with an ECG.

409. Pulmonary function testers

1. What are the four standard lung volumes?

2. What are the four standard lung capacities?

3. What is the primary piece of equipment used to test pulmonary function?

4. Match the spirometer in column A with the appropriate characteristic in column B. Each item in column B may be used once or more than once.

Column A	*Column B*
____ (1) Water-sealed.	a. Consists of a lightweight piston mounted horizontally in a cylinder.
____ (2) Dry rolling-sealed.	b. Known as a pneumotachometer.
____ (3) Bellows type.	c. Turbine type.
____ (4) Flow-sensing.	d. The oldest type of spirometer.
	e. Wedge type.
	f. Consists of a large bell suspended in a container of water.
	g. One type uses the vortex shredding principle.
	h. Expands and contracts like a fan.

5. Which type of pulmonary measurements cannot be made with spirometry?

6. What are the two types of body plethysmographs?

7. List at least three signs displayed by a patient that may indicate the need for pulmonary testing.

8. What is the primary difference between obstructive lung and restrictive lung diseases?

2–3. Inpatient Care and Labor and Delivery

If you are in a small MTF or other facility with no inpatient care, you might think this section does not apply to you. Actually, it does. The information will help you no matter the size of your MTF or its capabilities because some of this equipment will be found outside of inpatient care areas. Also, if your present facility does not have this equipment, you may find yourself at a larger facility sometime down the road during your career. In either case, pay close attention to this material as it will cover some basic information every BMET must be familiar with.

In this section, we will begin by discussing the basics of monitoring patients' vital signs and the use of physiological monitoring systems. After that, you will receive a lesson on the concepts of central patient monitoring. We will end the section with a lesson on the fetal heart monitor.

410. Physiological monitoring systems

One of the most fundamental actions performed in any MTF is checking or monitoring a patient's vital signs. To fully understand the purpose of the equipment in future lessons, you must learn a little more information about vital signs and the purpose of checking them.

Vital signs

Vital signs are physical signs that indicate a patient is alive, such as heartbeat, breathing rate, temperature, and blood pressure. In addition, we observe, measure, and monitor these signs to assess

an individual's level of physical functioning. Normal vital signs change with age, sex, weight, exercise tolerance, and condition. The following are the four standard vital signs and their normal ranges for the average healthy adult:

1. Temperature: 97.8°–99.1° F (average 98.6° F).
2. Breathing rate: 12-18 breaths per minute.
3. Pulse: 60-80 beats per minute (bpm) (at rest).
4. Blood pressure: systolic – less than 120 mmHg; diastolic – less than 80 mmHg. We commonly designate this reading as 120 over 80 (120/80).

Of course, the vital signs for a medical patient may vary from these normal ranges, depending upon the patient's condition. Nevertheless, a patient's vital signs are the first indication of his or her condition. In general, the worse a patient's vital signs are, the worse his or her condition.

There are also supplementary patient parameters that providers and technicians take to give additional information. The following are some of these additional parameters that we may monitor:

- Arterial blood oxygen saturation (SaO_2).
- Cardiac output (CO).
- ECG.
- Electroencephalogram (EEG).
- Exhaled CO_2 (capnography).
- Apnea.
- Bispectral index (BIS) – A measure of the hypnotic effect of anesthetic gases.

Physiological monitors overview

The word physiological monitor is a broad term that covers equipment used to monitor a patient's vital signs. It is often an interchangeable designation with vital signs monitor. There are several types with differing uses; they vary somewhat from model to model but usually have many features in common. For example, all units have an alarm for heart rate to alert the medical staff if a patient gets into trouble.

Most units are small, portable, lightweight, and rugged, which we utilize in many areas of the MTF, as well as the ambulance. The small portable units are especially useful in less specialized sections, such as pediatrics, family practice, or in some cases the emergency room (ER). They can be hand carried, wall mounted, or mounted on wheeled stands to move freely throughout the MTF. These units measure several patient parameters but are preset by the manufacturer (i.e., they can only measure the parameters the manufacturer designates). Larger multi-parameter and network-integrated units serve various purposes in inpatient and surgical departments, as well as some ERs. We will cover the networked units of central patient monitoring in the next lesson. The primary parameters measured using physiological monitors are the standard vital signs. These units are excellent tools to help give the medical staff a quick assessment of a patient's overall condition.

Now that you have a general idea about physiological monitoring, we will explore the more specific applications for its use.

Non-invasive blood pressure

Arterial blood pressure is the force exerted on the blood vessel wall due to the pulsing action of the blood flow. Blood pressure depends on cardiac output, resistance in the blood vessels, condition of the blood (viscosity), and elasticity of the arterial wall. Blood pressure measurement is a very important clinical tool in a patient's diagnosis. Measured blood pressure characterizes circulatory changes due to a wide variety of causes, such as hypertension (high blood pressure), hypotension (low

blood pressure), physiological stress, stroke, trauma, shock, and arteriosclerosis (narrowing or clogging of vessels due to high cholesterol).

Because the heart rhythmically alternates pumping and relaxing, arterial pressure is cyclic. The maximum pressure reached during each cycle is the systolic pressure; the maximum pressure recorded before the next pumping action is the diastolic. Clinically, these values are reported as systolic over diastolic, for example, 120/80 mmHg. The average of the systolic and diastolic pressures measured is the mean pressure, which generally increases with age. Another clinically useful value derived from the measured systolic and diastolic values is the numerical difference between the two, called the pulse pressure. Blood pressure measurements can be direct or indirect. Direct techniques, which we cover later, involve catheterization and the use of transducers. Indirect measurement utilizes a sphygmomanometer and stethoscope, Doppler shift transducer, or finger plethysmograph.

Manual methods

The sphygmomanometer (fig. 2–22) consists of an inflatable bag or cuff wrapped snugly around an extremity (usually the arm), pressure gauge to monitor air pressure in the cuff, valve to allow the release of pressure, and hand pump with which to inflate and pressurize the cuff. By inflating the cuff, pressure exerts onto the arteries, which squeezes them shut as soon as the cuff pressure exceeds the systolic arterial pressure.

Once the inflated cuff occludes (cuts off) the arterial blood flow, it is then slowly released while monitoring the sound of arterial blood flow with a stethoscope. With the cuff inflated, you cannot hear any sound. As the valve opens slightly allowing the cuff pressure to bleed off, you can observe a slight tapping sound as the cuff pressure drops to the systolic pressure and blood begins to squeeze past the restrictive cuff. Upon hearing the first sounds, we can record a close approximation of the systolic pressure from the cuff pressure gauge. As the pressure continues to release, the sound changes into a loud thud that fades and disappears just below the diastolic pressure, which is then recorded.

The dicrotic notch, the irregularity appearing on the falling slope of the arterial pressure waveform, occurs when the aortic valve closes (fig. 2–23). The dicrotic notch is only a pressure waveform change, which you cannot hear through the stethoscope. As you recall, at the end of systole, the heart just finished pressurizing the arterial system with blood and is relaxing. As it relaxes, the pressure gradient (heart to arteries) reverses, and blood tends to flow back into the heart, as well as continuing out toward the blood vessels. Fortunately, the aortic valve prevents this back flow and shuts when it is attempted. The pressure rise just beyond the dicrotic notch is due to the inertia of the blood attempting to flow back toward the heart. Once the inertia expends and the blood flows away from the heart and out into the system, the arterial pressure continues to decline until the next ventricular contraction.

The sounds observed during the occlusion and release of the blood pressure cuff are known as Korotkoff sounds. They are simply the result of blood squirting past the restrictive cuff as the pulse pressure overcomes cuff pressure. Because of ambient room and motion noise interference, and the fact that we reach diastolic pressure just before the blood flow sounds totally disappear, this method of blood pressure measurement can be somewhat subjective. However, it is certainly easier, faster, and less dangerous than invasive measurement techniques.

Automatic methods

Automatic blood pressure monitoring devices (commonly called non-invasive blood pressure [NIBP] devices) are a mainstay throughout the MTF. They are especially useful for trauma patients and others who must have continual blood pressure monitoring on a moment’s notice or for only a short time. There are two primary methods for checking blood pressure automatically: auscultatory and oscillometric.

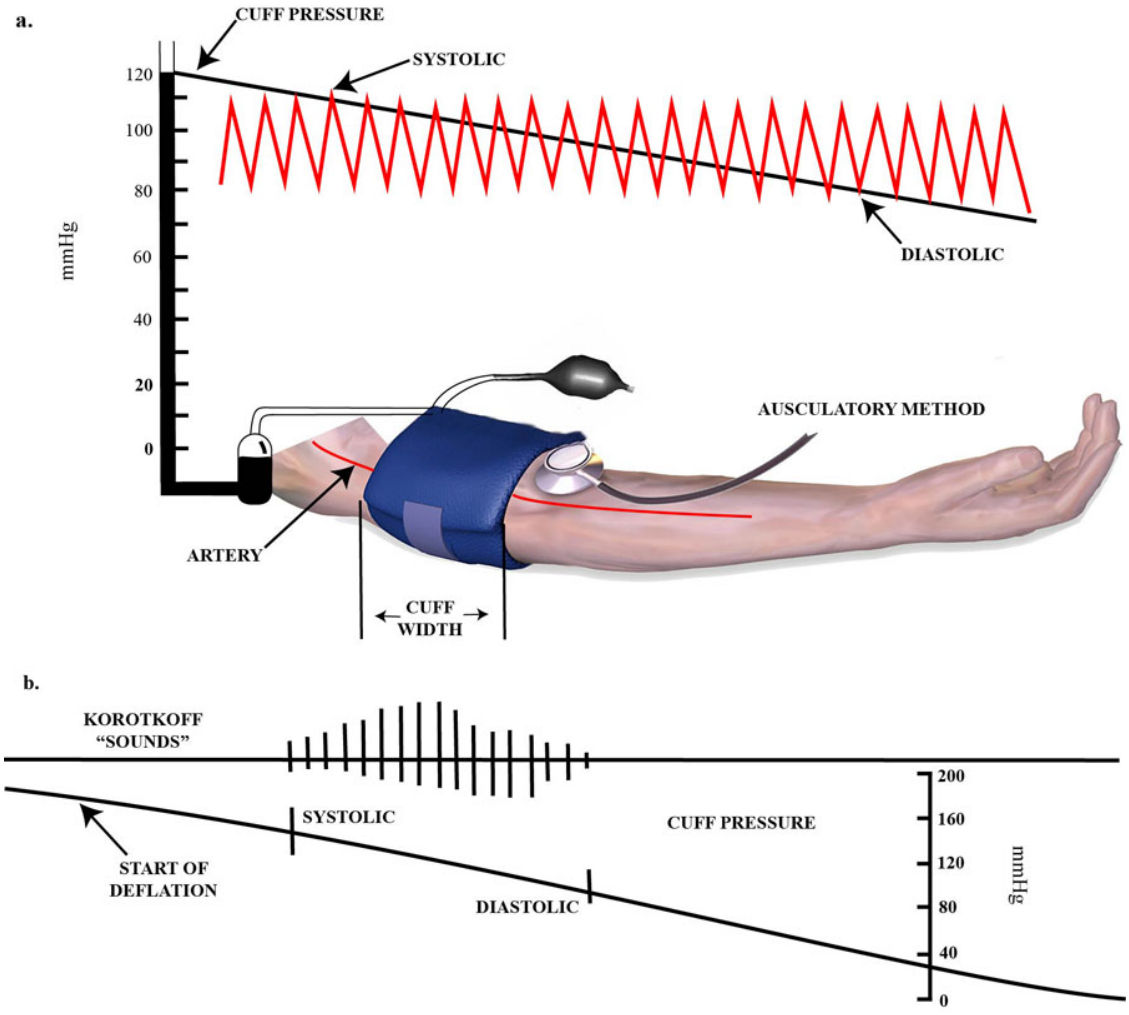


Figure 2–22. Indirect blood pressure measurement.

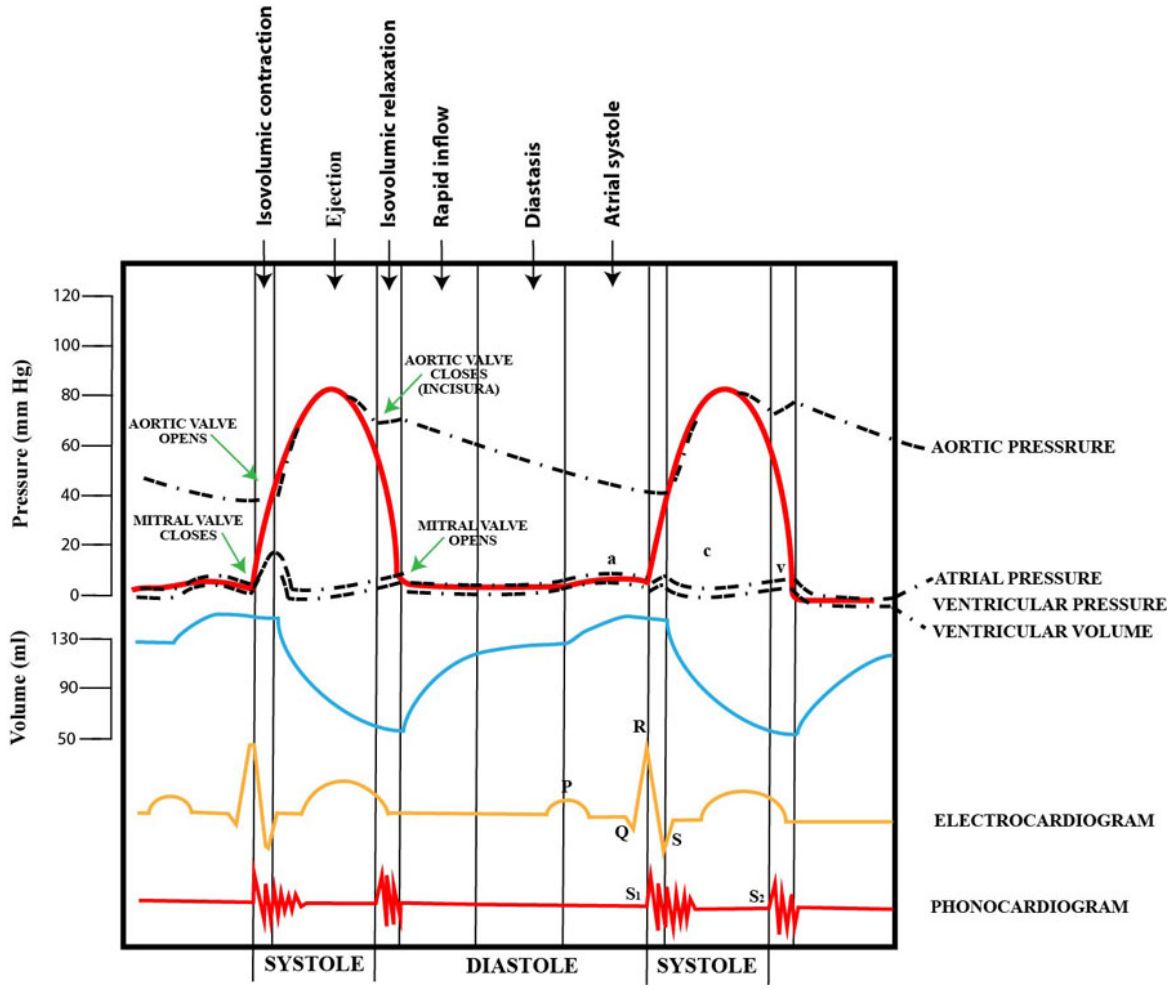


Figure 2–23. Pressure waveforms.

Auscultatory technique

The first method of NIBP monitoring is similar to the manual method and works by simply inflating and releasing a pressure cuff while listening electronically for Korotkoff sounds with an audio transducer (microphone). These sounds are an effect of Doppler shifting and allow the system to detect the movement or shift in frequency. Figure 2–24 is an example of auscultatory technique. Each movement of the reflecting surface (the arterial wall) generates a characteristic Doppler-shift signal at the instrument output. The pressure-sampling rate or frequency can usually be user-determined, allowing the flexibility necessary to adapt to a wide variety of situations.

In addition to reporting systolic and diastolic pressures, automatic blood pressure devices have other uses. Since they are microprocessor based, they can calculate mean arterial pressure and rate, and also provide alarms.

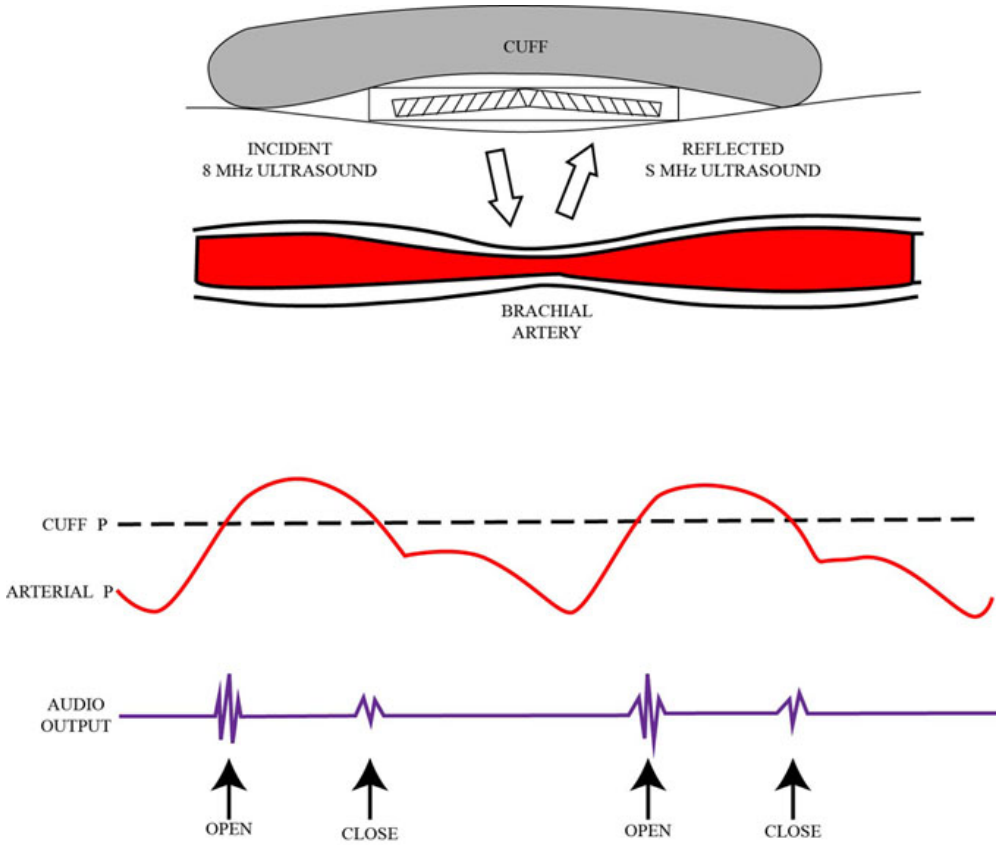


Figure 2–24. Indirect blood pressure measurement using the auscultatory technique.

Oscillometric technique

The second technique is known as the oscillometric method and is the most commonly used. This technique does not use Korotkoff sounds to determine blood pressure; rather, it monitors the changes in cuff pressure caused by blood flow through the artery. The unit inflates the cuff to a pressure that occludes blood flow through the patient's artery. Even during occlusion of the artery, the pumping action of the heart against the artery continues. This pumping action creates small pressure pulses in the cuff baseline pressure. Next, the unit lowers cuff pressure at a controlled rate. As this action occurs, blood starts to flow through the artery, which causes the amplitude of the pressure pulses to increase. These pulses continue to increase in amplitude until they reach maximum amplitude, at which point they begin to decrease in amplitude with decreasing cuff pressure. The cuff pressure at which the pulse amplitude is the greatest is known as the mean arterial pressure (MAP). The manner in which the pulse amplitudes vary is known as the pulse envelope (an imaginary line that connects the peak of each pressure pulse and forms an outline). The NIBP unit observes the shape of the envelope, which then utilizes various techniques to convert that information into systolic and diastolic pressure readings.

Clinical applications

As we mentioned earlier, blood pressure is one of the four basic vital signs. Clinicians routinely measure blood pressure at almost any visit to the MTF or doctor's office, as it gives a quick indication of a patient's overall heart health. It also indicates if a patient has high or low blood pressure. High blood pressure (hypertension) is always one of two types. The first, and far more common, type is known as essential hypertension. Essential hypertension has no known cause but seems to be hereditary.

The second, and least common, type of high blood pressure is called secondary hypertension. This type of hypertension is the result of secondary factors, such as kidney disorders, endocrine system

disorders, neurological disorders, drugs or chemical side effects, or other miscellaneous causes. While it may seem we hear about this type of hypertension far more often, in truth, only about 5-10 percent of people with hypertension have secondary hypertension.

A different problem that we can detect with blood pressure measurements is low blood pressure (hypotension). This condition can be equally as dangerous as high blood pressure because it can mean an inadequate supply of blood to the brain and other vital organs. Serious medical conditions, such as heart failure, heart attacks, heart arrhythmias, shock, or advanced diabetes can often be the cause of chronic low blood pressure. It can also be the secondary result to side effects from various medications.

Invasive blood pressure

Invasive blood pressure (IBP) measurement (also called direct measurement) is a much more complex procedure than non-invasive measurement. Of course, you have probably figured out direct blood pressure measurements are not standard, everyday procedures. This form of blood pressure measurement is reserved for the most seriously ill patients that require very accurate and long-term continuous monitoring. Direct techniques can be minimally invasive involving only a needle inserted into a vessel, but, most often, they involve catheterization.

The usual process of IBP monitoring involves the insertion of a catheter or needle into a large peripheral artery, such as the radial artery. The catheter is connected to a fluid-filled bag containing saline and heparin (a drug that prevents the blood from clotting). The entire fluid-filled system is under slight pressure to keep blood out of the tubing. Changes in blood pressure cause a corresponding change to the pressure within the fluid-filled system. These changes are sensed by a pressure transducer, which sends a signal to the blood pressure monitor. Figure 2–25 is a graphical representation of the components.

Clinical applications

Before we go any deeper into specifics, let’s find out more about the purpose of IBP monitoring. There are three primary pressures measured using invasive methods: arterial pressure, central venous pressure (CVP), and pulmonary artery pressure (PAP).

Arterial pressure measurement

While arterial pressure measurement can be measured using non-invasive techniques (this is the standard NIBP measurement), some patients in critical care areas require constant monitoring. If this monitoring were done using non-invasive methods, the patient would have a cuff inflating on their arm every 5 to 10 minutes. Imagine trying to rest with that happening! Invasive arterial measurement eliminates the need for a blood pressure cuff and the constant inflation/deflation cycle. Invasive techniques also provide a more accurate measurement of blood pressure without the risk of errors associated with non-invasive methods. Direct measurements actually monitor the pressure beat-by-beat and display a graphic waveform (a graph of pressure against time). An additional benefit to invasive monitoring is the medical staff has easy access to blood samples since a catheter is already in place within an artery. Patients with invasive arterial monitoring require very close supervision, as there is a danger of severe bleeding if the line becomes disconnected. It is generally reserved for critically ill patients or patients undergoing certain surgical procedures where rapid variations in blood pressure are anticipated.

CVP measurement

CVP is the pressure within the superior vena cava (the major vein in the chest that carries blood from the upper body to the right atrium). To monitor CVP, a catheter is inserted into a vein in the arm, chest (just below the shoulder), or jugular vein in the neck. The line is then advanced down to a point just above the heart. The catheter is actually part of an intravenous (IV) line that may have several different ports for other purposes, such as drawing blood, or giving fluids or nutrition. Monitoring CVP helps the medical staff assess a patient’s cardiac function, evaluate venous blood return to the

heart, and indirectly gauge how well the heart is pumping. It also helps to evaluate patient fluid levels and responses to fluid administration.

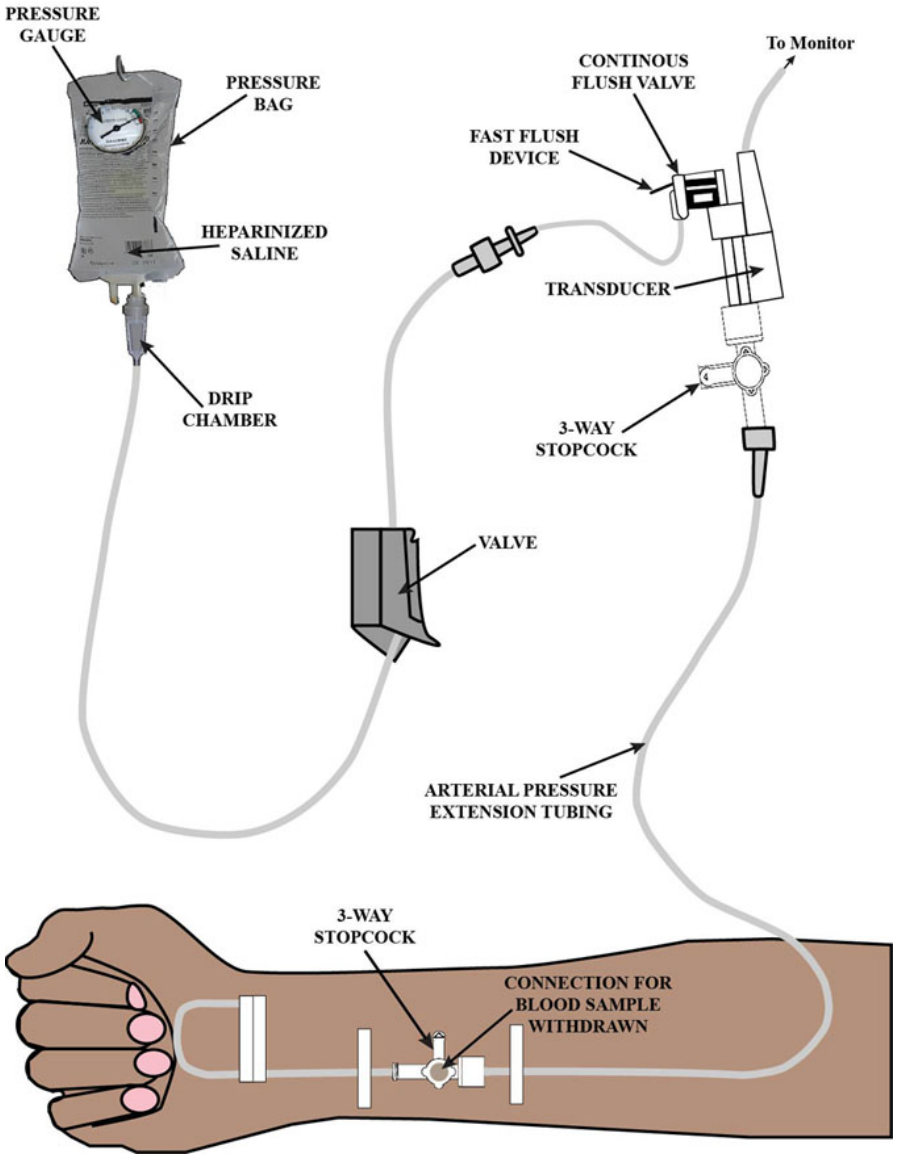


Figure 2–25. Components of an IBP monitoring system.

PAP measurement

PAP measurement provides the medical staff with information about the functional characteristics of a patient's right and left ventricles, as well as other heart functions. The pulmonary artery is the artery that leads from the right ventricle of the heart to the lungs. Pulmonary artery catheterization is usually performed at the bedside of a patient in the intensive care unit (ICU). A catheter is threaded through a vein in the arm, thigh, chest, or neck until it passes through the right side of the heart. Once the catheter is in place, the doctor briefly inflates a tiny balloon at the end of the catheter, which temporarily blocks the blood flow and allows the doctor to make a pressure measurement in the pulmonary artery system. Pressure measurements are usually recorded for the next 48–72 hours in different parts of the heart. During this time, the patient must stay in bed so the catheter remains in place. Once the pressure measurements are no longer needed, the catheter is removed. Pulmonary artery catheterization is performed to evaluate heart failure; monitor therapy after a heart attack;

check the fluid balance of a patient with serious burns, kidney disease, or after heart surgery; and check the effect of medications on the heart.

Percutaneous needle

Percutaneous (meaning passed through the skin) needle insertion is a minimally invasive technique, which involves inserting a needle fitted with a transducer through the skin directly into a vein or artery. Refer back to figure 2–25, which shows a percutaneous needle joined to the transducer by a three-way stopcock. Through the stopcock, the needle is flushed with saline to prevent air bubbles and allows the blood pressure to be coupled directly to the transducer by a fluid link. The stopcock also allows easy extraction of arterial blood samples and injection of medication.

Catheters

Blood pressure measurement by catheterization involves two basic techniques. In the first, an open-tipped, fluid-filled catheter connects to the pressure in the blood vessel via the fluid column to a pressure transducer located outside the body. This is similar to the percutaneous method, except a catheter replaces the needle. In the second, a catheter is outfitted with a tiny pressure transducer at the tip, which transmits the transduced pressure signal directly from the end of the catheter via wires without an intermediate fluid column.

In the percutaneous needle insertion and fluid-filled catheter techniques, the length and diameter of both fluid-filled devices, as well as the flexibility of their walls, have a great influence on the frequency response of the system. The fluid hydraulic system of the catheter must be carefully designed and matched to the transducer to be responsive to blood pressure changes, while at the same time not being overly responsive and unstable. Even the smallest air bubble can drastically upset the frequency response of a fluid-filled system. Because air is relatively compressible compared to the fluid, flushing the catheter system for bubbles is essential. Transducer-tipped catheters do not experience such problems.

Most transducer-tip catheters operate on an induction principle similar to the linear variable differential transformer (LVDT) discussed in Unit 2 of Volume 2. By varying the position of an inductor core in conjunction with the in-and-out flexing of the catheter tip, the voltage across the coil varies in proportion to the flexing and the sensed blood pressure. Unfortunately, for all the advantages this method has in terms of signal quality, it has practical disadvantages because it is fragile and costs more than external transducers. Figure 2–26 is an example of a Millar Mikro-tip® catheter pressure transducer; it is the most well-known of the transducer-tip catheters. For the constant and often rough use of the ICU and critical care unit (CCU), fluid-filled catheters and external transducers are much more popular.

Liquid column and external transducer blood pressure techniques use hollow, flexible catheters made of rubber, Teflon, or polyethylene, which are rounded at the end for ease of movement and have an opening slightly back of the tip to allow a blood/saline interface for pressure transmission. Typically, the fluid catheter and transducer are interconnected through a three-way stopcock that allows easy flushing of the system and the addition of medication. Such a configuration is shown in figure 2–27. The complete catheter is not shown in the figure; however, the catheter stopcock to which it connects is visible. Stopcocks using standard taper connections, called Lure connectors, are used extensively whenever patients are connected to fluid-filled catheters or tubes. This allows safe and repeated connection/disconnection with minimum disturbance.

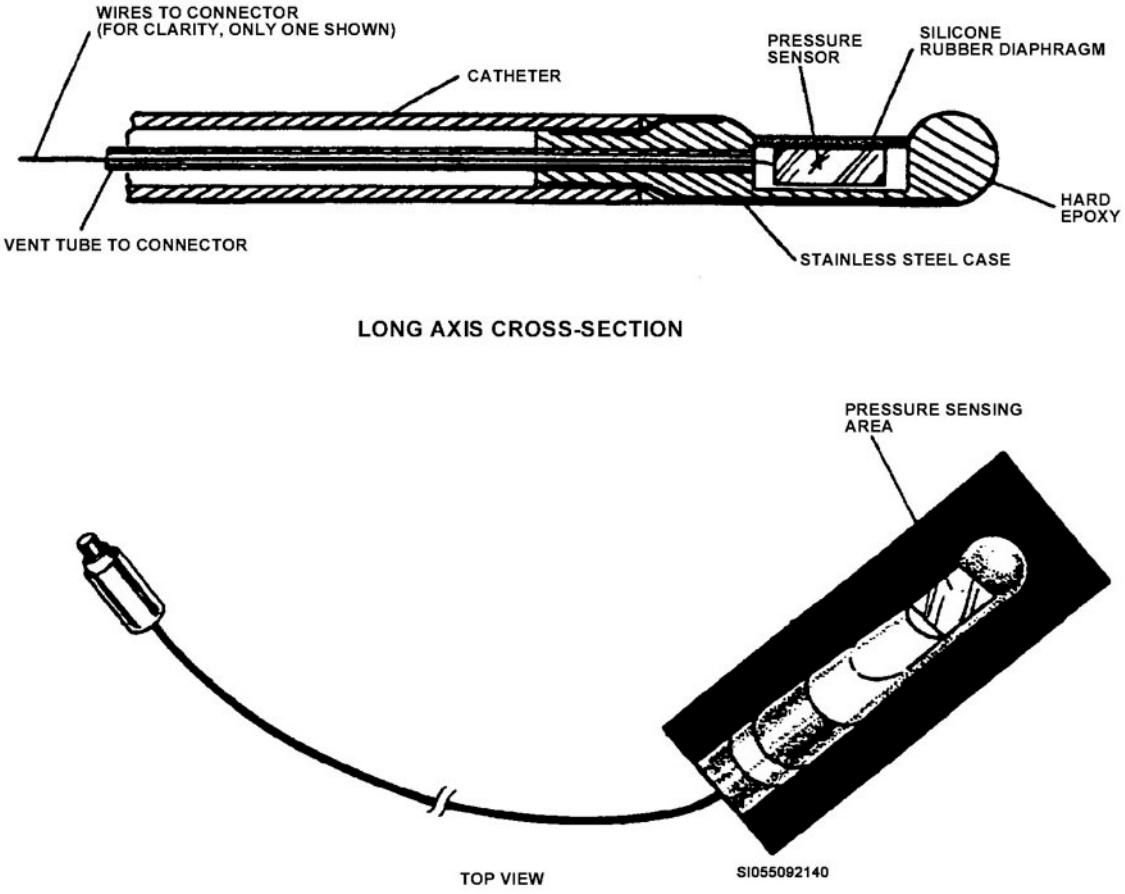


Figure 2–26. A Millar Mikro-tip® catheter pressure transducer.

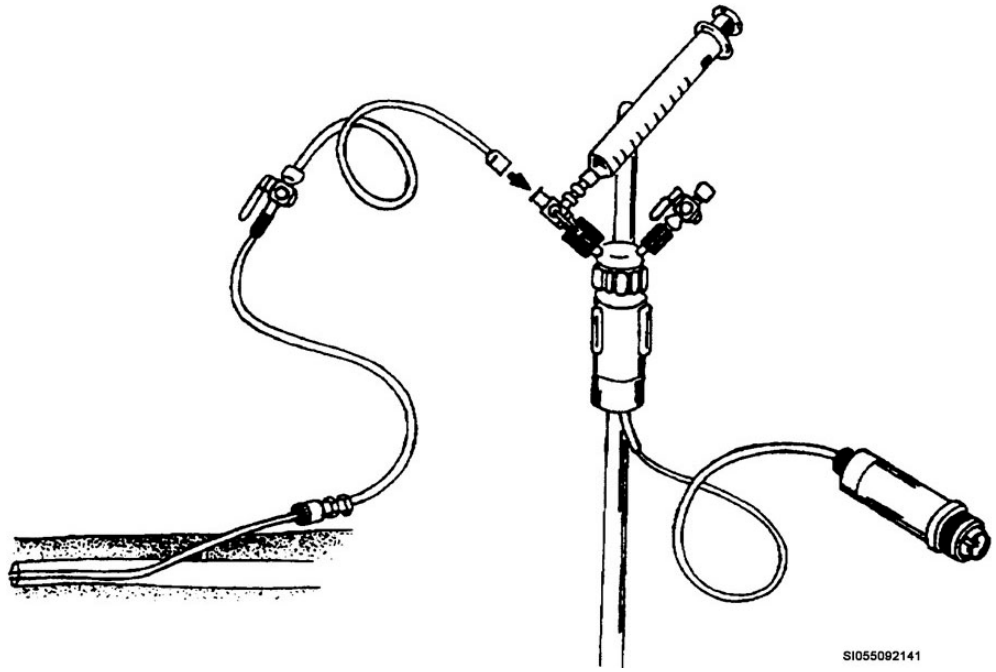


Figure 2–27. Catheter pressure measurement system.

Transducers

Most of the pressure transducers used with fluid catheters follow the standard dome-type design shown in figure 2–28. The sensing membrane or diaphragm forms the flat surface of the transducer's pressure chamber, which is dome shaped. The pressurized fluid enters the dome through one of the two connectors; the other is used to fill and bleed the dome and catheter system. The dome itself is clear to allow the presence of bubbles and fluids to be visually detected.

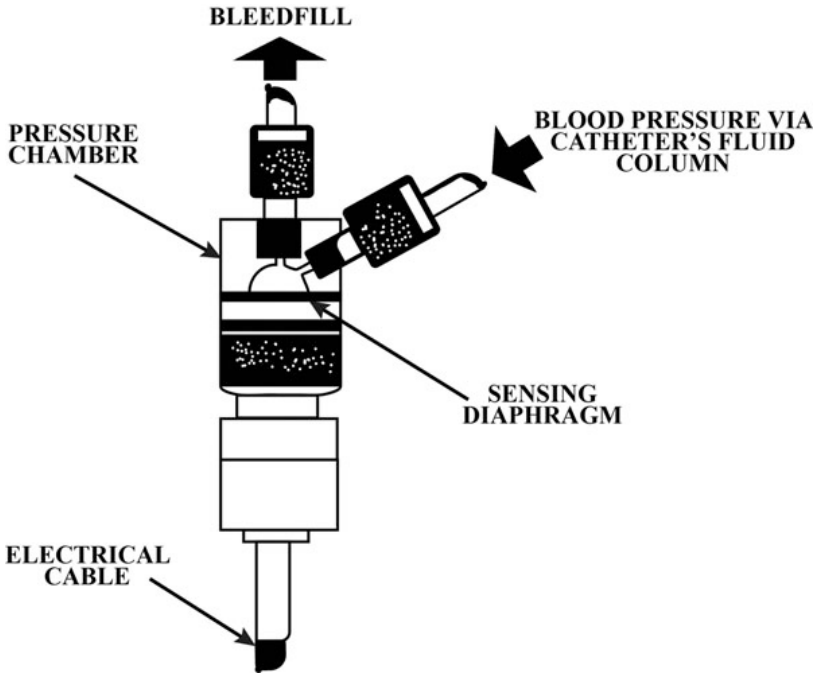


Figure 2–28. Standard dome type blood pressure transducer.

Dome-type pressure transducers use strain gauges and LVDTs driven by the diaphragm to develop the electrical pressure signal. The design of the dome/transducer interface connection is rather fragile and should be stressed in only one direction. Inadvertent negative pressures caused by flushing syringes can easily destroy the transducer. Frequently, staff members not familiar with the use of transducers are unaware of the high potential for destruction by negative pressures and should be reminded during in-service lectures.

Catheterization techniques

There are three basic catheterization techniques that can be used, depending on which chambers of the heart are to be examined:

1. Right heart catheterization – Insertion is made in the left arm. From there, the catheter is advanced through the venous system to the superior vena cava, where it enters the right atrium and, in turn, the right ventricle.
2. Retrograde catheterization – Used to monitor pressures in the left ventricle; insertion is made in an artery of the arm or groin, and the catheter is advanced through the aorta and into the left ventricle.
3. Transseptal catheterization – Used to examine the left atria; a large bore catheter is inserted in the femoral vein of the right leg and advanced to the right atrium. A needle is inserted through the catheter, puncturing the tissue wall between the right and left atrium. Through the puncture, a smaller diameter catheter is inserted into the left atrium. If comparison pressures are needed, the catheter can then be advanced into the left ventricle.

When fluid-filled and transducer-tipped catheters are inserted, the insertion process is often done in a catheterization laboratory with the aid of a fluoroscopic X-ray machine. With fluoroscopy and a

radiopaque catheter, the physician is able to monitor and guide the travel of the catheter into any of the heart's chambers, or wherever else it may be needed. In addition to measuring pressures, blood samples can be taken for O_2 and CO_2 content analysis, and contrast media can be injected to allow X-ray of the flow of media and blood mixture through the heart. Catheterizing the patient and injecting contrast media at the source of the coronary blood supply reveals occlusions in the coronary arteries. With contrast media, the coronary angiogram provides visualization of the coronary arteries.

Swan-Ganz catheterization

An alternate and increasingly popular method of obtaining internal cardiac pressures is done in the ICU and CCU without the aid of an X-ray machine. This alternate method uses a flotation- or balloon-tip catheter, called the Swan-Ganz, connected to a transducer and blood pressure waveform monitor.

Physically, the Swan-Ganz catheter (fig. 2–29) has a polyvinyl chloride (PVC) tube with an inflatable balloon at the tip. Internally, the catheter is subdivided into two to four internal passages (lumens), one of which is used for inflation of the balloon. The number of lumens depends upon the specific functions of the particular Swan-Ganz catheter being considered. All Swan-Ganz catheters measure CVP, PAP, and pulmonary capillary wedge (PCW) pressure, and allow sampling of mixed venous blood for O_2 concentration analysis. Some Swan-Ganz catheters also measure simultaneous arterial pressure and contain temperature-sensitive thermistors for making cardiac output determinations.

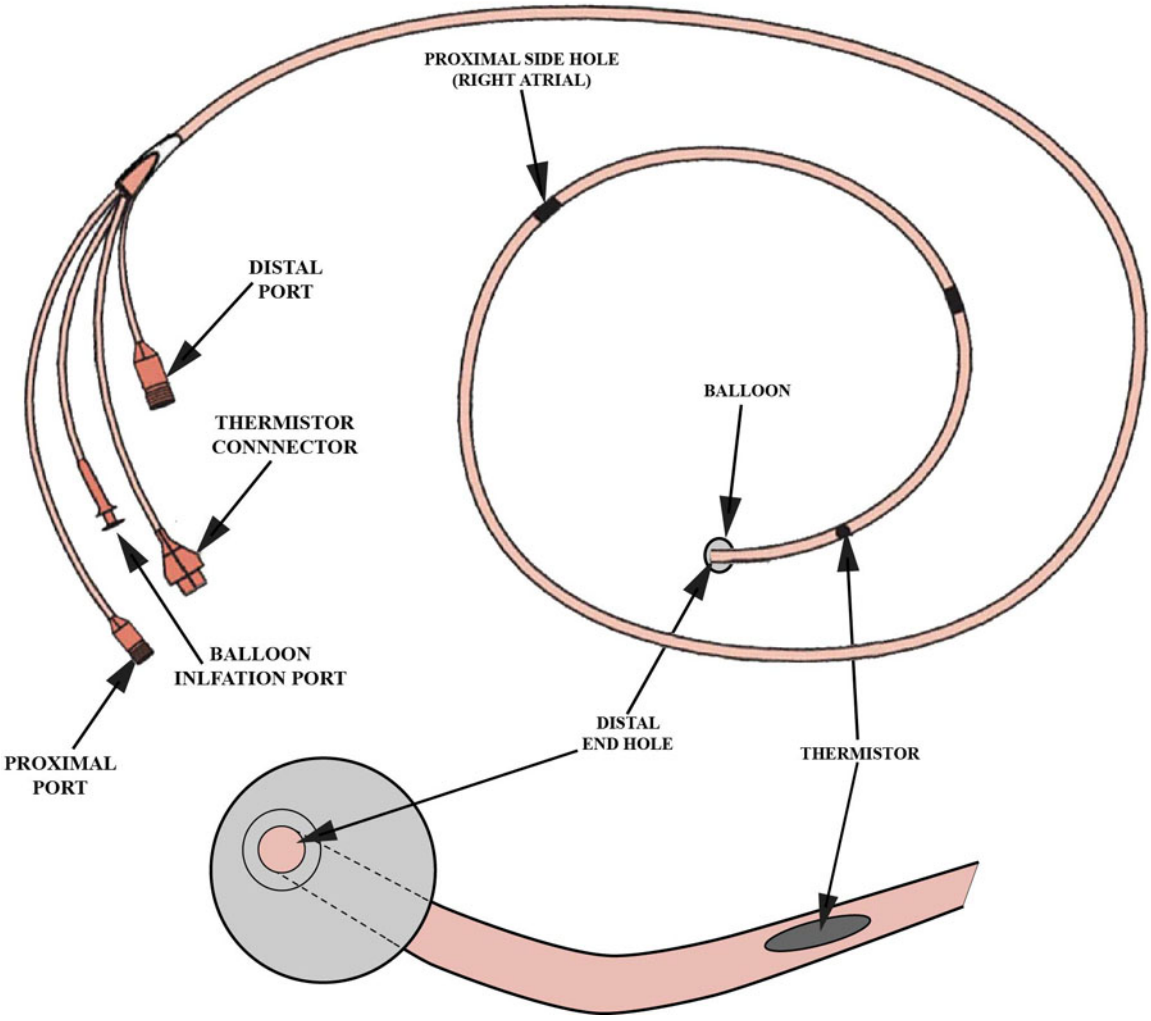


Figure 2–29. Swan-Ganz catheter.

The Swan-Ganz is inserted into a large vein, such as the subclavian vein in the shoulder or internal jugular vein in the neck. With slight inflation of the balloon and gentle pushing assistance, the balloon advances toward the heart guided by the venous blood flow returning to the heart. By observing the waveform monitor for the presence of a right atrial pressure tracing, the exact location of the catheter can be determined. Once the catheter is confirmed to be in the right atrium, the balloon can be fully inflated. It then passes into the right ventricle with the flow of blood, indicating a ventricle pressure waveform on the monitor, and, in turn, passes into the pulmonary artery. As the catheter passes along the pulmonary artery, it wedges in a vessel when it encounters a smaller diameter than that of the balloon. The PCW pressure then appears on the monitor. Figure 2–30 illustrates the catheter position during PCW pressure measurement. Once recorded, the balloon is deflated, and the PAP returns to the monitor. Comparisons made between the systolic, diastolic, and mean pressures present in the right atrium, right ventricle, pulmonary artery, and pulmonary wedge can yield a detailed analysis of the quality of the heart's operation on the right side and provide a good indication of left heart functions.

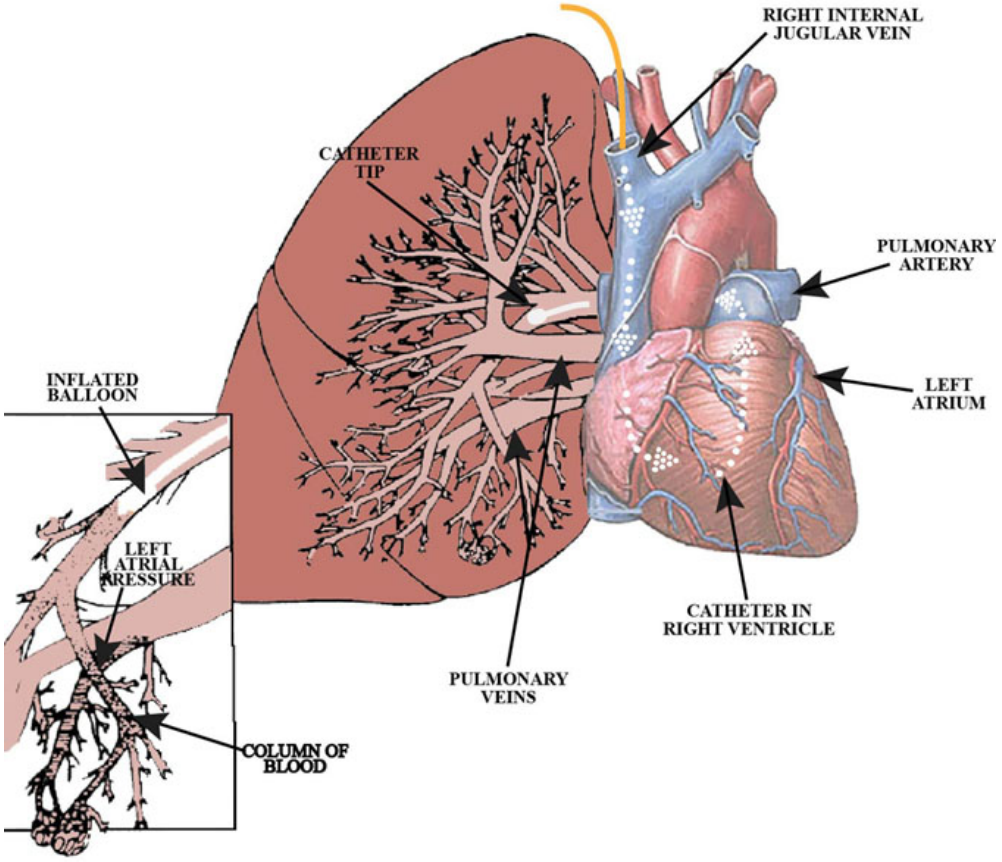


Figure 2–30. Pulmonary wedge position.

Catheters of all kinds are inserted either by a vessel cut down or percutaneous technique. With a vessel cut down, the artery or vein is surgically exposed and opened to insert the catheter. A simpler method, and the one used more frequently, especially with Swan-Ganz catheters, is the percutaneous technique. The peripheral artery or vein is entered first with a cannula (essentially a large bore needle), which serves as a guide for the nylon or metal wire guide. With the cannula removed, the catheter can be slid comfortably down the guide wire. Once inserted a small distance, the guide wire is removed, and the catheter is ready to be advanced.

Pulse oximetry

The pulse oximeter is a very common equipment item found nearly anywhere in the MTF. Pulse oximetry is a very important measurement, so let's spend a little more time examining it.

Clinical application

Pulse oximetry measures the body's oxygen saturation level, which is often called "the fifth vital sign;" this shows the importance of this piece of medical equipment. The pulse oximeter is used in many different fields of healthcare where SaO_2, pulse rate, and pulse strength information is required. This includes areas, such as operating rooms, ICU, outpatient clinics, ER, and emergency land/air transport. When referring to pulse oximetry, we often use the term oxygen saturation determined by pulse oximetry (SpO_2), which more accurately describes the SaO_2 measurement determined by pulse oximetry.

The oximeter can be a portable, compact, lightweight stand-alone monitor, or in its most common application, part of a physiological monitoring system. For the purpose of this lesson principle, we will refer to it as a single unit. It provides non-invasive, continuous monitoring of pulse rate, and, more importantly, SaO_2. This basically means the pulse oximeter tells what percent of a patient's hemoglobin molecules are carrying O_2. The normal adult level of SaO_2 is 97-99 percent.

Let's now look at some specific areas in the MTF where the pulse oximeter can be found, along with its associated uses:

- Operating room – To monitor a patient under anesthesia to ensure their SaO_2 level does not drop to critical levels.
- ER/ambulance – Used in conjunction with the vital signs to give a quick overview of a patient's condition.
- Respiratory therapy – Helps determine how well the respiratory system is working by indicating SaO_2; used to monitor the effectiveness of treatment for lung disease or disease progression.
- ICU – Used to provide a continuous indication of a patient's SaO_2 level and overall condition, and indicates if the patient requires an increased O_2 supply.

Operating principles

The oximeter determines SaO_2 and pulse rate by passing two wavelengths of light, one red and one infrared, through body tissue to a photodetector. Pulse identification is possible by using plethysmographic techniques; SaO_2 measurements are determined using spectrophotometric oximetry principles.

In simple terms, a probe surrounds the patient's finger, toe, ear lobe, or nose. Two LEDs produce beams at red and infrared frequencies, which pass through the body part to a photodetector on the other side. The LEDs flash at approximately 30 times per second, and switch on in sequence with a pause with both diodes off. This allows compensation for ambient light. The microprocessor analyzes the changes of light absorption during the pulsating arterial flow and ignores the non-pulsating component of the signal (which results from the tissues and venous blood). The unit estimates the SaO_2 by measuring the transmission of light through the pulsating tissue bed.

During measurement, the signal strength resulting from each light source depends on the color and thickness of the body tissue, sensor placement, intensity of the light source, and absorption of the arterial and venous blood (including the time varying effects of the pulse) in the body tissues. SaO_2 calculations are possible, because blood saturated with O_2 predictably absorbs less red light than blood depleted of O_2.

Since measurement of SaO_2 depends on a pulsating vascular bed, any condition that restricts blood flow (i.e., the use of a blood pressure cuff or extremes in systemic vascular resistance) may cause an inability to determine accurate pulse and SaO_2 readings.

Figure 2–31 shows several different probe placement techniques for SaO_2 and pulse readings:

- A universal “Y” probe on an ear (A). This also is an adult application. A close-up of the universal “Y” probe ear clip attachment is shown in item B.
- A universal “Y” probe on a finger (C). This is an adult application.
- A finger probe (D). This is for adult application only.
- A universal “Y” probe on an infant’s hand (E).
- A universal “Y” probe attached to an infant’s foot (F).

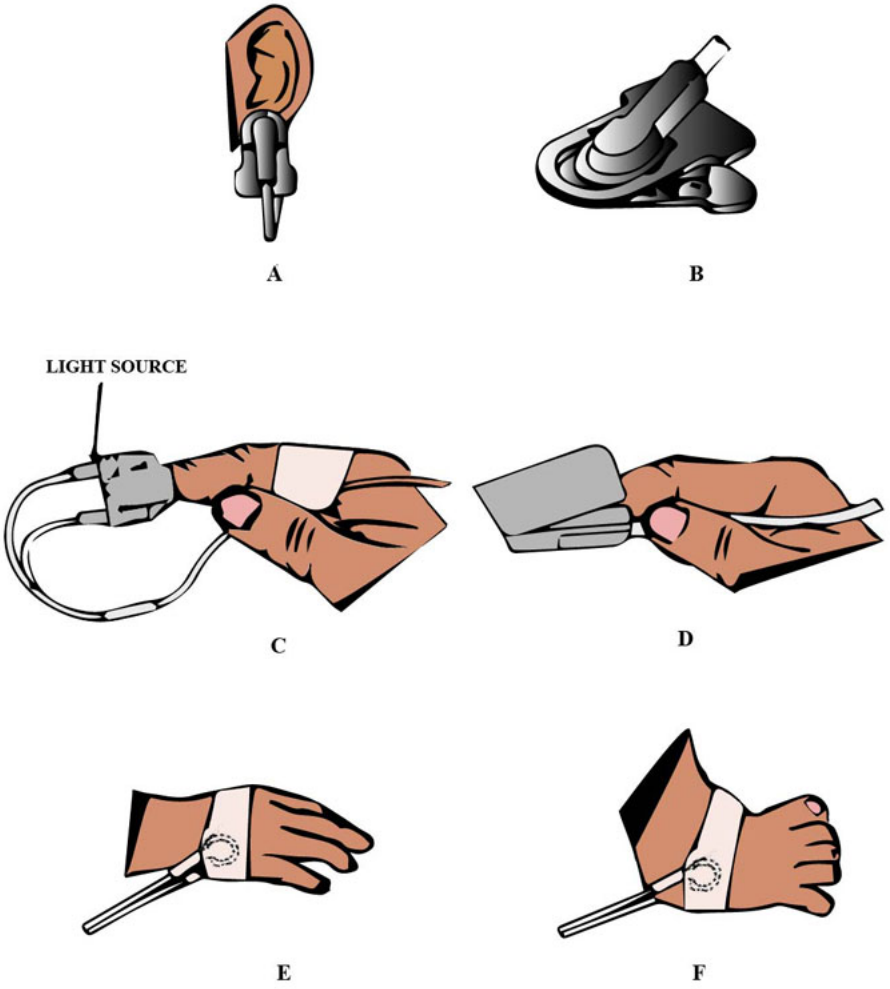


Figure 2–31. Pulse oximetry probes and site locations.

Cardiac output monitor

CO is the amount of blood ejected by the heart to the circulation system every minute. The formula for CO is heart rate (number of bpm) multiplied by the stroke volume (SV), which is the amount of blood pumped by the ventricle during each beat. We express CO as liters per minute (L/m). So why is CO measured?

CO measurements routinely occur during and after major surgical procedures and with critically ill patients in the ICU. Measuring CO helps the medical staff to assess the state of a patient’s circulation system. The simple measurements we discussed earlier, such as heart rate and blood pressure, may be adequate for many patients; but, if there is a cardiovascular abnormality, then more detailed measurements are needed. One common problem that may require CO measurement is hypotension (low blood pressure), which can occur in a wide range of patients, especially those in intensive care or

postoperative units. CO measurement is useful in establishing a patient's initial cardiovascular state and measuring the response to various treatments. Currently, there are two basic invasive methods for determining CO; the first uses a bolus dye solution and the second uses a Swan-Ganz catheter.

Invasive methods

The measurement of CO by dye dilution requires a central venous and an arterial catheter. Figure 2–32 shows the setup for this procedure. The patient receives a rapid injection of a bolus of dye, usually indocyanine green, directly into the central venous circulation system. Blood is withdrawn continuously from the artery and passes through a densitometer, which determines concentration by spectrophotometry. A chart tracks this information with time along the bottom and concentration on the side. The area under the plot of concentration versus time is inversely proportional to CO. Dye dilution is not suitable for routine clinical use. Calibration of the dye densitometer is difficult and the accumulation of dye in the circulation limits repeated determinations of CO. A second method of measuring the dye concentration incorporates an inflatable rubber earpiece. Before taking a measurement, the earpiece squeezes venous blood out of the ear for calibrating a zero level. After calibration, the staff removes the earpiece and measures the change in light absorption caused by only the blood. Then, the dye injection occurs and measurement starts. The earpiece method is non-invasive but requires calibration before dye injection.

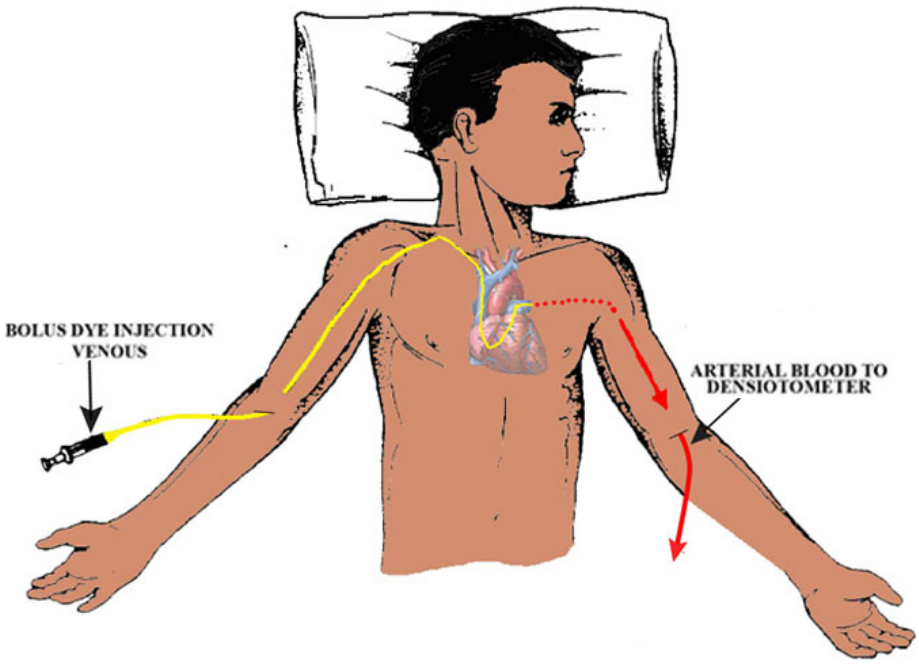


Figure 2–32. Dye injection for CO.

The second technique is known as the thermodilution technique. It uses a special thermistor-tipped Swan-Ganz catheter, which you learned about in the invasive blood pressure lesson, which inserts from a peripheral vein into the pulmonary artery. This technique injects a cold saline of a known temperature and volume into the right atrium from a proximal catheter port. The saline mixes with the blood as it passes through the ventricle and into the pulmonary artery, thus cooling the blood. The units then measure the blood temperature at the catheter tip lying within the pulmonary artery, and a computer acquires the thermodilution profile and computes flow.

Minimally invasive and non-invasive methods

There are several new methods of computing CO, which are not as invasive as the standard methods. As the purpose of this lesson is just to familiarize you with the concept of CO, we will just briefly describe a few methods in use today.

Pulse dye densitometry

One new method is called the pulse dye densitometry method. It is a less invasive version of the dye dilution method that does not require calibration before measurement. This method injects dye into a vein close to the atrium but does not require a catheter. There is also no requirement for blood sampling—dye concentration measurements occur continuously and non-invasively by pulse spectrophotometry using a clip-on probe. This method is nearly as accurate as those previously mentioned and will continue to increase in popularity over time.

Transesophageal echocardiography

Transesophageal echocardiography (TEE) has now been a widely used monitor in perioperative setting. It is an important tool for the assessment of cardiac structures, filling status and cardiac contractility. This uses the Doppler technique to measure CO using SV multiplied by heart rate, with the ultrasound beam parallel to the blood flow. It is a useful tool in hemodynamically unstable patients under mechanical ventilation. Limited availability and high cost are major limitations for its use; additionally, it requires a skilled operator. A standard TEE probe also cannot remain in the patient for too long.

Partial gas re-breathing

The partial gas re-breathing monitor uses indirect Fick's principle to calculate CO, which is essentially the release of a substance by any organ being the product of the arteriovenous concentration difference of the substance (O_2 in this case) and the blood flow to that organ. We mostly use this method in intubated patients under mechanical ventilation. At a steady state, the amount of CO_2 entering the lungs via the pulmonary artery is proportional to the CO and equals the amount exiting the lungs via expiration and pulmonary veins. During 30 seconds of re-breathing, the amount entering does not change, but the amount eliminated by expiration decreases and end tidal CO_2 increases in proportion to the CO. A major limitation is that it requires tracheal intubation with fixed ventilator settings. It is also not very accurate in patients with severe chest trauma, significant intrapulmonary shunt, high CO stats and low minute ventilation.

Thoracic bioimpedance

Thoracic bioimpedance (TEB) is a non-invasive method of CO monitoring. Initially used by astronauts in 1960s, the basis relies on the hypothesis of considering the thorax as a cylinder perfused with fluid with specific resistivity. It measures the electrical resistance of the thorax to a high frequency, low amplitude current. Major limitations like interference with electrocautery, proper electrode placement, patient's movements and arrhythmia may affect its accuracy.

Ultrasonic cardiac output monitors

Ultrasonic cardiac output monitor (USCOM) are portable non-invasive devices that use a probe placed suprasternal to measure flow through the aorta, or on the left chest to measure transpulmonary flow. It uses the Doppler principle as used with TEE. The main advantage is the portability of the device and its ease of use in the ER, operating room (OR), ICU, and even in wards. Trained nursing staff are able to use this device, as it is non-invasive. This is an important screening tool for postoperative cardiac surgical patients as well. A major limitation is probe positioning, as misalignment of the ultrasound beam with blood flow may lead to errors. The estimation of proper cross sectional areas in various physiological states is also important.

Respiration monitor

Measuring respiration is a very important aspect of a physiological monitoring system. Breathing is, of course, one of the most fundamental biological functions; therefore, respiration monitoring is a common use of physiological monitors. Let's look more specifically at why and when we use respiration monitors.

Clinical applications

Respiration monitors are common equipment items found throughout the MTF. Just like the lessons before, some may be stand-alone units, while others may be part of a physiological monitoring system. We are focusing on equipment that is part of the latter, but the clinical applications for both are basically the same. Let's now look at some specific applications of a respiration monitor.

Conscious sedation

Conscious sedation is used as a method to reduce pain or anxiety associated with many medical procedures but without rendering the patient unconscious. Pharmacologic drugs perform conscious sedation and almost always have a suppressant effect on respiration. The extent and duration of the effects are not always predictable and require close monitoring of the patient, usually for a much longer period of time than that necessary for the actual medical procedure.

Pain management

Pain management refers to the administration of narcotic drugs to patients with moderate and severe pain, often using a pump through which the patient can control the amount of medicine delivered. Like most sedatives, narcotic drugs also have suppressant effects on respiration, and their use requires respiratory monitoring.

Minor surgical procedures

Some minor surgical procedures occur in areas of the MTF other than surgery. Most of these procedures require some form of sedation, pain management, or anesthesia, and, therefore, monitoring.

Major surgical procedures

Of course, one of the primary uses of respiration monitoring is during and after anesthesia related to a major surgical procedure. Patients require monitoring for a period of time immediately following the procedure in a specialized recovery area. After leaving the recovery room, patients will most likely continue to have their respiration monitored because respiratory complications are usually the main post anesthesia concern.

Sleep disorders

Many physical problems are the cause of sleep disorders. These disorders may be associated with, or caused by, respiratory abnormalities, such as "sleep apnea syndrome." Evaluation of such disorders always includes respiratory monitoring during sleep.

Types

Respiration monitor designs offer differing capabilities. For example, some may only measure the presence of respiration, while others may measure more detailed information, such as the volume of air moved during each respiration. Obviously, with different purposes come different equipment designs. Let's spend a few moments looking at some of the various types of respiration monitoring methods.

Impedance pneumograph

This device operates on the principle of changing alternating current (AC) impedance across the chest of a patient during respiration. This technique applies to many neonatal respiration monitors and apnea alarms. Surface electrodes, identical to those used in ECG monitoring, apply a low voltage, 50-500 kHz, AC signal to the chest of the patient. Many of these types of monitors are also ECG monitors, sharing a common set of electrodes and a single pair of lead wires. High-value fixed resistors connected in series with each electrode create a constant AC source. The signal voltage applied to a differential AC amplifier is the voltage drop across the resistance representing the patient's chest resistance. Figure 2–33 illustrates a simplified circuit analogy.

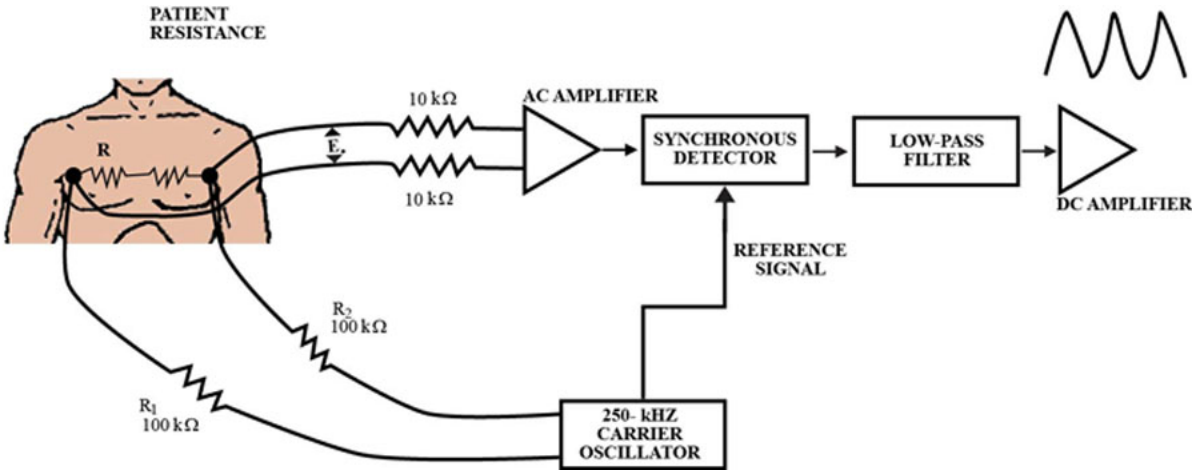


Figure 2–33. Impedance pneumograph.

The current passed through the patient's chest is very small and is nearly constant without respiration. The reason is the source voltage is constant and patient resistance is very small with respect to the sum of R_1+ R_2 + R.

A synchronous amplitude modulation (AM) detector receives the amplified output signal. The respiration waveform is contained within amplitude variations in the output due to patient-varying chest resistance. A low-pass filter following the detector removes any residual carrier signal, and a direct current (DC) amplifier increases the output waveform to the level required by the display device or pneumotachometer after this circuit. This output contains only rate data and the existence of respiration.

The primary type of the pneumograph uses a piezoresistive strain gauge transducer (constructed of wire, foil, or semiconductor) to sense respiration. In the pneumograph, the strain gauge element is attached between two elastic bands. When this assembly is stretched across the patient's chest, the element changes resistance with movement of the patient's chest. As the chest rises and falls, the resistance varies and is translated into a changing voltage signal. Only rate and existence information is contained in the output signal.

Thermistors are also used as flow detectors in some pneumographs. One type of transducer consists of a bead thermistor placed just inside of the patient's nostril. A constant current is passed through the thermistor, but its value is limited to the current required to barely allow self-heating of the thermistor. This level is 5 to 10 milliamperes (mA) in most thermistors. Power dissipated is usually limited to less than 40 milliwatts (mW) to avoid injury or discomfort to the patient. The thermistor changes resistance due to the temperature difference between inspired and expired air.

A thermistor transducer can be used on a patient fitted with an endotracheal tube, or on a respirator or ventilator. Figure 2–34 illustrates this special fitting design. Two thermistors are placed inside a tee-piece (a standard piece of equipment used by respiratory therapy). Thermistor R_1 is in the flow path of inhaled or exhaled gases, while R_2 establishes a reference point by being in a nonturbulent dead space. In some transducers, the thermistor is replaced with a platinum wire stretched taut across a short section of tubing. This wire is resistive and changes value as the temperature changes. Again, these types give only rate and respiration existence.

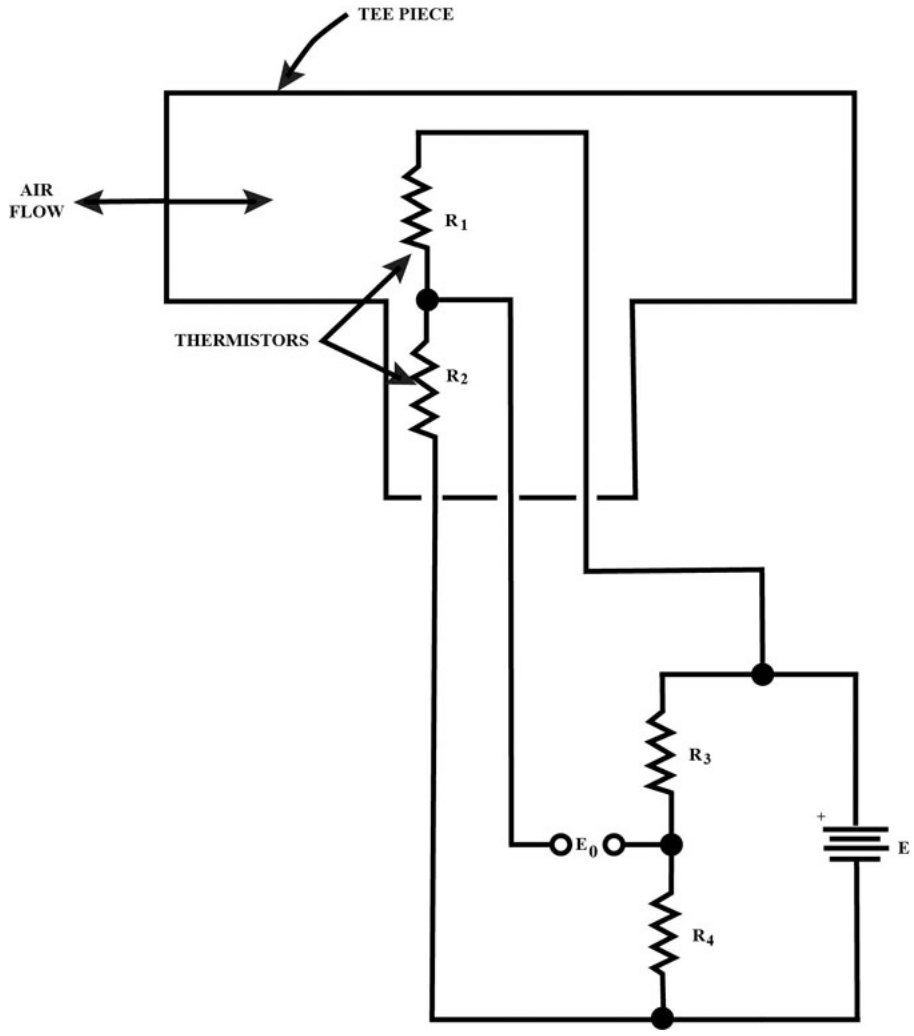


Figure 2–34. Thermistor transducer.

Flow volume transducer

This device is capable of making quantitative measurements. Flow volume is measured in L/m. Similar to the same concept you learned from figure 2–17 in the spirometer section, the transducer unit consists of a differential pressure transducer and an airway containing a wire mesh obstruction. When a mesh is placed in an airway, it causes a pressure drop measured as a differential pressure across the mesh. The pressure transducer is connected so this difference can be measured on either side of the mesh.

It is necessary to keep the pressure drop to less than 1 cm H_2O, or it will affect normal breathing. The standard transducer usually offers a 50-millimeter (mm) diameter mesh that has a grid density of 158 wires per centimeter. Manufacturers of respiratory equipment using this mesh transducer calibrate the machine to the transducer, but calibrations may be checked in the field by using a precision pneumatic flow meter to create a known flow volume.

Airflow rate is flow volume per unit of time. This rate can be obtained by integrating the volume-time signal for a known period of time. One version of this type of measurement frequently seen in medical devices is the minute-volume measurement, in which the inspiratory volume is measured for a period of one minute. This is usually obtained by integrating the volume signal for a 1-minute period.

411. Central patient monitoring systems

As more medical equipment becomes network integrated, the concept of central patient monitoring (or remote monitoring) increases. In areas where you used to have individual physiological monitors, now you might find a networked system monitored by a central station. We generally refer to this as the tele system. You will commonly find these units in several areas of the MTF, including the ICU/CCU, coronary care unit (also CCU), pediatric intensive care unit (PICU), OR, and increasing in popularity within the emergency department (ED). Each of these areas has something in common; they are specialized and designed to care for critically ill or seriously injured patients that require constant monitoring. These units are normally part of a monitoring system made up of two main parts: the bedside monitor or telemetry device and the central station itself.

Bedside monitor

The first, and most familiar, part of the system is the bedside monitor. This part of the system keeps a constant watch over a patient's vital signs (and other selected parameters). It has a screen with a readout for various monitored parameters, which may consist of a single parameter to many depending on the configuration. Most bedside monitors are the modular type with interchangeable modules that allow many configurations, depending on the department or requirements of the patient.

The primary benefit of the modular unit is the ability to change which patient vital signs you want to monitor—done by utilizing separate "modules" for each parameter. Figure 2–35 shows a standard bedside monitor with different options. The basic unit contains the case, screen, and control panel. The user can then add modules that plug into the basic unit, with each module designed to measure a particular parameter. For example, let's say a patient is admitted into the ICU and requires his or her ECG, temperature, blood pressure, and respiration rate to be monitored. The user can insert these particular modules into the unit, and it is ready to go. Later, the unit configuration can change for a different patient that requires monitoring for ECG, blood pressure, SpO_2, and CO. Some units also offer the option to use a multi-parameter module, which we sometimes refer to as a brick. Generally, in a basic brick, you will find connections such as ECG, NIBP, IBP, temperature, and SpO_2 all rolled into one module. Additional brick configurations might have the basic vital signs along with some additional combination of CO or CO_2 monitoring. Newer units have added the capability of internal storage allowing the brick to transfer with the patient and plug into another base. This adds the benefit of continuous patient monitoring during transport as well as seamlessly transferring all patient admission and vital signs information. With this flexibility, each user can configure the system to monitor what is required.

A patient will be "hooked up" to the system through the appropriate leads, cuff, or sensors, depending upon which vital signs are being monitored. The particular patient parameters monitored will vary from one patient to another, and may even depend upon the attending physician's preference; however, one parameter always measured is the ECG waveform.

The basic monitor mounts to either the wall or a wheeled stand that can move to different rooms. The major disadvantage of this type of unit, especially for the BMET, is tracking down all the different modules. We generally track modules individually in the Defense Medical Logistics Standard Support (DMLSS) system, as they are each serially controlled units and require scheduled maintenance. The modules frequently wind up in drawers, cabinets, storage rooms, or end up in neighboring departments due to their transportability. Like all small equipment items, they often require skills, patience, and open communication with the equipment custodian to track them down.

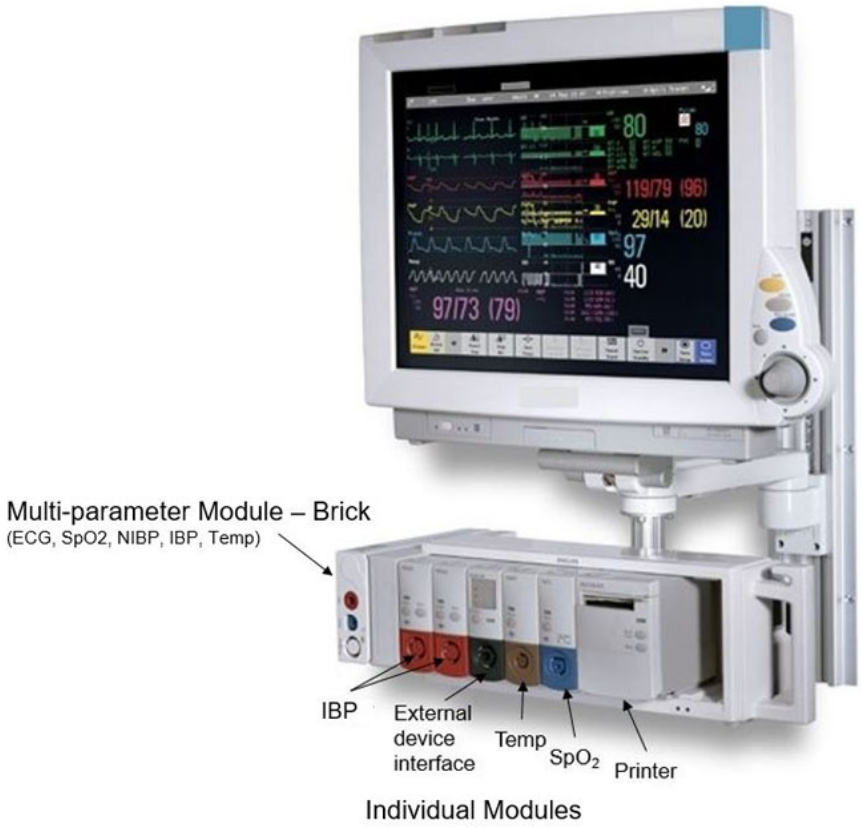


Figure 2–35. Typical modular bedside monitor.

Telemetry monitor

These are specialized wireless physiological monitoring systems that allow patients to move around the MTF while still being monitored. We use these units in various areas of the MTF, but the most common utilization is in intermediate care areas and for patients recovering from cardiac surgery. There are two basic forms of telemetry monitors:

1. Patient worn – This is the oldest type of telemetry monitor and consists of a wireless transmitter worn by the patient. The transmitter is usually in a pouch that hangs from a strap around the patient's neck or shoulder. Data, normally only ECG signals, transmit to a central monitoring station monitored by a medical staff member. Some types will only transmit data (unidirectional), while others can transmit and receive data from the central station (bidirectional).
2. Portable monitor – This is the newest type of telemetry monitoring system. It is basically a portable, self-contained physiological monitor with a special transmitter attached. Of course, the major benefit of these newer units is they can measure many patient parameters in addition to ECG signals.

The central station for telemetry is similar to the central station monitor of the intensive care monitoring system. All central stations have waveform displays, and audible and visual alarms; many have advanced features, such as data storage. Data transmits to and from the central station to the patient monitors through a series of antennas located throughout the MTF.

As we mentioned earlier, these systems have many clinical applications in the MTF. Most often they are used for patients that have improved and moved out of the ICU or other critical care area. They may be used on patients that have a closely monitored heart condition, but require normal activities, such as walking around, to be accurately assessed. Another common use is for patients being seen in

the ER. These patients may be already being monitored; however, mobile monitoring may be required if they need an X-ray, which necessitates their leaving the department. Whatever the use, the equipment will match the application. For example, a patient who only needs his or her heart rate monitored will use the simple patient-worn transmitter, but a patient who requires a wider range of parameters to be monitored will walk around with the portable physiological monitor on a stand.

One important thing to remember about telemetry systems is they should operate in a specific frequency range designated by the Federal Communications Commission (FCC). This frequency band is known as the Wireless Medical Telemetry Service (WMTS) band, which operates in the 608-614, 1,395-1,400, and 1,427-1,432 megahertz (MHz) ranges. WMTS spectrum serves as a dedicated band for remote monitoring of a patient's health. The FCC developed this band in 2002 to alleviate interference of devices such as walkie-talkies or cellular phones, since older medical telemetry devices would use vacant television channels or private land mobile frequency bands.

Central station

The second part of this unit is the central station monitor. In an ideal medical facility, patients in the ICU would have a nurse or other medical professional by their side 24/7 to monitor their status; however, this is rarely an option. The next best scenario is to have each patient connected to a bedside monitor (set-up to observe whatever parameters are required) and the readings from each bedside monitor fed to a central station monitored by the medical staff on duty.

The primary benefit of the central patient monitoring system is to decrease operating costs because it decreases the number of staff members required on any particular shift. It also allows a dedicated eye to continuously monitor vitals for any issues, given that the nursing staff has to jump around between different patients. The central monitor has a wide array of displays, an alarm panel, some type of printer for hardcopy printouts, and a communication system. All these features allow the medical staff to monitor many patients at one time, record any significant events, and properly respond to any emergencies. Most models are computer controlled, which allows many additional features, such as the storage of several days' worth of patient data or admitting and discharging patients in the system from the central station. Depending on the system in your facility and the departments requiring monitoring, the central station could be a hub with an overview of every department. For instance, if the central station for the hospital is located in the ICU, the staff could have oversight of the patients admitted in the ICU, wards, and even the ER. Using a keyboard, video, mouse (KVM) switch, you would be able to switch between the dedicated servers using the same hardware. This allows you to use just one keyboard, mouse, and set of viewing monitors and be able to switch the viewing and control functions between multiple servers.

One very important feature of the central monitoring system is the alarms. There may be several different alarms available, such as heart rate, respiration rate, or blood pressure. These alarms are usually set for a range (i.e., 70-120 bpm) and any signals that fall out of this range trigger the alarm. Another important alarm is the lead-off detector alarm or lead fault indicator. If an ECG lead becomes loose from a patient, the display could show no heart activity (flatline). The lead fault indicator indicates this situation to prevent the medical staff from reacting as if there were a true emergency.

Preventive maintenance

Preventive maintenance (PM) on central patient monitoring stations follows the same basic principles you learned in the computer volume from CDC 4A251A Volume 4. As mentioned earlier, your central station might monitor multiple sections. In this case, you could find a desktop computer for each dedicated department server (essentially these are the units the KVM switches between). Ensure that these units are free of dust and have enough clearance to provide proper air circulation. Although the systems department performs routine service on most computers in the MTF, these units might fall under the responsibility of the BMET to ensure proper upkeep. It is important to keep these computers up to date on any required security patches and antivirus software. Another aspect to

consider is uninterruptable power supplies (UPS). Whether stand-alone or rack-mounted units, ensure you replace the batteries according to the required maintenance intervals.

Common malfunctions

There are a few medical equipment items that keep on call phones ringing throughout the BMET field. The tele system is among them and can seem like an intimidating unit, but if you know the basics, you will be able resolve many of the common issues. The most common problems that you will run into are communication issues between components. Whether between the servers and the central station, between the bedside monitor and the server, between the telemetry monitoring device and the receiver, or even between the hardware components within the central station, these are all common problems. The first step is to isolate the area that is experiencing issues. Determine if it appears to be a problem with one monitoring unit or many. If your keyboard and mouse are not working, determine if it is occurring on just one server or across the whole system using the KVM switch. Once you have narrowed down the problem area, make sure you assess the physical connections between components and verify if the system recognizes a connection.

If physical connections appear to be stable, similar to many other electronic systems, one of the easiest fixes is to simply restart the power. Cycling the power can help to reestablish communication (or a handshake) between various components of a system. Now, before you go flipping switches and pressing power buttons, make sure you understand how to do so properly and only attempt to reboot components effected by the issue (i.e., the desktop computer in the viewing station versus all of the servers affecting multiple departments). Just remember, cycling power on a unit affects everything downstream of that component. Always make sure that you inform the proper sections beforehand if you do intend to restart the system. If the problem is in the ICU, but a restart also affects the wards or the ER, make sure they are aware that the system will be down for a few moments in order to keep a better eye on their patients. Depending on your system, some setups will lose recording capability during the down time, while others might continue to live monitor at the bedside and temporarily store data to backfill the server upon reconnection. While many systems are different, there are generally two ways to reboot the actual server. You might have the option to reboot it from the central station desktop itself or a rack-based laptop in the server room. Your shop technical literature, DMLSS notes, or on-call binder should have the admin name and password to access the system. Just remember if you do not feel comfortable attempting to reboot the telesystem, don't; ask your supervisor for help instead.

412. Multiparameter patient simulator

Now that we have learned many of the aspects of physiological monitoring, naturally this lesson will discuss equipment to help calibrate and verify functions of some of the previously covered parameters. In the past, we used to use a separate piece of equipment to test each component on a physiological monitor (i.e., ECG simulator, NIBP analyzer, SpO_2 simulator, etc.). Newer test equipment now allows us to measure many of these functions simultaneously using one unit, known as a multiparameter simulator. Some units incorporate patient simulation functions such as ECG, CO, IBP, and temperature, while more advanced units also incorporate a NIBP analyzer function. Although many different manufacturers make versions of multiparameter simulators, the general functional concepts remain the same. For the purpose of the following principles, we will use a commonly found unit (Fluke ProSim™ 8) to illustrate the concepts and setups. Let's discuss some of the individual functions of multiparameter patient simulators.

Electrocardiogram patient simulation

The purpose of ECG simulation is to mimic the actual heart functions of the body, from normal readings to induced abnormalities, in an effort to measure the diagnostic unit against controlled readings and conditions. Because the ECG machine monitors and records something as critical as a patient's heart activity, it is imperative that we maintain and calibrate the equipment as accurately as possible. The voltage potentials produced by the activity of the heart are extremely small, and the

ECG unit must detect them through layers of skin. Therefore, the ECG machine must respond and record the smallest of signal variations. This reiterates the importance of these performance checks. While it is not the intent of this lesson to teach you the calibration procedures for an ECG unit, you do need to have a basic idea of the procedures to understand the patient simulator.

ECG calibration procedures

As you already learned, an ECG is printed out on special graph paper. There are large (5 mm) and small (1 mm) squares on the paper, with each square used to record vertical and horizontal information about the heart's activity. Horizontally, each large square represents 0.2 seconds of heart activity; vertically, each large square corresponds to 5 mm of signal movement. To check the calibration and performance of the unit, most ECG machines will have a built-in test signal (actually, a 1-millivolt [mv] signal) on each ECG machine. When the appropriate button is depressed, the simulator produces a 10-mm square wave signal, which should correspond to two large vertical squares on the ECG paper. The width of the pulse will depend upon the length of time the button is depressed. The medical staff completes this check on a regular basis according to local protocol.

As BMETs, we are required to do more stringent testing of the ECG unit's performance during normal periodic maintenance. This testing involves introducing certain test signals via the patient simulator into the unit and checking the accuracy of the unit's response.

Use of the simulator

The ECG unit connects to the patient simulator through the normal snap connectors that attach to the patient electrodes (fig. 2–36). The connections on the simulator are color-coded to match with the appropriate patient lead. Once connected, refer to the operator's manual to start the desired test signals.

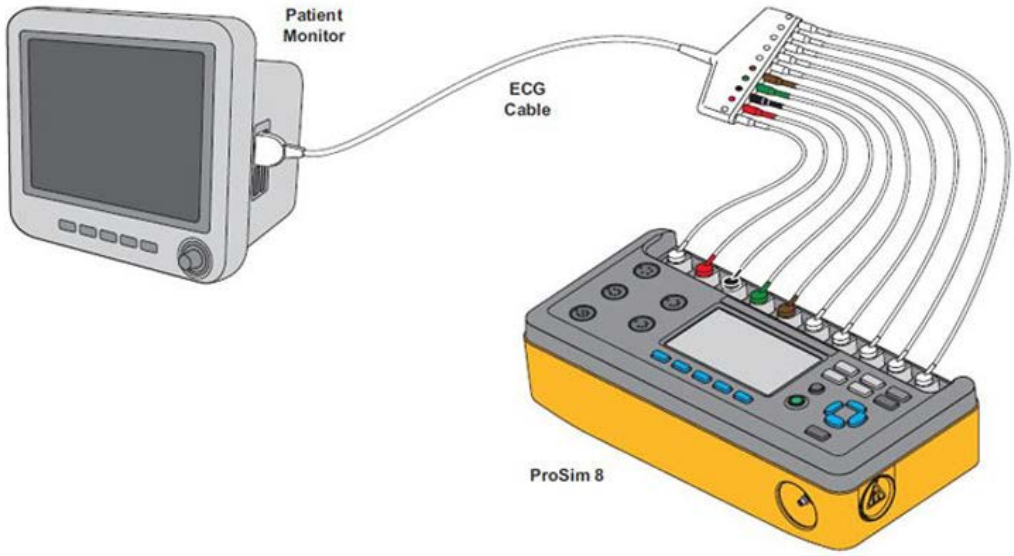


Figure 2–36. ECG patient simulator.
(Printed with permission, Fluke Biomedical.)

Most patient simulators are capable of numerous different waveforms, many of which are not particularly useful for BMETs, such as various arrhythmias, and so forth. There are, however, other waveforms a BMET will find very useful. The most useful of these patterns are known as ECG performance testing waves. These special patterns are usually waveforms, such as square waves, triangle waves, wave trains, sine waves, and ECG waveforms of a specific bpm.

Remember, the purpose of these waveforms is for you to test the performance of the ECG unit. No matter which waveforms the test equipment outputs, the ECG unit should accurately reproduce them.

Since there are many possible waveforms, this lesson will not attempt to address each one individually, but we will look at two common waveforms and their uses.

Square wave

Most patient simulators will have a square wave of a set width (i.e., 2 Hz or 0.5 second). If you inject this signal into the ECG unit, it should print out an exact replica on the graph paper. If you use your math skills, you should be able to figure out that a 2-Hz signal should take up 2½ large horizontal squares on the ECG paper; if the simulator has a 1-Hz signal, that would correspond to 5 large horizontal squares on the ECG paper.

The square wave will also have a set amplitude, which corresponds to the voltage level of the signal. For example, if the square wave has a voltage of 1 mV, that would produce a square wave on the ECG paper of 2 large vertical squares. The ECG printout (or display, if appropriate) should accurately reproduce these waveforms without rounding of the corners or extraneous activity (i.e., noise).

Wave train

The wave train is a set of fixed width pulses (i.e., 60 milliseconds) produced at a set rate, such as 30 per minute (0.5 Hz) or 60 per minute (1 Hz). When you inject these signals into the ECG machine, the printout should display pulses corresponding to the simulator setting. For example, if you inject a wave train of 60 pulses per minute, the ECG printout should produce a pulse every second (1 pulse every 5 large squares) for the length of the wave train. In addition, just like the square wave, these pulses should have sharp corners with no rounding or noise.

Non-invasive blood pressure analyzer

You may already have had some experience with this common test equipment item, either as a stand-alone unit or as a function of a multiparameter patient simulator. If you have not used this piece of equipment yet, you certainly will soon. While there are several different manufacturers of blood pressure analyzers, most units are comparable with many similar features. One important note before we begin; if you recall from the NIBP lesson, there are two methods with which automatic NIBP monitors measure blood pressure—auscultatory and oscillometric. While most modern blood pressure analyzers can test either type of monitor, it is best to ensure your analyzer is compatible with the type of NIBP monitor you are testing. Different physiological monitor manufacturers use different proprietary algorithms to determine systolic and diastolic pressures. When you couple this with the fact that different NIBP analyzer manufacturers also use different proprietary algorithms to simulate Korotkoff sounds and pressure waves, some combinations of monitor/analyzer may produce wildly varying results. You should determine if the test equipment is compatible with the unit under test, or try using another type of analyzer before failing or troubleshooting the equipment you are testing. Newer units may have a menu option to select various preset manufacturers based on the unit under test. This option will allow a variation of preset tolerances or offsets that correlate to the specifications of your unit.

Basic components

While there are various manufacturers of blood pressure analyzers, most will require similar components. There will be the main unit, a simulated arm, various pieces of hose with connectors, and any applicable adapters for the particular unit and cuff that you are testing (fig. 2–37). There may be additional equipment required for testing NIBP monitors that utilize the auscultatory method of sensing blood pressure.

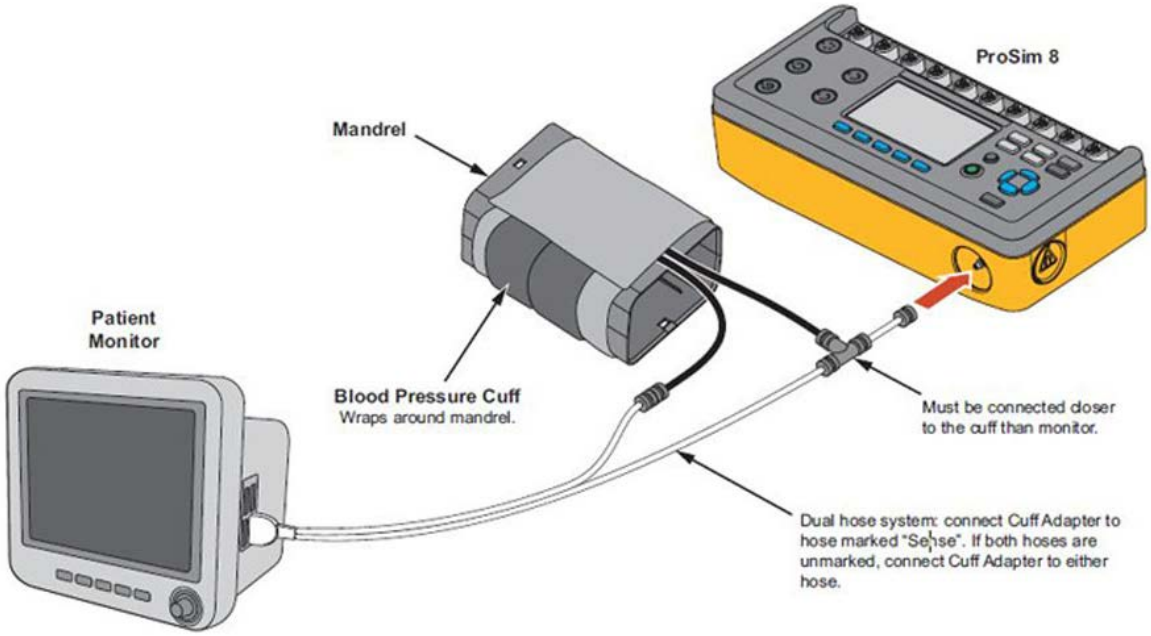


Figure 2–37. Blood pressure analyzer.
(Printed with permission, Fluke Biomedical.)

Just as the blood pressure monitor has different size cuffs to accommodate various patients, the analyzer may have different sized accessories that simulate the shape of an arm. Make sure to use an appropriately sized device to match the size of the cuff (i.e., adult versus neonatal), whether it is a manufactured testing accessory or some good old fashioned BMET ingenuity. See figure 2–38 for an example of the simulated arm size ranges from neonatal to large adult.

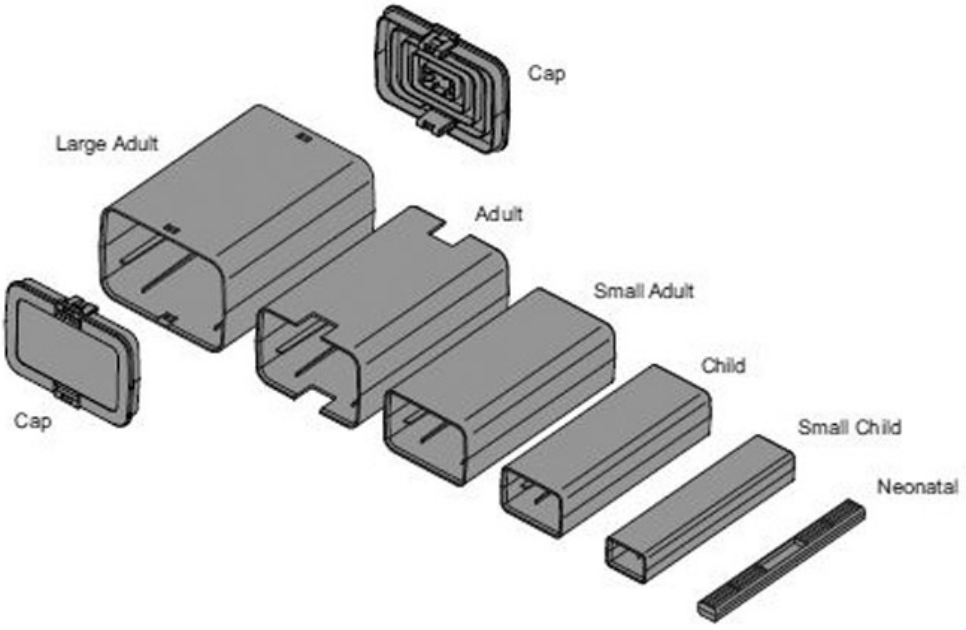


Figure 2–38. NIBP cuff mandrel examples.
(Printed with permission, Fluke Biomedical.)

Tests performed

Analyzers can perform many different types of tests. While you might not use all of the functions that an analyzer can perform, based on the requirements of the unit under test, the following are some of the more common tests you will most likely use.

Adult blood pressure

For this test, there are usually various pressure ranges available, generally between 60/30 and 255/195 (systolic over diastolic pressure respectively, as you learned earlier). Most units will require testing at several different ranges since the results of this test are the primary indicator of how accurately your NIBP monitor is measuring. A general rule is to at least use a low, medium, and high setting to test accuracy and pump strength. You can set pressure, heart rate, pulse volume, brand, and wave through the unit controls to simulate different patient conditions. You can also simulate arrhythmia waveforms in the NIBP simulation (set through ECG). To begin the test, once these parameters are set, simply activate the NIBP measurement function on your diagnostic monitoring unit.

Neonatal blood pressure

Various pressure ranges for neonatal blood pressure readings are normally available between 60/30 and 150/100. These should also be checked thoroughly to ensure the NIBP monitor will accurately measure pressures on a smaller arm. Be sure to use the appropriate neonatal cuff and accessories.

Pulse

As with blood pressure, this will have various ranges available, usually between 30 and 240.

Deflate time

This test determines how long the NIBP monitor takes to deflate the cuff at the end of the blood pressure cycle. This is an important test because no patient wants the cuff inflated for longer than necessary. Also, there may be instances when the clinician needs to interrupt the blood pressure cycle and deflate the cuff.

Deflate rate

Similar to deflate time, this test indicates the rate of cuff deflation, in mmHg/second, at the end of the blood pressure cycle.

Inflate time

This test shows how long, in seconds, it takes the NIBP unit to inflate the cuff during the blood pressure cycle.

Inflate rate

Indicates the rate, in mmHg/second, of cuff inflation during the blood pressure cycle.

Leak test

This important test evaluates the NIBP unit, hoses, and cuff(s) for leaks. Areas of possible leaks are incorrect or broken connections, cracks in the cuff, O-ring deterioration, and so forth. The manufacturer’s literature for the NIBP unit will indicate the maximum leakage rate for their particular model.

Before you do a pressure leak test on a monitor, do the pressure leak test without the monitor to identify the leak rate of the analyzer. Use this leak rate to offset the rate of the full system with the monitor connected. You should put the NIBP monitor in “calibrate” or “service” mode to close the vent valve, so the analyzer can inflate the pneumatic system. If the NIBP device has an internal system leak test or one that vents the cuff inflation pneumatic circuit to the atmosphere when idle, do not use the analyzer leak test. Rather, do a manometer check to test for internal system leaks. Refer to the NIBP monitor operator’s manual for the recommended test protocol.

Maximum pressure (overpressure test)

This test checks the overpressure point, also called the pressure relief test, on the NIBP unit. The overpressure point is the point at which cuff pressure is great enough to initiate emergency deflation. In this test, the analyzer pressurizes the pneumatic system to the target pressure with the pressure measurement and a graph of the pressure shown on the display. When it senses the pressure valve has opened, the test stops and the results show on the display. You should perform around three pressure relief tests in case the relief valve is intermittent. If there is no drop in pressure and the pressure climbs to the target pressure, then the pump will stop and indicate a test failure.

Additional features

There may be additional features available on the analyzer in your shop. Some common extras include an RS–232 or universal serial bus (USB) connector that can connect to a printer and produce hard-copy test results, and computer memory, which can hold the results of several different test cycles.

Pulse oximetry simulation

The pulse oximetry function allows us to test various pulse oximeters by representing a range of simulated SaO_2 patient readings. Just like with the NIBP analyzer, some simulators will allow you to select different manufacturer's preset tolerances based on some common industry standard probes. This will allow the most accurate measurements for your unit. As we discussed in a previous lesson, an SpO_2 measurement unit uses light to shine through parts of the body, with a sensor on the receiving end. The amount of light that passes through determines the amount of O_2 saturation in the blood. The principle theory of the simulator is that as the probe shines light into the simulator, it adjusts the translucency of the signal allowing the amount of light that reaches the receiver to correspond to the preset readings.

Components

The components of a pulse oximetry simulator are pretty basic. You will have a main control unit, whether stand-alone or integrated with a multiparameter simulator, and a simulated finger with an optical emitter and detector.

Testing SpO_2 monitor functions

To test the SpO_2 functions of a monitor, place the finger probe on the simulated finger as shown in figure 2–39. Ensure that the LED portion of the sensor is on the bottom of the simulated finger. Most test equipment will have a signal strength indicator that lets you know if your sensor alignment is correct. Adjust the sensor on the finger for maximum signal strength.

The simulator is capable of mimicking a variety of patient parameters to include O_2 saturation, pulse rate, and pulse amplitude.

O_2 saturation

This tests the O_2 saturation signal response of the monitor. You can increase or decrease the saturation values in 1 percent increments from 30 percent to 100 percent. As a normal healthy person should be able to achieve normal blood oxygen saturation levels of 94 percent to 99 percent, most manufacturers will only require you to test values from around 80 percent to 100 percent. Consult your technical literature for the required testing range.

Pulse rate

Pulse rate allows you to verify heart rate values from 0 bpm to 300 bpm. Decreasing the heart rate to 0 bpm simulates an asystole condition or no pulse.

Pulse amplitude

Pulse amplitude tests the peak-to-peak amplitude of the blood pressure wave tested. In this test, you can decrease the amplitude to find where the oximeter fails to sense a pulse.

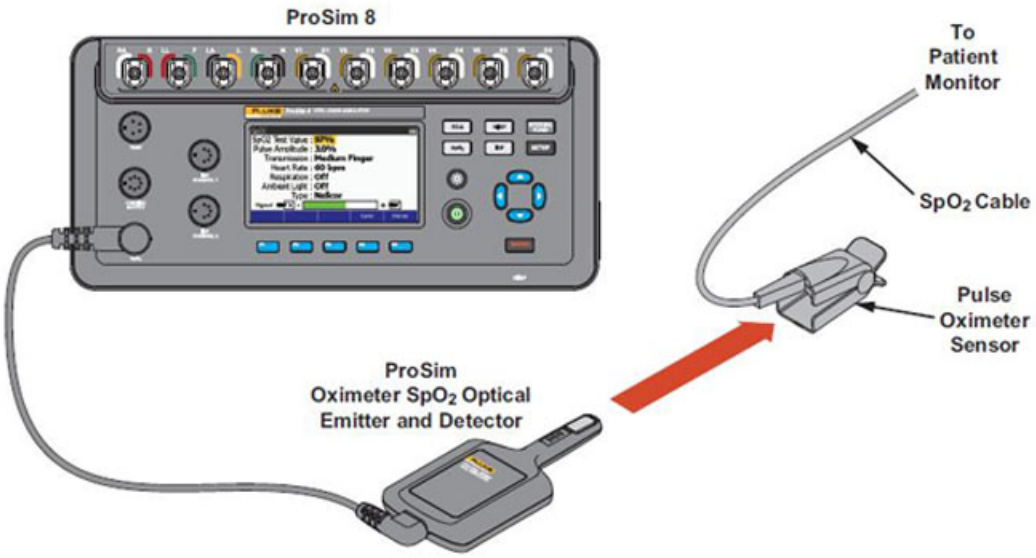


Figure 2–39. SpO_2 simulator finger attachment. (Printed with permission, Fluke Biomedical.)

413. Fetal heart monitor

The fetal heart monitor is found primarily in only one area of the hospital—labor and delivery. The mother is usually hooked up to a fetal heart monitor to monitor the length and strength of contractions, along with the baby's heart rate, during childbirth. This unit enables the doctor and staff to be proactive if complications should arise during the sometimes long delivery process.

There are two methods of electronic fetal heart monitoring in use today—external and internal. The external type employs the use of external transducers placed on the mother's abdominal wall to assess heart rate and uterine activity. The internal type uses a spiral electrode to assess the fetal electrocardiogram (FECG), and the intrauterine or transcervical catheter to assess intrauterine pressure.

Functions

Fetal monitors assess the viability and physiological status of the baby by monitoring fetal heart rate (FHR), especially in relation to fetal movements and uterine contractions. Fetal monitors are a screening tool to detect fetal distress. Fetal monitors can also reveal information about the mother's uterine contractions. A decrease in the strength or frequency of contractions may indicate dysfunctional labor. Many obstetricians routinely monitor the babies of all patients in labor, switching from external to internal monitoring after the amniotic sac ruptures. Others may only monitor high-risk patients.

Measuring fetal heart rate

Now that you know what FHR monitors are used for, let's examine how the monitors are actually used. FHR monitors detect deviations in FHR that, for purposes of our discussion, occur when the patient is not in labor, when the patient is between uterine contractions, or during the interval between periodic changes. The baseline rate is usually 120–160 bpm in the normal full-term baby.

Two fetal conditions you must be familiar with when working with FHR monitors are tachycardia and bradycardia. Tachycardia is considered to be a baseline heart rate greater than 160 bpm, or more than

30 bpm from the normal baseline for at least a 10-minute duration. Moderate tachycardia is 160–180 bpm, and marked tachycardia is above 180 bpm. You should not confuse tachycardia with accelerated heart rate of the baby, which is a transitory periodic change. Fetal bradycardia is generally considered to be a baseline heart rate less than 120 bpm, or less than 30 bpm from the normal baseline for at least a 10-minute duration. Moderate bradycardia is 100–120 bpm, and marked bradycardia is below 100 bpm. Do not confuse bradycardia with deceleration of heart rate, which is a periodic change. Both tachycardia and bradycardia conditions may be normal for some babies, thus, the reason for 10-minute verifications.

Measuring uterine contractions

Clinically, palpation of the maternal abdominal wall usually determines the frequency and intensity of uterine contractions. This technique, in addition to being imprecise and uncomfortable for the mother, is dependent on the continuous presence of a nursing or medical staff to obtain a good estimation of labor.

Various types of tocodynamometers (toco) have been used to obtain continuous records of uterine activity from the maternal abdominal wall (fig. 2–40). All types suffer from the difficulties associated with the use of belts, which attach to the mother by encircling the body. The changes in belt tension with changes in maternal position cause large baseline shifts, so frequent adjustments are necessary. In favorable circumstances, it is possible to obtain a good indication of the frequency and some idea of the intensity of uterine contractions. There is, however, a need for a simple external technique to provide an objective measure of labor.

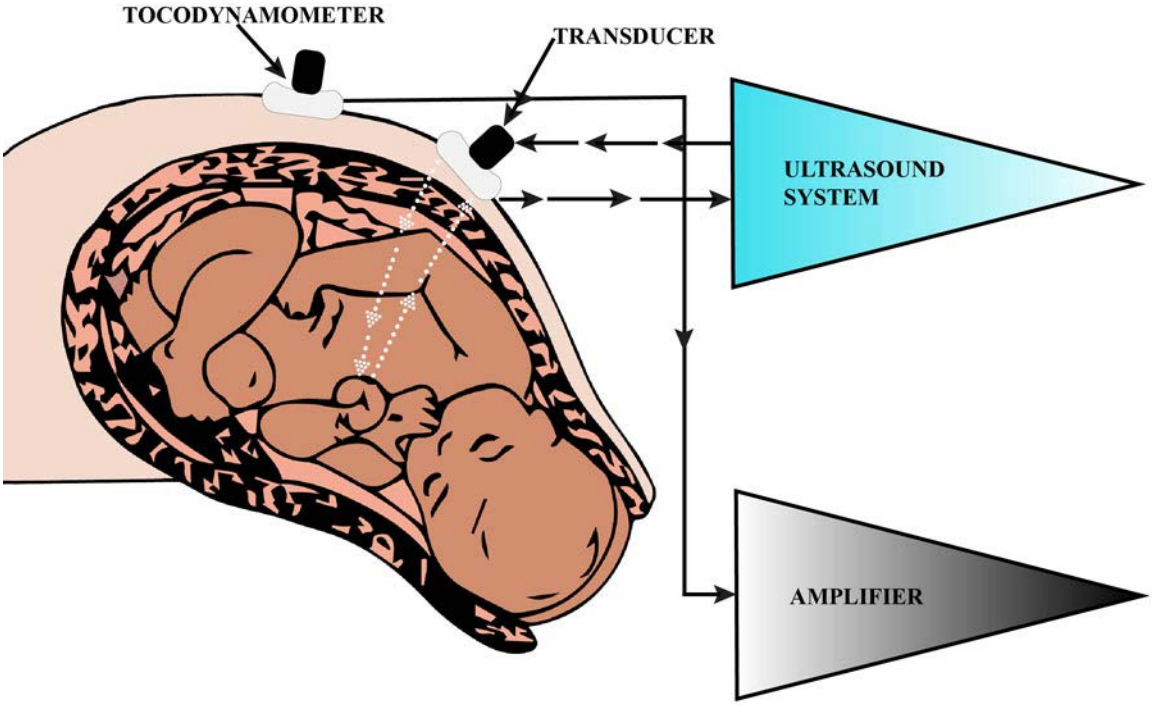


Figure 2–40. Toco and ultrasound transducer placement.

Measurement methods

Direct techniques for measurement of uterine activity use small balloon or open-tipped catheters of polyethylene or Teflon. They may be introduced transabdominally or transcervically into the uterine cavity. The transcervical approach is simpler and better accepted by the patient; however, its disadvantage is that it requires rupturing of the membranes.

Fetal phonocardiography

Early attempts to provide a method for continuous monitoring of the FHR during labor and delivery solely used fetal phonocardiography (PCG). A transducer, such as a sensitive microphone, tightly fixes to the abdominal wall with a belt, which detects the mechanical energy associated with a fetal heartbeat. Since much of the PCG signal covers a wide frequency range that overlaps considerably with noises generated within and on the surface of the mother, mechanical and electronic filters help to narrow the band pass and improve the signal-to-noise ratio.

Clinicians use fetal PCG both ante- and intrapartially. This does not require rupturing of the membranes or cervix dilation. The procedure is simple and does not require the presence of an obstetrician. There are no known fetal hazards associated with the procedure. Most of the time, it is possible to get an acceptable record before and during the early stages of labor if the patient lies quietly. In late labor when the patient may be quite active, there is a possibility to lose much of the data.

Ultrasound

Ultrasound is another method used to detect the mechanical energy of the fetal heartbeat. The most common ultrasonic technique used in obstetrics for this purpose uses the Doppler principle. A continuous wave train in the 2-10 MHz range transmits in the direction of the fetal heart. The unit will detect, amplify, and display the difference in frequency between the transmitted and reflected waves. The result is an audible signal with a relatively wide frequency spectrum. While this signal is similar in some ways to that of the PCG, in a given situation its signal-to-noise ratio is better than that of the PCG. Appropriate filtering can further improve the signal.

The ultrasound output records on a strip chart similar to the PCG. Measuring the interval between successive complexes or averaging the count over a period of time can determine the FHR. If we further condition and then couple the signal to a cardiotachometer, this allows us to compute and continuously record the FHR on strip charts, magnetic tape, or other types of display and storage media.

Like the PCG, the ultrasonogram has the advantage of being usable before rupturing the membranes or dilating the cervix. It is also simple to use and does not require the services of an obstetrician. It has a much better signal-to-noise ratio than the PCG and can obtain good signals from petite to obese patients. It is less subject to interference and patient movement than the PCG. It is possible to obtain highly satisfactory records throughout contractions and during the last stages of labor. The transducers are much more compact and lighter than those used for fetal PCG and patients readily accept this method more than the PCG.

Fetal electrocardiogram

FECG, in contrast to PCG and ultrasonography, detects the electrical energy associated with the fetal heartbeat, rather than the mechanical energy. In its simplest form, the instrumentation for FECG requires a high-gain, low-noise preamplifier between the patient and a standard adult ECG machine. This is necessary since the amplitude of the FECG, as recorded from the maternal abdominal wall, is usually one-hundredth to one-fortieth that of an adult ECG.

FECG uses two methods:

1. Indirect – Records the FECG from the maternal abdominal wall.
2. Direct – Records the FECG directly from the baby.

Indirect method

With appropriate instrumentation, it is possible to record a recognizable FECG throughout most of gestation and during labor and delivery, thus, permitting its use as a method of detecting activity or calculation of FHR. Unfortunately, the FECG signal-to-noise ratio is frequently poor, which restricts its use as a trigger for automatic counting of the FHR. Filtering the FECG and using cancellation or

blanking to reduce interference from the maternal ECG can improve the signal-to-noise ratio. Multiple electrode-multiple amplifier techniques may also help to enhance the FECG signal-to-noise ratio. As the techniques previously described, these are also usually too complicated for automatic FHR counting, except in a research environment where high-level technical support is available.

An advantage of indirect FECG, like auscultation and ultrasonography, is its use throughout gestation before membrane rupturing and cervix dilation. It is simple to use. The electrodes are comfortable, allowing the patients to wear them for long periods of time. Unfortunately, there is a considerable amount of electrical noise associated with patient movement. While this indirect method can record ECG during the contractions of early labor, electrical noise from the contracting abdominal muscles frequently obscure readings late in labor. You must keep these important facts in mind when dealing with your facility's professional staff. This information may save you many hours of valuable time troubleshooting a device that, in fact, is in good operating condition.

Direct method

The most widely used methods for continuous monitoring of the FHR during labor and delivery employ direct FECG techniques. Electrodes attach directly to the fetal buttocks by passing a wire through the maternal abdominal wall or attaching a clip electrode transcervically to the fetal presenting part (skull). With the latter method, which is most common, a silver/silver chloride insulated clip attaches to the fetal presenting part. This clip electrode is one electrode of a bipolar pair. The other electrode is a silver/silver chloride coil wrapped around the insulation of the wire connecting the clip to the amplifier. This coil electrode makes contact with the mother via the electrolytic content of the cervical and vaginal secretions. Since it is located in an area of the body where skeletal muscle is sparse, there is little or no interference from maternal or fetal movements, thus, permitting an artifact-free record throughout most of labor and delivery.

The quality of the FECG tracing obtained with this direct technique is far better than that obtainable from the maternal abdominal wall. The FECG signal-to-noise ratio is much higher, and it is usually possible to identify the various FECG baseline components, as well as the QRS complex. Tracings of this type permit a meaningful study of the FECG complex and a manual calculation of the FHR. With the addition of suitable signal conditioning and an appropriate fetal cardiotachometer, it is possible to have a clean artifact-free record of FHR throughout labor and delivery.

The major limitation of this direct FECG technique is the need to have the membranes ruptured, 2–3 cm of cervical dilatation, and the presenting part no higher than a 2 station. This method requires an obstetrician at the presenting time to attach the electrode; however, a specially trained nurse could perform this task. Since penetration of the epidermis overlying the fetal presenting part could result in infection, this is also a consideration as a disadvantage.

Spiral electrode

Another direct method is the spiral electrode, which monitors the FHR from the presenting part (fig. 2–42). This method can assess long-term variability and is the only signal source that can accurately monitor short-term variability. It has one disadvantage—you can only apply this technique after rupturing the amniotic sac, a cervix dilation of 2-3 cm or more, and when the presenting part is accessible and identifiable. Therefore, the spiral electrode can only monitor FHR during the intrapartum period. Figure 2–41 also demonstrates the use of the intrauterine catheter to monitor intrauterine pressure. The sterile water-filled catheter compresses during uterine contractions placing pressure on a strain gauge, which converts the pressure into mmHg on the uterine activity panel of the chart paper. You may recall this monitoring is also helpful in determining whether the baby is in distress, and uterine activity is the cause.

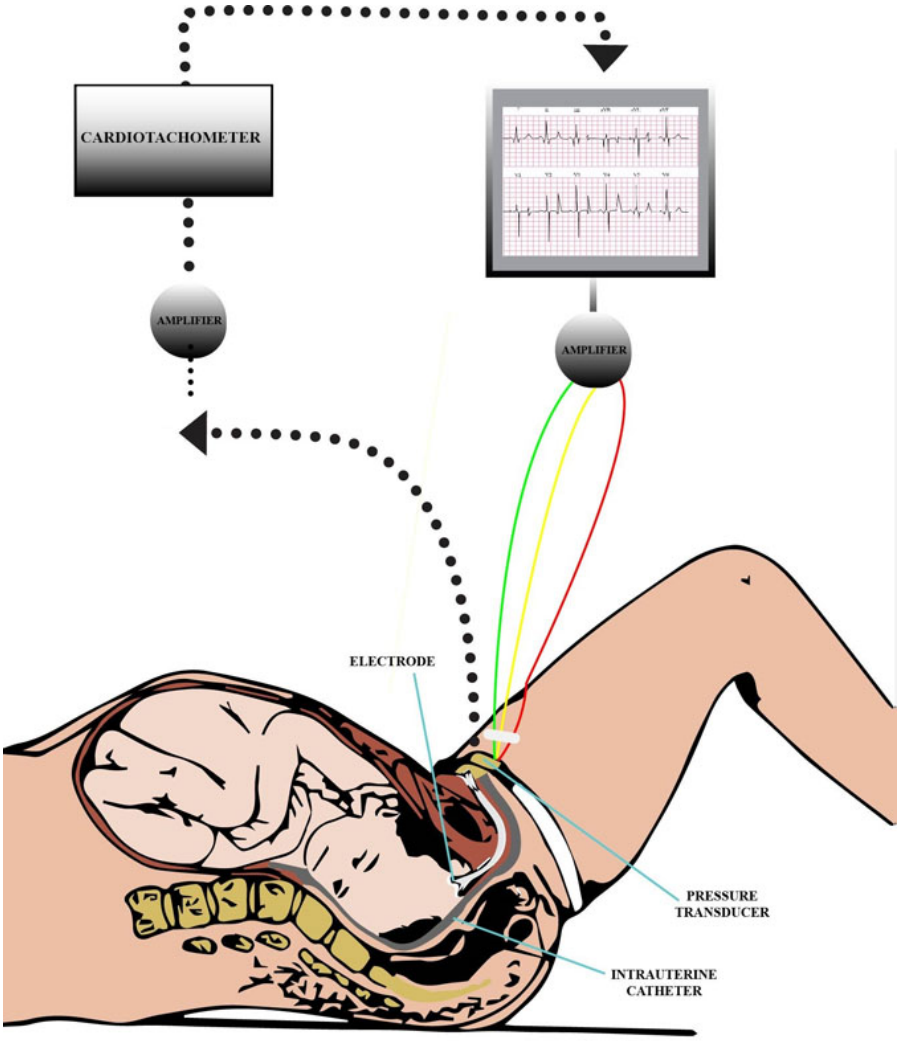


Figure 2–41. Spiral electrode and intrauterine catheter placement.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

410. Physiological monitoring systems

1. List the four standard vital signs including their normal ranges for an average healthy adult.

2. List three additional parameters that you could monitor with a physiological monitoring system.

3. Briefly describe systolic and diastolic pressure.

4. What are the two available methods for measuring blood pressure?

5. Briefly describe how blood pressure is measured using a sphygmomanometer.

6. What are Korotkoff sounds?

7. What are the two forms of hypertension and what are their differences?

8. Why is low blood pressure dangerous?

9. On which type of patient is invasive blood pressure monitoring used?

10. Briefly describe the process of direct blood pressure measurement.

11. What are the benefits of invasively monitoring arterial blood pressure?

12. Why is CVP monitored?

13. Briefly describe the process of PAP measurement.

14. What are the three basic catheterization techniques used during invasive blood pressure monitoring?

15. What is the normal range of SaO_2 for a healthy adult?

16. What are four areas of the MTF where a pulse oximeter may be found?

17. What condition may cause an inability to determine accurate pulse and SaO_2 with a pulse oximeter?

18. List at least three places a pulse oximeter probe may be placed.

19. Define cardiac output.

20. When is cardiac output routinely measured?

21. What are the two basic methods for measuring cardiac output?

22. Briefly describe the thermodilution technique of measuring cardiac output.

23. Explain how TEE works.

24. List at least four specific clinical applications discussed for the use of respiration monitors.

25. What operating principle does the impedance pneumograph type of respiration monitor use?

26. The flow volume type of respiration monitor is capable of making what type of measurements?

411. Central patient monitoring systems

1. Most bedside monitors are what type?

2 What is the primary benefit of the modular type of bedside monitor? What is a major disadvantage, especially for the BMET?

3. What are the two basic forms of telemetry monitors?

4. On what type of patients are telemetry monitoring systems most often used?

5. What frequency band is used for telemetry systems?

6. What is the primary benefit of a central patient monitoring system? Why?

7. What component allows you to use a single keyboard, video monitor, and mouse while switching between multiple servers?

8. Briefly describe the lead-off detector alarm.

9. Briefly explain some of the important PM requirements with central patient monitoring stations.

10. What do most issues with central patient monitoring malfunctions involve?

412. Multiparameter patient simulator

1. Why is it important to ensure accurate performance from an ECG unit?

2. On ECG graph paper, what do the large squares represent horizontally and vertically?

3. What is the vertical size of the built-in test signal on an ECG unit?

4. What ECG performance testing waves are useful to BMETs?

5. Match the blood pressure analyzer test in column A with the appropriate statements in column B. The items in column B may be used once or not at all.

Column A	*Column B*
____ (1) Adult blood pressure.	a. Checks the overpressure point on the NIBP unit.
____ (2) Neonatal blood pressure.	b. Indicates, in mmHg/sec, the rate of cuff deflation.
____ (3) Pulse.	c. Various ranges, between 60/30 to 150/100, available.
____ (4) Deflate time.	d. Indicates how long the NIBP monitor takes to deflate the cuff.
____ (5) Deflate rate.	e. Shows how long, in seconds, it takes the NIBP unit to inflate the cuff.
____ (6) Leak test.	f. Indicates the rate, in mmHg/sec, of cuff inflation.
____ (7) Maximum pressure.	g. Evaluates the NIBP unit, hoses, and cuff(s) for leaks.
	h. Various ranges, between 30 and 240, available.
	i. Various ranges, between 60/30 to 255/195, available.

6. What common additional features found on blood pressure analyzers enable the creation of hardcopy test results?

7. What is the principle theory behind a pulse oximetry simulator?

8. Briefly explain the pulse amplitude test.

413. Fetal heart monitor

1. What are fetal monitors used for?

2. Briefly describe fetal tachycardia and fetal bradycardia.

3. Briefly describe how fetal PCG works.

4. What are the advantages of using the ultrasonic method to monitor FHR?

5. What are the two types of FECG?

6. What is a major limitation of direct FECG?

7. What is the only signal source able to measure short-term variability of the FHR?

Answers to Self-Test Questions

406

1. (1) Pure tone.
   (2) Speech.
   (3) High frequency.
   (4) Free-field equivalent.
2. To determine the type, degree, and configuration of hearing loss and hearing sensitivity.
3. In a typical hearing test, the patient sits in a soundproof booth with headphones that deliver the tones from the audiometer. The patient holds a push-button response switch as instructed, and the test begins. A 250-Hz tone is introduced into the left ear at 0 dB and increased in dB until the patient can hear the tone—known as the PTT. PTTs indicate the softest sound audible to a patient at least 50 percent of the time. We use the recording chart paper to record the PTT for that specific frequency. The same procedure then continues for all remaining frequencies on the left ear and finishes by repeating the tests on the right ear. The resulting test culminates in what we refer to as an audiogram.
4. A graph that visualizes a patient's hearing sensitivity with frequency charted on the horizontal axis and intensity charted on the vertical axis.
5. A test that assesses hearing sensitivity when a signal is transmitted through the outer, middle, and inner ear, and then through the brain to the cortex.
6. To rule out, or confirm, problems with the middle or outer ear.
7. 250; 500; 750; 1,000; 1,500; 2,000; 3,000; 4,000; 6,000; and 8,000 Hz.
8. To connect or disconnect the patient's earphones from the output of the audiometer without turning the unit on or off.
9. To measure the movement of a patient's tympanic membrane and the condition of the middle ear.
10. The type of tympanogram that results from a patient with fluid behind the eardrum.
11. (1) A; a normal tympanogram.
    (2) B; there is fluid in the middle ear or a torn eardrum.
    (3) C; the Eustachian tube is not functioning correctly.

407

1. To view the anterior structures of the eye, such as the cornea, iris, and lens.
2. (1) Slit controls; controls the vertical and horizontal adjustment of the slit, as well as the orientation of the light beam.
   (2) Click stop; alters the position of the reflecting mirror to adjust the angle of the beam with respect to the viewing system.

(3) Filters; used to alter the appearance of the slit beam by use of filters.

3. The measurement of the pressure exerted by the fluids inside the eye.
4. NCT.
5. A gentle puff of air is shot into the patient's eye, and then the equipment calculates the time it takes the air pulse to flatten the cornea.

408

1. The electrical potentials on the body surface.
2. A recording of the depolarizations and repolarizations of the heart.
3. (1) The P-wave is the small, rounded pulse generated by the arterial depolarization at the start of each cycle of heart operations.
   (2) The QRS complex is the fast, high-amplitude, triangular pulse associated with contraction of the ventricles.
   (3) The T-wave occurs after a brief interval, and represents the relaxation and repolarization of the ventricles.
4. (1) Frontal.
   (2) Sagittal.
   (3) Transverse.
5. (1) Lead I; the potential between the right arm and left arm.
   (2) Lead II; the potential between the right arm and left leg.
   (3) Lead III; the potential between the left arm and left leg.
6. Because they measure the electrical potential at one point with respect to a null point.
7. Transverse.
8. Any four of the following:
   (1) The underlying rate and rhythm mechanism of the heart.
   (2) The orientation of the heart (how it is placed) in the chest cavity.
   (3) Evidence of increased thickness (hypertrophy) of the heart muscle.
   (4) Evidence of damage to the various parts of the heart muscle.
   (5) Evidence of severely impaired blood flow to the heart muscle.
   (6) Patterns of abnormal electric activity that may predispose the patient to abnormal cardiac rhythm disturbances.

409

1. (1) TV.
   (2) IRV.
   (3) ERV.
   (4) RV.
2. (1) Inspiratory.
   (2) Vital.
   (3) FRC.
   (4) TLC.
3. The spirometer.
4. (1) d, f.
   (2) a.
   (3) e, h.
   (4) b, c, g.
5. Any lung capacity that contains residual volume.
6. (1) Constant volume.

(2) Flow.

7. Any three of the following:
   (1) Diminished breath sounds.
   (2) Slow exhalation.
   (3) Chest deformity.
   (4) Unexplained crackling sounds.
8. Obstructive lung disease makes it difficult for a patient to breathe out; restrictive lung diseases make it difficult for a patient to breathe in.

410

1. (1) Temperature: 97.8°–99.1°F (average 98.6°F).
   (2) Breathing rate: 12-18 breaths per minute.
   (3) Pulse: 60–80 bpm.
   (4) Blood pressure: systolic – less than 120 mmHg; diastolic – less than 80 mmHg.
2. Any three of the following:
   (1) SaO_2.
   (2) CO.
   (3) ECG.
   (4) EEG.
   (5) Exhaled CO_2 (capnography).
   (6) Apnea.
   (7) BIS.
3. Systolic pressure is the maximum pressure reached during each pumping cycle; diastolic pressure is the maximum pressure reached before the next pumping action.
4. (1) Direct.
   (2) Indirect.
5. By inflating the cuff, pressure exerts onto the arteries, which squeezes them shut as soon as the cuff pressure exceeds the systolic arterial pressure. Once the inflated cuff occludes (cuts off) the arterial blood flow, it is then slowly released while monitoring the sound of arterial blood flow with a stethoscope. With the cuff inflated, you cannot hear any sound. As the valve opens slightly allowing the cuff pressure to bleed off, you can observe a slight tapping sound as the cuff pressure drops to the systolic pressure and blood begins to squeeze past the restrictive cuff. Upon hearing the first sounds, we can record a close approximation of the systolic pressure from the cuff pressure gauge. As the pressure continues to release, the sound changes into a loud thud that fades and disappears just below the diastolic pressure, which is then recorded.
6. The sounds observed during the occlusion and release of the blood pressure cuff.
7. (1) Essential hypertension has no known cause but may be hereditary.
   (2) Secondary hypertension is caused by secondary factors such as kidney disorders, endocrine system disorders, neurological disorders, drugs or chemical side effects, or other miscellaneous causes.
8. Because it can mean an inadequate blood supply to the brain and other vital organs.
9. The seriously ill requiring constant, accurate, long-term monitoring.
10. It involves the insertion of a catheter or needle into a large peripheral artery, such as the radial artery. The catheter is connected to a fluid filled bag containing saline and heparin (a drug that prevents the blood from clotting). The entire fluid-filled system is under slight pressure to keep blood out of the tubing. Changes in blood pressure cause a corresponding change to the pressure within the fluid-filled system. These changes are sensed by a pressure transducer, which sends a signal to the blood pressure monitor.
11. The constant inflation/deflation cycle of a blood pressure cuff is eliminated; a more accurate reading is produced; and there is easy access to blood samples.
12. Helps the medical staff assess a patient’s cardiac function, evaluate venous blood return to the heart, and indirectly gauge how well the heart is pumping.

13. A catheter is threaded through a vein in the arm, thigh, chest, or neck until it passes through the right side of the heart. Once the catheter is in place, the doctor briefly inflates a tiny balloon at the end of the catheter, which temporarily blocks the blood flow and allows the doctor to make a pressure measurement in the pulmonary artery system. Pressure measurements are usually recorded for the next 48 – 72 hours in different parts of the heart.
14. (1) Right heart.
    (2) Retrograde.
    (3) Transseptal.
15. 97-99%.
16. (1) Operating room.
    (2) ER/Ambulance.
    (3) Respiratory therapy.
    (4) ICU.
17. Any condition that restricts blood flow.
18. Any three of the following:
    (1) Ear.
    (2) Finger.
    (3) Infant hand.
    (4) Infant foot.
19. The amount of blood ejected by the heart to the circulation system every minute.
20. During and after major surgical procedures, and with critically ill patients in the ICU.
21. (1) Bolus dye solution.
    (2) Swan-Ganz catheter.
22. It uses a special thermistor-tipped Swan-Ganz catheter, which inserts from a peripheral vein into the pulmonary artery. This technique injects a cold saline of a known temperature and volume into the right atrium from a proximal catheter port. The saline mixes with the blood as it passes through the ventricle and into the pulmonary artery, thus cooling the blood. The units then measures the blood temperature at the catheter tip lying within the pulmonary artery, and a computer acquires the thermodilution profile and computes flow.
23. It uses the Doppler technique to measure CO using SV multiplied by heart rate (HR), with the ultrasound beam parallel to the blood flow.
24. Any four of the following:
    (1) Conscious sedation.
    (2) Pain management.
    (3) Minor surgical procedures.
    (4) Major surgical procedures.
    (5) Sleep disorders.
25. The principle of changing AC impedance across the chest of a patient during respiration.
26. Quantitative.

411

1. The modular type with interchangeable modules that allow many configurations, depending on the department or requirements of the patient.
2. The ability to change which vital signs are measured; the problems associated with tracking down the individual modules.
3. (1) Patient–worn.
    (2) Portable.
4. On patients that have moved from critical care areas, those with heart conditions that require close monitoring during normal activity, or in some cases patients seen in the ER.

5. WMTS.
6. Decreased operating costs; it decreases the number of staff members required on any particular shift.
7. KVM switch.
8. Indicates to the medical staff that an ECG lead has detached from the patient, allowing them to respond appropriately rather than as a true emergency.
9. Ensure they are free of dust and have enough clearance to provide proper air circulation, keep the computers up to date on any required security patches and antivirus software, and ensure you replace the UPS batteries according to the required maintenance intervals.
10. Communication issues between components.

412

1. Because it is measuring the activity of a patient's heart, which produces very small voltage potentials that must be detected through layers of skin.
2. Horizontally, they represent 0.2 seconds of heart activity; vertically, they represent 5 mm of signal movement.
3. 1 mV or 2 large vertical squares.
4. Usually waveforms, such as square waves, triangle waves, wave trains, sine waves, and ECG waveforms of a specific bpm.
5. (1) i.
   (2) c.
   (3) h.
   (4) d.
   (5) b.
   (6) g.
   (7) a.
6. An RS–232 or USB connection to enable printed test results.
7. As the probe shines light into the simulator, it adjusts the translucency of the signal, allowing the amount of light that reaches the receiver to correspond to the preset readings.
8. It tests the peak-to-peak amplitude of the blood pressure wave tested. In this test, you can decrease the amplitude to find where the oximeter fails to sense a pulse.

413

1. To assess the viability and physiological status of a baby by monitoring FHR.
2. Fetal tachycardia is a baseline heart rate greater than 160 bpm or more than 30 bpm from the normal baseline for at least a 10-minute interval; fetal bradycardia is a baseline heart rate less than 120 bpm or less than 30 bpm from the normal baseline for at least a 10-minute interval.
3. A transducer, such as a sensitive microphone, tightly fixes to the abdominal wall with a belt, which detects the mechanical energy associated with a fetal heartbeat.
4. Its ability to be used before the membranes are ruptured or the cervix is dilated.
5. (1) Indirect.
   (2) Direct.
6. The need to have the membranes ruptured, 2 – 3 cm of cervical dilatation, and the presenting part no higher than a 2 station.
7. The spiral electrode.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

20. (406) The pure tone threshold indicates the *softest* sound at a given frequency audible to a patient *at least*
    a. 20 percent of the time.
    b. 50 percent of the time.
    c. 75 percent of the time.
    d. 100 percent of the time.

21. (406) Which audiometric testing is used to *bypass* the outer and middle ear?
    a. Speech.
    b. Free-field.
    c. Sound field.
    d. Bone conduction.

22. (406) Which test produces a visual graph indicating how *stiff* a patient's eardrum is at various pressures?
    a. Static acoustic.
    b. Tympanogram.
    c. Audiogram.
    d. Eustachian.

23. (407) An ocular disease characterized by an *increased* pressure within the eyeball is called
    a. astigmatism.
    b. glaucoma.
    c. hyperopia.
    d. myopia.

24. (408) Which portion of an electrocardiogram waveform represents the *relaxation and repolarization* of the ventricles?
    a. P-wave.
    b. T-wave.
    c. R-wave.
    d. QRS complex.

25. (408) What factors are represented on an electrocardiogram recording?
    a. Signal and strength.
    b. Signal and voltage.
    c. Voltage and time.
    d. Signal and time.

26. (408) How many lead *sets* are required to make a *standard* electrocardiogram recording?
    a. 3.
    b. 6.
    c. 8.
    d. 12.

27. (408) What are the two *frontal* plane measurements in an electrocardiogram?
    a. Unipolar and transverse.
    b. Transverse and sagittal.
    c. Bipolar and transverse.
    d. Bipolar and unipolar.

28. (408) The *transvers*e plane measurements in an electrocardiogram are referred to as
    a. chest common leads.
    b. unipolar limb leads.
    c. bipolar limb leads.
    d. V leads.

29. (409) What is *not* a standard lung volume?
    a. Tidal.
    b. Total lung.
    c. Expiratory reserve.
    d. Inspiratory reserve.

30. (409) Some spirometers contain pneumotachs, which are used to measure
    a. capacity.
    b. volume.
    c. flow.
    d. time.

31. (409) Which type of lung disease causes a *decreased* total lung capacity?
    a. Restrictive.
    b. Obstructive.
    c. Emphysema.
    d. Chronic bronchitis.

32. (410) What is a *standard* vital sign?
    a. Pulse.
    b. Cardiac output.
    c. Oxygen saturation.
    d. Electrocardiogram.

33. (410) What is a measure of the hypnotic effect of anesthetic gases?
    a. Bispectral index.
    b. Cardiac output.
    c. Capnography.
    d. Apnea.

34. (410) What is the *maximum* pressure reached during each heart pumping cycle?
    a. Arterial.
    b. Systolic.
    c. Diastolic.
    d. Pulse pressure.

35. (410) What causes the dicrotic notch in an arterial waveform?
    a. Heart at rest.
    b. Restricted pressure.
    c. Aortic valve closure.
    d. End of systole period.

36. (410) Which type of *automatic* blood pressure measuring technique uses the Korotkoff sounds?
    a. Oscillometric.
    b. Auscultatory.
    c. Invasive.
    d. Direct.

37. (410) What is the *least common* type of hypertension?
    a. Hereditary.
    b. Secondary.
    c. Essential.
    d. Genetic.

38. (410) What is *not* a pressure measured using invasive blood pressure measurement techniques?
    a. Arterial pressure.
    b. Mean systolic pressure.
    c. Central venous pressure.
    d. Pulmonary artery pressure.

39. (410) What is the *greatest disadvantage* of linear variable differential transformer (LVDT) induction transducer-tipped catheters used for invasive blood pressure measurement?
    a. Physical size.
    b. Patient sensitivity.
    c. Fragile construction.
    d. Use of fluid medium.

40. (410) Which catheterization method does *not* require X-rays and uses a balloon-tipped catheter?
    a. Millar.
    b. Mikro-tip.
    c. Dome type.
    d. Swan-Ganz.

41. (410) What is the *normal* blood oxygen saturation level in a healthy adult?
    a. 74–78 percent.
    b. 82–88 percent.
    c. 89–96 percent.
    d. 97–99 percent.

42. (410) What two wavelengths of light are used in pulse oximetry to determine arterial blood oxygen saturation and pulse rate?
    a. Red and white.
    b. Red and infrared.
    c. Visible and white.
    d. Visible and infrared.

43. (410) In pulse oximetry, oxygen saturated blood absorbs
    a. less red light.
    b. more red light.
    c. less white light.
    d. more white light.

44. (410) What is the formula for cardiac output?
    a. Liters per minute (L/min) multiplied by the heart rate.
    b. Stroke volume (SV) multiplied by the heart rate.
    c. SV multiplied by the oxygen saturation (SaO_2).
    d. L/min multiplied by the SaO_2.

45. (410) In what situation would the cardiac output measurement technique *not* be used?
    a. Patient in the intensive care unit (ICU) with a cardiovascular abnormality.
    b. Patient with hypertension visiting family practice.
    c. Patient in the ICU with hypotension.
    d. Patient in postoperative care.

46. (410) Which type of cardiac output measurement technique uses a Swan-Ganz catheter?
    a. Bolus dye solution.
    b. Thermodilution.
    c. Bioimpedance.
    d. Ultrasound.

47. (410) Respiration monitors are used on patients who have received conscious sedation because
    a. anxiety about the procedure may disturb respiration.
    b. the drugs used have a suppressant effect on respiration.
    c. pain from the procedure performed may disturb respiration.
    d. the body's natural reaction to a medical procedure is to increase respiration.

48. (410) What is used as a flow detector in respiration monitors?
    a. Piezoresistive strain gauge.
    b. Impedance pneumograph.
    c. Amplitude modulator.
    d. Thermistor.

49. (411) What is the *primary* benefit of the modular type of bedside physiological monitor?
    a. Low cost.
    b. Increased patient safety.
    c. Easier to track in any medical logistics system.
    d. Flexibility to change which parameters are measured.

50. (411) What patient parameter is *always* measured with a bedside physiological monitor?
    a. Electrocardiogram waveform.
    b. Oxygen saturation.
    c. Cardiac output.
    d. Breathing rate.

51. (411) The Federal Communications Commission (FCC) developed the Wireless Medical Telemetry Service (WMTS) band to help alleviate interference from
    a. walkie-talkies and cell phones.
    b. local radio stations.
    c. vacant television channels.
    d. magnetic resonance imaging systems.

52. (411) Which alarm function of a central patient monitoring system prevents the staff from reacting as if there were a true emergency?
    a. Tachycardia indicator.
    b. Lead fault indicator.
    c. Bradycardia alarm.
    d. Flat line alarm.

53. (411) What are the *most common* problems encountered when troubleshooting a central patient monitoring system?
    a. Component power failures.
    b. Outdated antivirus software.
    c. Incorrect bed numbers assigned to zones.
    d. Communication issues between components.

54. (412) On electrocardiogram graph paper, the large *horizontal* squares represent
    a. 0.1 second of heart activity.
    b. 0.2 seconds of heart activity.
    c. 5 seconds of heart activity.
    d. 10 seconds of heart activity.

55. (412) What is the size and shape of the built-in test signal for *most* electrocardiogram machines?
    a. 5-millimeter square wave.
    b. 5-millimeter triangle wave.
    c. 10-millimeter square wave.
    d. 10-millimeter triangle wave.

56. (412) If an electrocardiogram (ECG) patient simulator produces a 1-Hertz test signal, how many large *horizontal* squares of the ECG graph paper should it cover?
    a. One.
    b. Two.
    c. Five.
    d. Ten.

57. (412) What are the *normal minimum and maximum* pressure ranges available on a blood pressure analyzer to test neonatal blood pressure accuracy?
    a. 60/30 to 120/80.
    b. 60/30 to 150/100.
    c. 120/80 to 200/100.
    d. 150/100 to 255/195.

58. (412) Which blood pressure analyzer test indicates in millimeters of mercury per second the rate of cuff deflation?
    a. Leak test.
    b. Deflate rate.
    c. Deflate time.
    d. Maximum pressure.

59. (413) The frequency range transmitted *toward* the fetal heart by an ultrasound transducer is 2–10
    a. Hertz.
    b. kilohertz.
    c. megahertz.
    d. gigahertz.

60. (413) Which fetal detection system *cannot* be used without rupturing the amniotic sac?
    a. Tocodynamometer.
    b. Phonocardiograph.
    c. Spiral electrode.
    d. Ultrasound.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Diagnostic Support Equipment

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Unit 3. Diagnostic Support Equipment

IT'S NOW TIME TO COVER the diagnostic support equipment you will be responsible for as a BMET. Although most of the diagnostic support equipment you will maintain are in the OR or clinical laboratory, there are a few other items we will cover that are found in other areas of the MTF. We will begin by covering optical equipment used in surgery, then on to the largest user of the diagnostic support equipment, the lab, and end with some miscellaneous support items.

3–1. Surgical Optics

The specific equipment we will learn about in this section is fiberoptic scopes, endoscopic systems, and fiberoptic scope washers. These units provide the viewing capability that allows providers to make an accurate diagnosis or simply access areas of the patient to aid in therapeutic procedures. All of these pieces of medical equipment are fairly common, and you are certain to deal with them at some point, if you haven't already.

414. Fiberoptic scopes

The broad medical term for a fiberoptic scope is an endoscope. If you recall from our review of medical terminology, the prefix endo means "within." So, an endoscope is an instrument used to look within the body. We will use this term interchangeably with the term fiberoptic scope.

We will go into the parts of an endoscope in more detail a little later; briefly, an endoscope is a hollow tube containing channels (called lumens) for fiberoptic glass fibers, which transmit light for illumination and viewing. There may be more lumens for additional procedures. There are many different kinds of endoscopes (named for the particular areas of the body that we use them, such as an arthroscope, laryngoscope, or gastroscope), but we can break them down into two broad categories: rigid and flexible. Sometimes fiberoptic scopes are further classified as semi-rigid, but, for the purposes of this lesson, we will keep it simple.

Clinical applications

When a physician wanted to look inside a patient's stomach before the widespread use of fiberoptic scopes, they had to perform surgery to open the patient for the exam. Now, the use of endoscopes is commonplace, which mitigates many of the complications, risks, costs, and long recovery times associated with many exploratory surgical procedures. Doctors now use endoscopes to peer into many

areas of the human body to find out exactly what is taking place. Often, the procedure can be done on an outpatient basis (the patient does not require hospitalization).

Doctors use endoscopes for many different procedures, but there are two basic ways they introduce a scope into the body. The first, and most common, is through a natural body orifice, such as the nose, mouth, anus, bladder, or vagina (fig. 3–1). The second method of insertion is through a tiny surgical incision. This method can reach areas inaccessible through a natural orifice. Depending on the procedure, a patient may receive anesthesia or simply just a tranquilizer to help them relax.

Endoscopes also have many uses besides just simply looking at the inside of a patient. Many scopes have special features, such as suction, irrigation, or accessory instruments that can perform surgical procedures. Using endoscopes for surgical procedures leads to reduced patient recovery times compared to other invasive surgical procedures. Sometimes after examining an area, the doctor may take a biopsy, a small sample of tissue, which they test for diseases such as cancer. They may also use a scope in conjunction with a recording system to record the procedure, allowing other physicians or specialists to review it or use it for comparison at a later date.

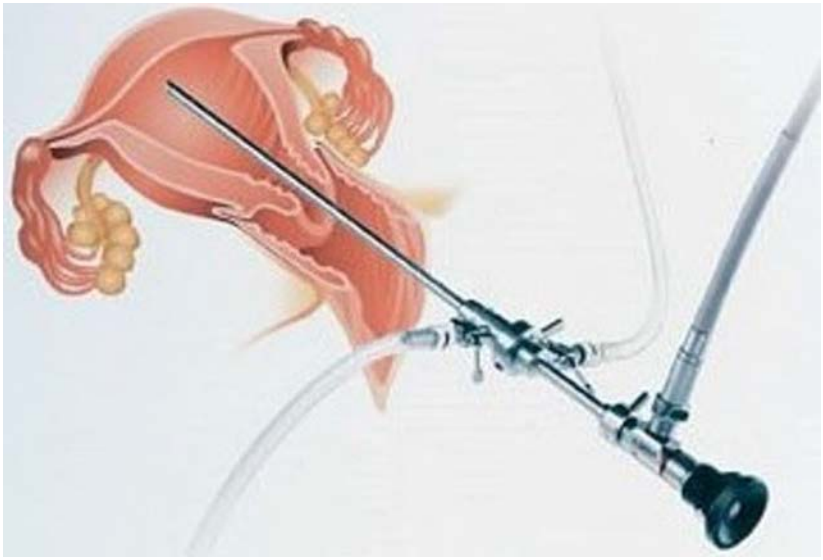

Figure 3–1. Clinical application of a fiberoptic scope.
(Printed with permission, Richard Wolf Medical Instruments Corp.)

The following table shows some common endoscopic procedures, along with the area of the body under examination and some common causes for the procedure.

Endoscopic procedure	Body area	Reason for procedure
Arthroscopy	Joints	Diagnosis and treatment of torn cartilage or other joint ailments.
Bronchoscopy	Trachea and bronchial tree	Abscesses, bronchitis, cancer, tumors, or tuberculosis.
Colonoscopy	Colon and large intestine	Polyps, tumors, ulcers, inflammation, or disease.
Colposcopy	Vagina and cervix	Cancer or inflammation.
Cystoscopy	Bladder, urethra, urinary tract, and male prostrate	Polyps, tumors, ulcers, inflammation, or disease.
Duodenoscopy	Duodenum (part of the small intestine)	Digestion problems, unexplained vomiting, or cancer.
Esophageal-gastroduodenoscopy (EGD)	Gastro-intestinal (GI) tract	Hiatal hernia, ulcers, or inflammation.
Gastroscopy	Esophagus, stomach, and	Ulcers, bleeding, or for biopsy of

Endoscopic procedure	Body area	Reason for procedure
	duodenum	suspected GI cancer.
Laparoscopy	Stomach, liver, and female reproductive organs	Polyps, tumors, ulcers, inflammation, or disease.
Laryngoscopy	Larynx	Inflammation, ulcers, or cancer.
Sigmoidoscopy	Rectum, colon, and large intestine	Abdominal pain; bowel disease or obstruction; colon cancer; or unexplained diarrhea.
Thoracoscopy	Pleura (sac that covers the lungs)	Cancer, unexplained bleeding, or breathing difficulties.

Parts of a fiberoptic scope

Now that you have a good idea about the general uses of fiberoptic scopes, let's examine the construction of a scope. Flexible and rigid scopes are very different in their construction and use. Generally speaking, a rigid scope provides a better image than a flexible scope, although the flexible scope is easier to manipulate into various body structures. We will begin by looking at the parts of a flexible endoscope, and then we will discuss the rigid scope.

Flexible endoscope

There are two basic types of flexible scopes: fiberoptic endoscopes and videoscopes. The fiberoptic endoscope has an eyepiece lens the doctor uses to view the image directly or with a hand-held camera. A videoscope uses a video chip, positioned at the far end of the scope, which transmits the image directly to a video monitor. In either type of scope, there are four basic parts:

1. Control body (fig. 3–2) – The part of the scope that remains outside of the body and is made up of the imaging controls, biopsy port, air/water channels, and eyepiece (only in the fiberoptic type).
2. Insertion tube – This is a flexible tube containing channels for suction, biopsy, irrigation, insufflation (filling with gas), fiberoptic light bundles, and fiberoptic image bundles.
3. Bending section at the distal tip (fig. 3–3) – This is the section manipulated by the physician using controls to steer the lenses in various directions to view the internal structure.
4. Light-guide connector unit – This section connects to the light source, suction, and insufflation source.

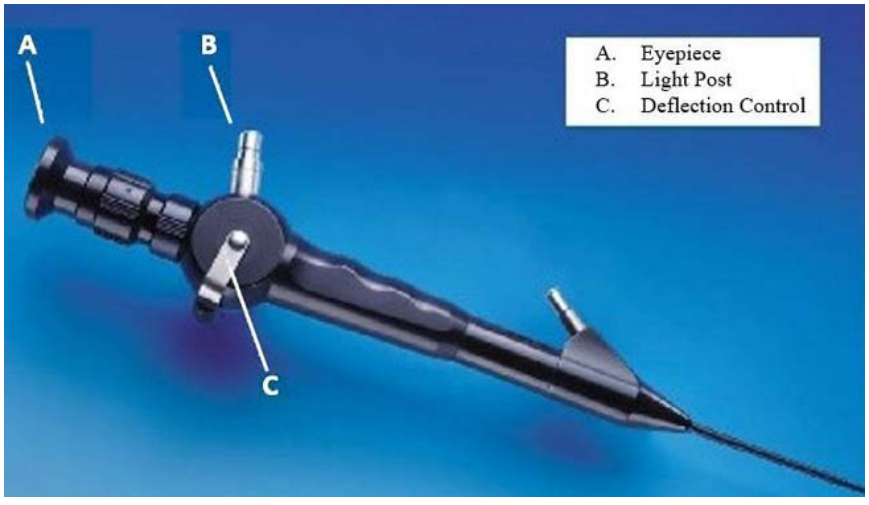

Figure 3–2. Control body of flexible endoscope.
(Printed with permission, Richard Wolf Medical Instruments Corp.)

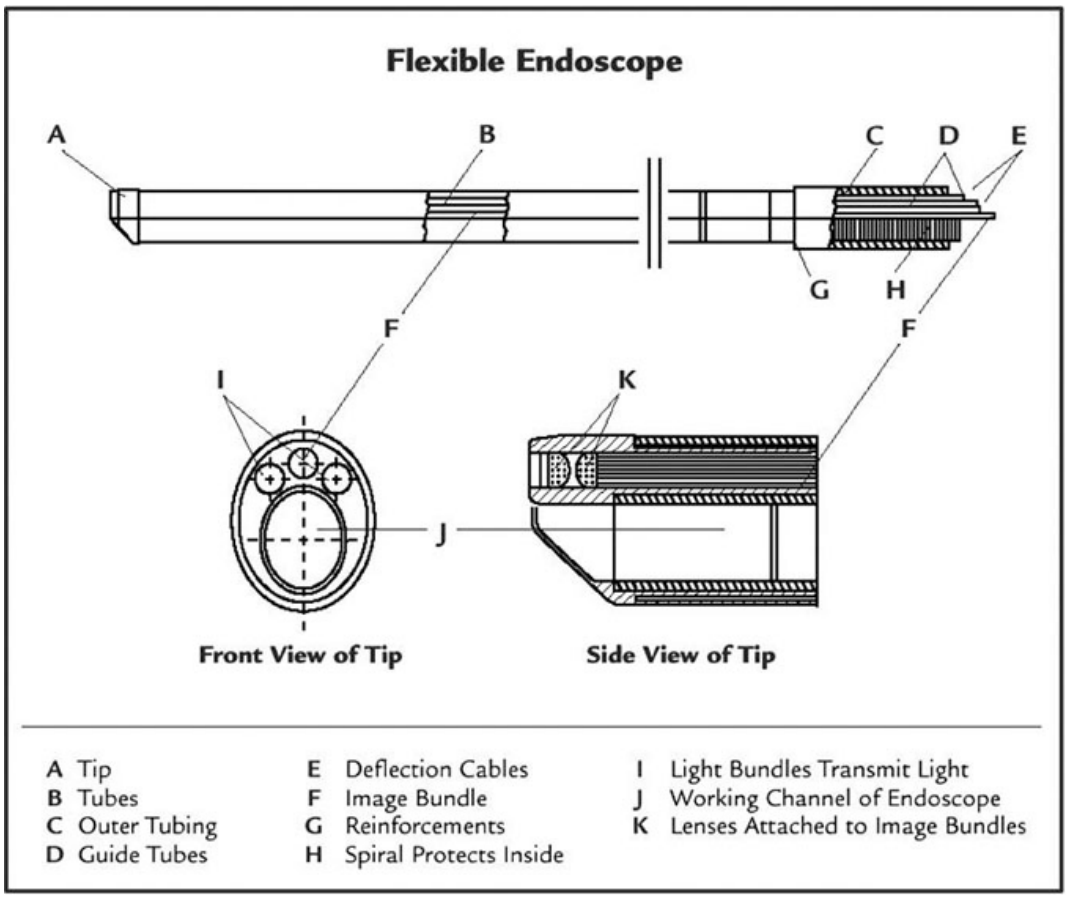

Figure 3–3. Flexible endoscope including tip components.
(Printed with permission, Richard Wolf Medical Instruments Corp.)

Rigid endoscope

Rigid endoscopes (fig. 3–4) come in a variety of lengths and diameters, which depend on the particular procedure the doctor will perform. This scope also comes with many different viewing angles, such as 120° for backward viewing, 90° and 70° for lateral viewing, 45° and 30° for forward oblique views, and 0° for forward viewing. The rigid scope is a surgical stainless-steel instrument and contains four basic parts:

1. Objective lens – Located at the distal tip, this lens determines the viewing angle of the scope.
2. Telescope – This is the most fragile and expensive part of the scope and transmits the image and light that allows image viewing through two separate systems. The first system, the optical lens train, transmits the image to the physician or a video camera, and consists of precisely aligned lenses, spacers, and mirrors. The second system, the fiberoptic light cable, transmits light from a light source through illumination fibers located around the lens train.
3. Light post – This part allows attachment of the light cable to the telescope.
4. Eyepiece – Also known as the ocular lens, this part remains outside the patient's body. The physician may view the image directly through the eyepiece or attach a camera to the eyepiece and view the images on a video monitor.

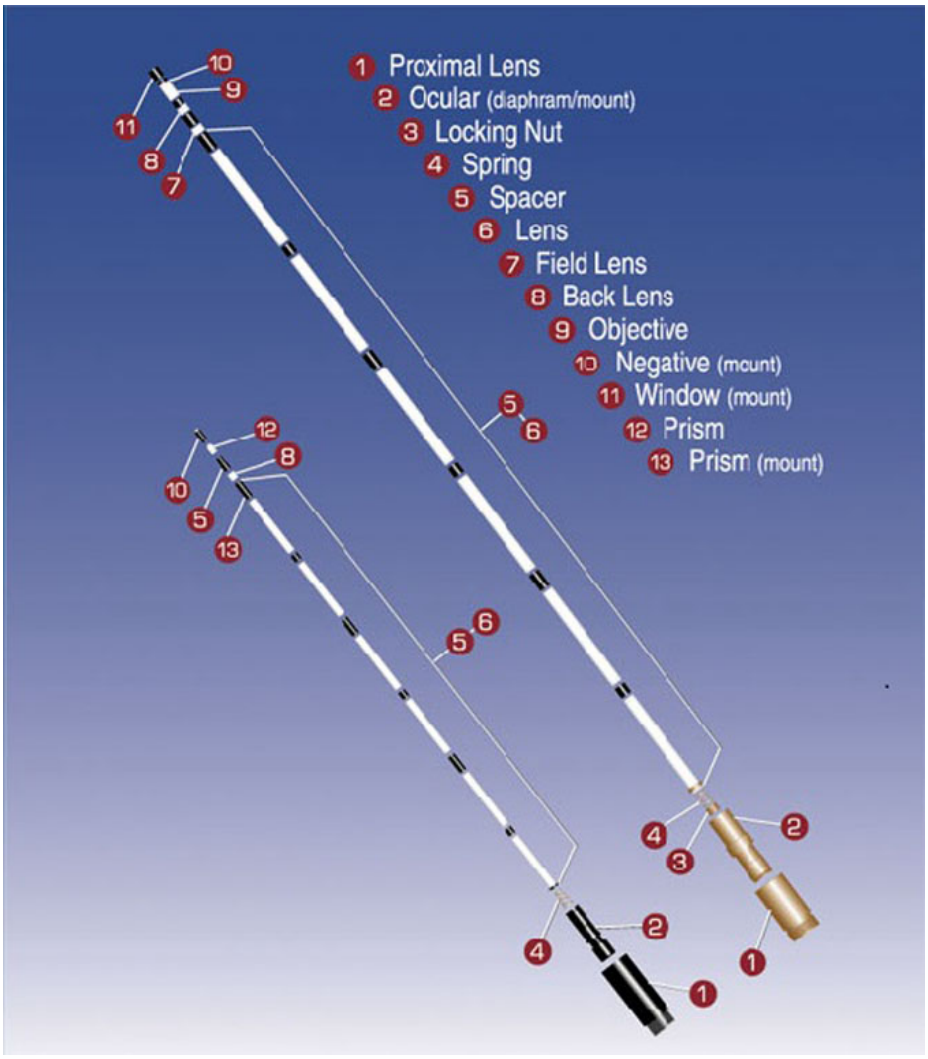

Figure 3–4. Rigid endoscope.
(Printed with permission, Richard Wolf Medical Instruments Corp.)

Endoscopic tower system

The tower is a mobile cart system containing much of the support equipment elements of an endoscopic system. These units are employed in conjunction with a scope to provide the illumination, image processing, and recording functions for a procedure. The following items are the most common equipment and accessories used with an endoscopic tower:

- Light source – This is the most basic required item used with scopes since it provides the light for illumination inside the body. It utilizes either an LED, xenon or halogen bulb to produce the light. The unit will connect to the scope through the light post and illuminate the target tissue by transmitting light to the tip of the endoscope via a fiberoptic bundle.
- Camera – A high definition camera attached to the eyepiece transmits the image through a processor, and then to a monitor that allows the physician to view internal structures without needing to look directly into the endoscope. The camera can actually magnify the image to make viewing easier.
- Video processor – The camera transmits the image back to a video processor on the endoscopic tower. As the name implies, this unit processes the images and converts them to standard analog or digital output for viewing on a video monitor.

- Monitor – There is generally at least one monitor attached to the tower itself, but you might also find additional monitors mounted on the walls or hanging from booms in the OR. This allows for redundant viewing by the medical staff.
- Digital capture system – This equipment allows the physician to record procedures, take still pictures, burn digital versatile discs (DVD) or store images for future reference or diagnostic purposes. Many newer units incorporate some of the processing and capturing functions together into one unit.
- Insufflator or fluid pump – Clinicians can view abdominal organs or spaces between joints more easily by expanding the cavities with gas (CO_2) from an insufflator or clear fluid from a fluid pump. These two accessories aid in accomplishing the task. They possess adjustable flow rates, various modes and sensitivities (such as neonatal flow rate of 0.1 L/m), built-in heating units, and safety venting systems.
- Operative instrumentation – These instruments perform surgical procedures during an examination. They include biopsy forceps, grasping forceps, cytology (the study of cells) brushes, snares for tissue removal, and electrosurgical probes. Flexible endoscopes have a working channel through which instrumentation can pass to reach the procedure area.

415. Fiberoptic scope washers

While using an endoscope for various exploratory and surgical procedures has many benefits, its complex design and numerous construction materials complicate the cleaning and sterilization process. The endoscope is a potential nightmare for infection control and is much more difficult to clean and sterilize than many other surgical instruments. As you have learned, endoscopes have long, dark, and narrow channels contaminated with body fluids, which create a perfect breeding place for microorganisms. These long, narrow lumens are not directly accessible and are very difficult to clean.

As technology advances, fiberoptic scopes get smaller; as the diameters decrease, the fibers are also becoming smaller and more fragile. This fragility, in turn, results in easier fracturing or misalignment from improper handling. As these instruments become more sophisticated, they are increasingly difficult to clean and sterilize. Endoscopic instruments always require thorough cleaning and high-level disinfection or sterilization between uses.

Manual cleaning method

Reprocessing an endoscope using manual methods is a very tedious procedure. While it is not the intent of this lesson to teach you how to perform this procedure, you will better appreciate the automated process by having an idea of the manual method. Let’s briefly look at the manual method for reprocessing.

The first step involves preparing a special cleaning solution. The scope is then pre-cleaned (while still connected to the light source/accessories) by cleaning all exterior surfaces and suctioning the cleaning solution through all the channels. After this, the clinician removes the scope from the light source and performs a leak test to ensure there are no cracks, tears, or holes in the scope. After the leak test, they disassemble the scope in the cleaning solution. Next, they must use brushes of various types to clean the different ports and other parts; special long brushes help to clean out the different channels.

After a thorough cleaning, the tech must completely rinse every part of the scope with water and dry it. Then, they must purge the scope with air to remove any remaining water. After that, they force a chemical germicide through the channels and leave it briefly to soak; then, rinse the scope again with sterile water. Next, they dry and purge the scope with air to remove any remaining liquid. Lastly, the tech will again leak test the unit to ensure there are no leaks. During the entire process, proper infection control procedures are critical to protect the user from biological hazards, such as blood, fecal matter, or bodily secretions.

Automated method

Now, we come to the main focus for this lesson. As you can see, the manual method for reprocessing endoscopes is quite tedious; therefore, automation would make the job much easier. However, to effectively and efficiently clean fiberoptic scopes using automated methods, we must consider two primary factors—the time it takes to perform reprocessing and the sterilization process.

One of the primary concerns with endoscopes, especially in busy surgical departments, is the time it takes to reprocess a scope. Endoscopes are specialized and can be quite expensive (as is anything termed "medical equipment"); therefore, a department may not have a lot of endoscopes on hand and will need a rapid reprocessing turnaround. As you probably noted from the description of the manual cleaning method, scope reprocessing can be a rather time-consuming process. So, for an automatic reprocessor to be beneficial to an MTF, it must perform the job much quicker than the manual method.

The second factor concerning the reprocessing of a scope is the sterilization process. There are basically four ways to sterilize medical equipment: high-pressure steam, ethylene oxide (EtO) gas, plasma sterilization, or a liquid chemical germicide (LCG). Flexible endoscopes are very delicate and cannot withstand high temperatures, such as in a steam sterilizer. Because of this, we can rule out high-pressure steam (although we may use this method for some rigid scopes). Next, gas sterilization generally takes about two hours to complete, followed by a 12-hour aeration phase, not to mention nearly all EtO sterilizers have been phased out due to the dangers associated with EtO. Given these facts, we are left with LCG and plasma sterilization as the only options available to sterilize flexible fiberoptic scopes. While plasma sterilization remains an option, we would still need to perform the remainder of the cleaning and rinsing tasks manually if we used this option. Based on these factors, we will limit the remainder of our discussion to LCG since that is the most common sterilization method that automatic scope reprocessors use.

There are several different chemicals used as an LCG in automatic reprocessors, usually depending upon the manufacturer of the unit. Most manufacturers design their reprocessing units to operate with a specific chemical; each chemical will perform satisfactorily only under the correct conditions. For example, two important factors are that each LCG must remain in contact with a scope's surface for a specific amount of time as well as in a specific temperature range to sterilize effectively. If the time is too long, corrosion could occur; if the time is too short or the temperature is not correct, sterilization may not be complete.

One point that we should note here is not all endoscopes are actually sterilized. Actual sterilization is the killing of all microorganisms. Sometimes, endoscopes only require disinfection at a high level. This means the killing of all vegetative bacteria, fungi, and viruses but possibly leaving some bacterial endospores. Now, you don't need to be an expert and understand all the terminology here; just understand there is a difference between sterilization and high-level disinfection. Whether an endoscope must be sterilized or just disinfected to a high level depends upon the particular procedure the scope is used for; scopes that pass through an incision, rather than a body orifice, require sterilization. Also, reprocessors may only disinfect, rather than sterilize, an endoscope; the manufacturer will specify what action their unit performs.

Of course, there are other processes we must perform for endoscope reprocessing besides sterilization or high-level disinfection. There are numerous models of scope washers on the market, and they vary in the amount of reprocessing they actually perform. With all models, the accessible surfaces of a scope will still need pre-cleaning using manual methods before placing them in the reprocessor. Also, it is important to note not all scopes are cleanable using automated methods and some models of scope cleaners may not be compatible with certain scopes. Always consult the manufacturer's literature before use to clear up these details.

Parts of an automatic reprocessor

As we mentioned previously, there are many different manufacturers and models of automated scope reprocessors, but they all have similar designs. The following are the basic features found in most units:

- Basin – This is the main body of the unit where the scope is actually reprocessed and includes a lid.
- Channel tubing with adapters – This is the portion of the unit that cleans out the channels of the endoscope and includes adapters to fit the various scopes the unit can reprocess.
- Electronics section – This is the part that controls the activity of the reprocessor and includes a timing section to monitor the soaking and irrigation times of the unit.
- Fluid reservoir(s) – This is where the unit stores the chemicals used to clean and sterilize the scope. Some units utilize individual chemical packets placed in the unit before reprocessing a scope, thus eliminating this requirement.
- Water filter – Most units connect to the MTF water supply but require the water to be filtered (usually to 0.2 micron) to prevent contamination. Some units use multiple filters, such as internal (final stop micron filters), external carbon filters, or even ultraviolet (UV) lighting systems that aid in killing bacteria. Your filtration system will depend on your MTF supply filtration system, as well as the local area water hardness and potential of hydrogen (pH) values.
- Fume containment – The fumes from the reprocessing chemicals can be very toxic; therefore, the unit must provide some method to contain or eliminate the vapors.
- Alarms – There are normally alarms to warn of cycle interruption due to power failure or the lid raising during a cycle, as well as other problems, such as low pressure or water supply.

Automatic reprocessor designs will vary by model and manufacturer; they may be floor standing, tabletop, or cart mounted. Some units may be able to process more than one endoscope per cycle.

Reprocessor cycles

The cycles of a reprocessor depend upon the steps the unit actually performs. At a minimum, all reprocessors have a disinfecting stage followed by a rinse phase. Most units have additional phases, such as a cleaning phase and a forced-air phase to remove leftover liquid, and a pressurization phase to check for leaks. Many units utilize ultrasonic energy to enhance the cleaning activity of the unit. Nearly all units have some type of memory and printout to provide documentation of the actions completed.

Preventive maintenance

Timely preventive maintenance, just as you learned in the sterilizer section of 4A251B Volume 2, is one of the most critical components of a scope washer system. Most units that combine water, electrical, and mechanical components will require periodic spare parts replacements and preventive maintenance checks, as sediment build up across flow components and wear and tear on seals can hinder operation. Each unit publishes different maintenance requirements, so you should always consult your manufacturer's literature to ensure you are meeting or exceeding established guidelines. Let's explore some general maintenance areas and timelines for what you might see in the field.

Daily maintenance

Daily maintenance is generally a function of the operator, and proper upkeep can reduce potential problems for the section and the BMET. While mostly a user function, it is a good practice for the BMET to perform some of these daily actions, or inspect that the user is performing them when the unit is due for scheduled maintenance. The user should wipe down the exterior of the unit every day, or at least every day the unit is in use, with a soft cloth dampened with 70 percent isopropyl alcohol. As scope washers use various chemicals and deal with contaminated equipment, the potentials for chemical spillage and cross contamination are high. The next step is to remove the scope tray and

wipe down the tray and seals to ensure it are free from buildup. Finally, check the drain or drain screen and remove any debris that can obstruct the unit from properly draining.

Spare parts replacement

The manufacturer will recommend intervals for scheduled parts replacement (SPR) based on research and average failure rates. Depending on your MTF's water filtration system and local water quality, you might find it beneficial to increase the frequency of scheduled maintenance in order to reduce unscheduled downtime due to poor water conditions. Remember, you must always follow the manufacturer's requirements as the minimum standard, but you can use even more stringent applications to meet mission requirements.

Most applications of SPR for scope washers revolve around filters, check valves, and seals. Scope washers utilize multiple filtration components including internal and external unit filters. Your unit may have single or multiple external prefilters ranging from 0.1 to 2.5 micron filtration. The purpose of the external filters is to filter the incoming potable water prior to reaching the unit. Depending on your unit and the local water, you might also have an external carbon filter or UV filtration system upstream from your prefilters. The carbon filter will require less frequent replacement than your prefilters or internal filters. Another type of filtration maintenance is ensuring that chamber of the UV filtration system remains clean, if applicable to that particular unit. You can do this by using a chemical descaler to periodically flush the UV chamber; however, you might also need to replace the chamber sleeve all together. Use caution, however, as the sleeve can be both fragile and expensive.

Units will typically have an internal pharmaceutical sterilizing-grade filter around 0.1 to 0.2 micron, which provides filtered water to rinse processed instruments as well as a sterile air filter. These filters are your last line of defense against particulates inside the unit and offer the highest level of filtration. Many issues common to dealing with scope washer failures might involve dirty or clogged filters. These can cause slow fill times or failure to reach pressure alarms. Ensure you are replacing filters and PM kits at the appropriate intervals.

Check valves are another common component that you will either replace or rebuild at predetermined frequencies. Even though proper filtration goes a long way, the natural properties of water place a lot of wear and tear on check valve components. Check valves generally require replacement on an annual or bi-annual basis, or as needed. Be sure to follow the replacement procedures correctly, as an improperly installed check valve can create more problems than what you started with.

Functional checks

After replacing any PM kits or components, be sure to run a diagnostic cycle to ensure each component in the system is working as intended. Check that the unit passes through each stage at the appropriate time, and check for any water or air leaks during all cycle phases. The maintenance service mode will allow you to activate each stage or individual solenoid directly, (i.e., if the unit fails to drain, you can activate the drain solenoid directly to verify component function). This is a very valuable tool when diagnosing a malfunction. Always be sure to wear the appropriate personal protective equipment (PPE) when dealing with scope washers to prevent harm from chemicals as well as reduce biological exposure.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

414. Fiberoptic scopes

1. What is an endoscope?

2. What are the two broad categories for endoscopes?

3. What are two basic ways doctors introduce an endoscope into the body?

4. List at least six endoscopic procedures and the associated area of the body being examined.

5. What are two basic types of flexible endoscopes?

6. What are the four basic parts of a flexible endoscope?

7. What are the four basic parts of a rigid endoscope?

8. List at least four addition pieces of equipment used in conjunction with endoscopic towers.

9. How does the light source illuminate the target tissue?

10. How can clinicians view abdominal organs or spaces between joints more easily?

415. Fiberoptic scope washers

1. Why would you perform a leak test on fiberoptic scopes?

2. Why is endoscope reprocessing time one of the *primary* concerns in busy surgical departments?

3. List the four ways to sterilize medical equipment.

4. What are two important factors concerning the proper performance of liquid chemical germicides?

5. Briefly describe the difference between high-level disinfection and sterilization.

6. List at least five basic features of an automatic endoscope reprocessor.

7. What are the minimum two cycles an automatic endoscope reprocessor will have?

8. What would you use to clean a scope washer during daily maintenance?

9. What could you do in order to proactively decrease unscheduled down time due to poor water conditions?

10. What is the purpose of the external filters?

11. What kind of internal filters does a scope washer use?

12. What should you do after replacing PM kits or components?

3–2. Clinical Laboratory

The clinical laboratory (normally referred to as the “lab”) plays a crucial role in the detection, diagnosis, and treatment of diseases. Laboratory personnel perform most of these tests using various pieces of diagnostic support equipment. Some of the common tasks performed include examining and analyzing body fluids, tissues, and cells. Also, laboratory personnel look for bacteria, parasites, and other microorganisms; analyze the chemical content of fluids; match blood for transfusions; test for drug levels in the blood to show how a patient is responding to treatment; and count cells and look for abnormal cells. Results of the various tests performed are relayed to the attending physician. Because much of the equipment in the lab is automated and computer controlled, the work of laboratory personnel has become less hands-on and more analytical.

416. Tissue processors

The tissue processor can be found in the histology laboratory. Tissues are removed from the body for the diagnosis of disease by surgery, biopsy, or autopsy. The most common method for examining tissue is through the microscope. The tissue is prepared by sectioning. Since fixed tissues are not firm and cohesive enough to permit thin sections to be cut on a microtome at 4 to 6 microns, it is necessary to completely impregnate them with some supporting medium to furnish stability and hold cells and intercellular structures in proper relationship to each other. Before this can be accomplished, chemical processing must occur.

Clinical applications

Tissue treated in a processor is put through four separate stages before it is ready to be placed on a glass slide for examination:

1. Fixation preserves tissues in a life-like state. This procedure should be done as soon as the tissue is removed. There are five major groups of fixatives used in tissue processing—aldehydes, mercurials, alcohols, oxidizing agents, and picrates. The aldehydes include formaldehyde and glutaraldehyde. The most common form of fixative is formalin (10 percent formaldehyde in water). Formalin penetrates the tissue well but is a slow process. Mercurials penetrate the tissue poorly and may cause some hardness. The process is fast, though, and provides excellent nuclear detail. Alcohols are hardly used due to brittleness and hardness. Oxidizing agents are used infrequently due to denaturation; picrates are an explosion hazard in dry form and turn everything they touch to yellow.
2. Dehydration is the next step in processing tissues. Water is removed from the tissue before the tissue is fixed with paraffin. Dehydration is done in a series of steps from 70 percent to 95 percent to 100 percent. Isopropyl alcohol is a common dehydrate. Other dehydrants have serious disadvantages. Acetone is a fast agent but is a fire hazard and is only used during manual processing. Dioxane is another dehydrate but is very toxic.
3. Clearing is the removal of the dehydrant before it is embedded with the paraffin. The most common clearing agent available is xylene. Toluene and methyl salicylate work well but are very expensive. Clearite™ is a new clearing agent that is becoming popular.
4. Embedding is the final stage in tissue processing before it is sectioned for slide placement. Paraffin is the common form of embedding agent. Paraffins are purchased according to levels of hardness preferred and climate. Vacuum can be used in the tissue processor to assist with the penetration of the embedding agent.

Automated method

Labs process large volumes of tissue using an automated tissue processor. A typical automated tissue processor moves the tissue through the various previous stages on a preset timer. Most of the newer models are computerized, have sealed reagent wells, and have vacuum and heat stages that can be applied. Tissues are put in plastic cassettes for processing. Units can be programmed for a short run for small biopsies and overnight for routine processing. Routine processing consists of several stations of all four stages that may take 12-16 hours to process.

417. Centrifuge

The process by which substances of different densities separate from one another by centrifugal force is centrifugation. Centrifugal force is the force that makes rotating bodies move away from the center of rotation. The centrifugal force developed depends primarily on the speed of rotation, distance from the center of rotation, and density. Heavier particles move further from the center of rotation and collect at the bottom of the container.

A machine designed to separate substances by centrifugal force is called a centrifuge. It consists mainly of an electric motor to produce the rotation, an apparatus called the head to hold the samples, and a speed control. There are many variations in sizes, type of heads, and rotation speeds. Common laboratory centrifuges operate at a speed of about 3,000 revolutions per minute (rpm), but they can attain a speed as high as 5,000 rpm. An ultracentrifuge is capable of speeds in the range of 20,000-70,000 rpm, and is capable of generating forces 50,000-500,000 times the force of gravity.

Ultracentrifuges are very large, high-cost, specialized machines used mostly in research labs for separation of proteins and nucleic acids. In addition, some specialized centrifuges are equipped with heating or refrigeration systems to provide controlled temperatures.

Three common uses of the centrifuge are separation of plasma and blood cells, determining hematocrit, and separation of solutes in urine. Two types of tabletop centrifuges are in common use.

One has a fixed speed with a variable time; the other has variable speed and time. The time of centrifugation includes the time of acceleration but not deceleration.

Aside from the necessary preventive maintenance checks, routine control checks of rpm and time of centrifugation are mandatory. The force created by the spinning of the centrifuge head is the relative centrifugal force (RCF) or G force. This is determined by the speed (rpm) and the radius of the centrifuge head. The formula for deriving RCF is:

$$G = 0.00001118 \times rpm^2 \times R.$$

The R in this formula stands for radius. The rpm is determined by instruments such as the strobe light or Jaquet™, worm gear, or vibrating reed tachometers. Measure the radius of the head in centimeters from the center spindle to the outer tip of the test tube in cup. By using this formula, directions stating G forces and time required can be applied to any centrifuge.

Additional factors to be considered are:

- Most centrifuges have an automatic timer that, after continuous use, is frequently not in alignment. Check the timer with a stopwatch and the correction marked on the face of the timer.
- The time of acceleration and deceleration varies from one centrifuge to another.
- The viscosity of the medium affects the sedimentation of RBCs; a greater force or longer time is required to sediment RBCs suspended in 30 percent albumin than in saline.

Calibrate each centrifuge empirically to find the speed and time that will produce clearly recognizable agglutination but will not cause false positive reactions. Centrifugation must be of sufficient force to bring the cells together, but not so great that the unagglutinated cells cannot be resuspended with gentle manipulation.

Centrifugal processes are also common in a variety of specialized instruments. Centrifuge analyzers use centrifugal forces to add, transfer, and mix reagent and sample. Samples are processed in a modified centrifuge head, which contains an optical cuvette along its outer wall for each sample.

Blood cell washer

The blood cell washer found in the immuno-hematology section of the laboratory is a device used to separate and prepare cells for *in vitro* diagnostic testing. The most common device used for this purpose is the centrifuge. The automated centrifuge or automated cell washer is used to wash cells, decant saline, and spin. It is also used to remove undesirable proteins and metabolites before transfusions.

The automated cell washer is generally a tabletop model that runs at 3,500-3,800 rpm and completes a wash cycle in 60-85 seconds. The wash cycle in a cell washer distinguishes it from other centrifuges. It consists of four stages.

1. Fill is the first stage in a wash cycle. Saline is drawn up from a peristaltic pump, passed through a rotor distributor, and goes into the tubes. This step ensures the resuspension of cells. The cycle is usually run at 700 rpm.
2. Spin is the longest stage in a wash cycle. It takes approximately 45-60 seconds at 3,500-3,800 rpm. The system is brought to full speed for the effective separation of cells from the wash solution.
3. Decant is the third stage in the wash cycle. It is run at 700 rpm, and the tube is at a negative angle to expel spent saline from the tubes. The cells are retained in the tube.
4. Agitate is the final stage in a wash cycle. Agitation is used to resuspend the cells.

Tachometer

An important part of inspecting a centrifuge or a blood cell washer is the ability to measures its rpms. As different specimens or tests require various ranges of centrifugal force, we must be able to accurately measure the rotations to verify compliance. Spinning too slowly may give inadequate results, while spinning too fast may damage cell structures. To validate these ranges, we use a measurement device called a tachometer. In the clinical laboratory, we use laser tachometers or non-contact tachometers, as opposed to direct measurement tachometers you might find in the automotive industry.

A non-contact phototachometer uses infrared light to measure the speed of rotation of a shaft, wheel, rotor, or any other rotating object. The tachometer requires some type of contrast in color on the surface of the object. If there is no such contrast or if the surface is highly polished, then you would mark a spot on the surface using a marker or by sticking a piece of reflective tape onto the surface. The infrared light from the tachometer falls on the surface and reflects back to the detector on the tachometer. The amplitude of the returning signal, reflected alternately by the object surface and the contrast spot, determines what a “pulse” is. The frequency of pulses per unit of time gives the speed of rotation of the object in rpms. Most centrifuges have an enclosed lid to prevent spilling its contents or causing harm to the operator, but for accuracy verification they provide a window on the lid with a clear line of sight to the rotor.

To verify rpms, simply hold the tachometer over the marked measurement spot and hold the measurement button. The unit will give instantaneous real-time results. Be sure to allow enough time for the centrifuge to reach the desired set speed. If you are having trouble attaining a reading, adjust your measurement angle to ensure the infrared light is able to hit the target and reflect back to the detector. Follow the manufacturer’s literature of the unit under test for specific testing requirements, but you will generally attain a low, medium, and maximum speed calibration verification.

418. Electronic particle counter

Most work in hematology consists of complete blood counts (CBC) using an electronic particle counter. It will be extremely helpful to you to be familiar with the procedures inherent in a CBC and know normal values. The CBC consists of five tests: RBC count, WBC count, hemoglobin, hematocrit, and differential WBC count.

Automated methods

There are at least two automated methods available for counting blood cells: optical and impedance. The optical method is based on the production of light impulses. In this system, cells are diluted and drawn through the counting zone by a positive displacement metering pump. As cells pass through the counting area, they produce photoelectric impulses that can be counted.

The other method of automating blood cell counting uses the principle of resistance in an electrical field. Since blood cells are poor electrical conductors, they act as an impedance to current flow. As more cells pass into the electrical field, they offer correspondingly more resistance. The changes in the current flow caused by the change in resistance is sensed and counted by a digital counting apparatus. The digital counter is designed to produce numbers in a range that approximates the number of blood cells that cause the resistance.

Devices with optical systems

Several instruments employ a photoelectric counting device that uses an optical sensing system and electronic counting system. As the diluted blood specimen enters the counting area, the sample is “inspected” by a reversed dark field microscope arrangement. A schematic presentation of this arrangement appears in figure 3–5. When no particles are present in the sample, the narrow light beam from the lamp passes straight through to a dark field disc blocking further passage. However, any suspended particles, such as blood cells, interrupt the light beam. Scattering of the light beam due

to the mass of each blood cell causes a light flash to pass around the dark field disc. The light flash is focused into a detection system and converted into an electrical pulse that can be counted.

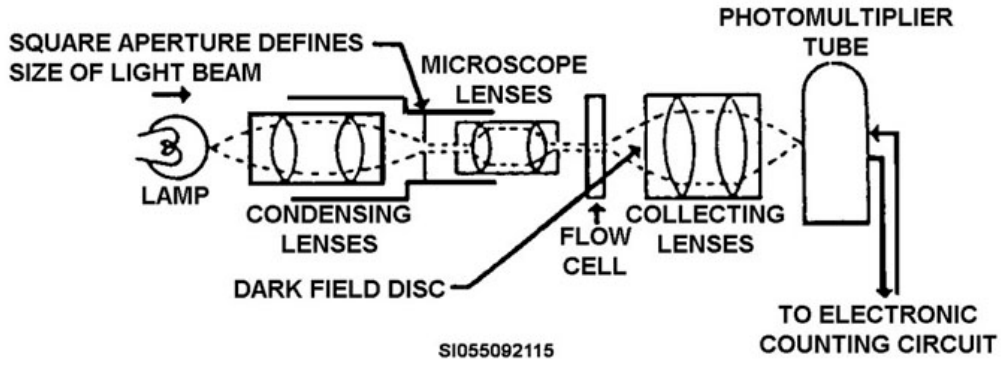

Figure 3–5. Schematic of a photoelectric particle counting system.

Impedance (resistance) counters

If a suspension of erythrocytes in an electrolyte is drawn through an aperture having electrodes on each side to form an electrical circuit, the system can be utilized to count the RBCs in suspension. As the blood cells pass through the aperture, the mass of the cell changes the resistance between the electrodes. This changing of the resistance alters the current flow and causes electronic pulses as a result of the variation in the field. The changes are amplified, inspected, and counted electrically. The end product is a number representing the number of blood cells in the sample being counted. By arranging the pulses, sampling volume, and sampling time, this device can be used to directly report the number of cells per cubic millimeter. Figure 3–6 is a schematic of the operation of one commercial instrument that counts blood cells by using the electronic principle of resistance change.

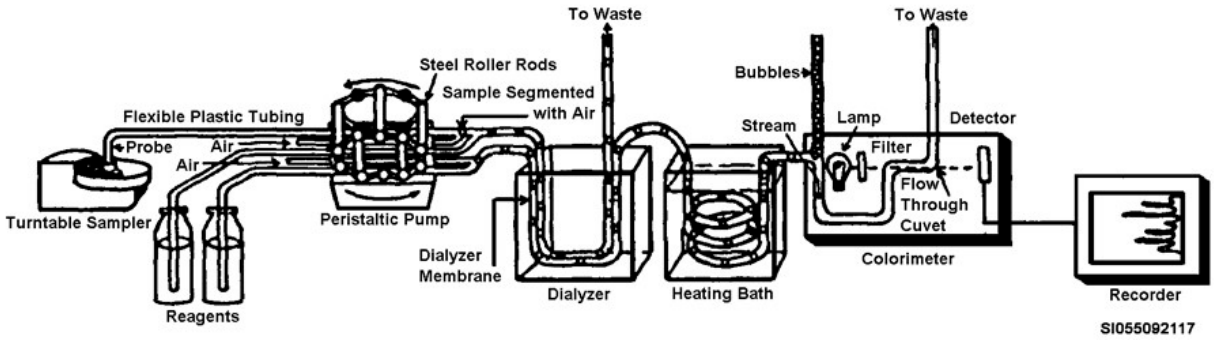

Figure 3–6. Schematic of resistance impedance of electronic counting apparatus.

When the valve is opened, the mercury falls, thus creating a vacuum in the sampler. This change in pressure causes cells in the sampler to be sucked through the aperture and into the sampler. The removal of cells from the sample causes a change in electrical conductivity between the two electrodes. This change is amplified and displayed on the scope. It is further amplified and registered on the digital counter. The higher the count, the greater the probability more than one cell will enter the aperture at one time (coincidence passage). For this reason, WBC counts over 10,000 and all RBC counts are corrected for coincidence passage.

Clinical applications

Automated and electronic equipment are used for enumerating (counting) the formed elements in the blood. They have several advantages over the hemacytometer techniques. They provide methods that have greater precision (reproducibility), as indicated by a lower coefficient of variation, and the capacity for completing a large quantity of determinations quickly and without increasing error due to fatigue. The cost of the electronic cell-counting instruments runs into several thousands of dollars.

Nevertheless, if a large number of determinations are to be made each day, the economic factors justify their use in the laboratory.

419. Blood gas analyzer

The blood gas analyzer is one of the cornerstone pieces of equipment in the medical laboratory. This lesson looks at clinical applications, electrodes, and the testing of blood properties.

Clinical applications

The past 20 years have seen a rapid development in blood gas analyzers. Not only does the newest generation of blood gas analyzers accurately and reliably measure pH, partial pressure of carbon dioxide (PCO_2) and PO_2 on samples as small as 65 microliters (µl), but they are also able to self-calibrate and self-diagnose malfunctions, and have computer capability for measuring plasma bicarbonate, base excess or deficit, temperature corrections, and other algorithms. The combination of these measurements reflects many facts about what is happening in the body of the patient whose blood is under test.

Interfacing blood gas analyzers and computer systems allow patient data storage with analysis and "trending," as well as automated blood gas interpretation and billing. Often, the capability of manipulating the primary blood gas values of pH, PCO_2, and PO_2 exceeds clinical practicality. The purchase of a blood gas analyzer must depend primarily on the performance of the analyzer in basic blood gas measurements and secondarily on the manipulation of these measurements.

Proper care and operation of this system are extremely important; therefore, it is generally found in a location such as a medical laboratory or cardiopulmonary/inhalation therapy section where two or three primary operators are assigned to the unit. In some instances, you can find the system in intensive or cardiac care units, or possibly on the medical ward; these cases are exceptions to the rule.

Electrodes

Although there are numerous differences among manufacturers, all modern analyzers contain three electrodes: the pH (Sanz), PCO_2 (Severinghaus), and PO_2 (Clark).

pH electrode

It was discovered more than 70 years ago that if two solutions of different pH values are separated by a particular type of glass membrane, there will be a potential difference across the pH sensitive glass. If a solution of known pH (6.840) is separated by pH sensitive glass from a solution of unknown pH, a measurable voltage develops across the glass.

Chemical half-cells accurately measure the small potential differences accompanying blood pH variations. The reference electrode is usually composed of mercury-mercurous chloride (calomel)—a substance that supplies a constant reference voltage as long as the temperature remains stable. The measuring electrode is usually composed of a silver-silver chloride substance, whose function is to convey the potential difference across the glass membrane to the electronic circuitry.

The modern pH electrode has the measuring half-cell imbedded within a 6.840 buffer chamber. This half-cell and the adjacent sampling chamber are encased in a constant temperature environment. The reference half-cell is electronically connected to the measuring half-cell by a contact bridge—a potassium chloride (KCl) solution that completes the electronic circuit path. The KCl solution is protected from blood contamination by a membrane or various mechanisms, such as pinch valves and peristaltic pumps.

A clinical system for pH measurement must meet three criteria before considering it to be practical and applicable:

1. The blood sample must remain anaerobic.
2. The measuring cycle must require a minimal volume of blood.
3. It must maintain a constant temperature.

Figure 3–7 illustrates the typical design of a modern, ultramicro pH electrode referred to as the Sanz electrode. The pH sensitive glass has been rolled into a fine capillary tube allowing the necessary blood volume to be as small as 25 µl and remain anaerobic. The entire electrode is small enough to be contained in a thermostatically controlled environment to assure a constant temperature.

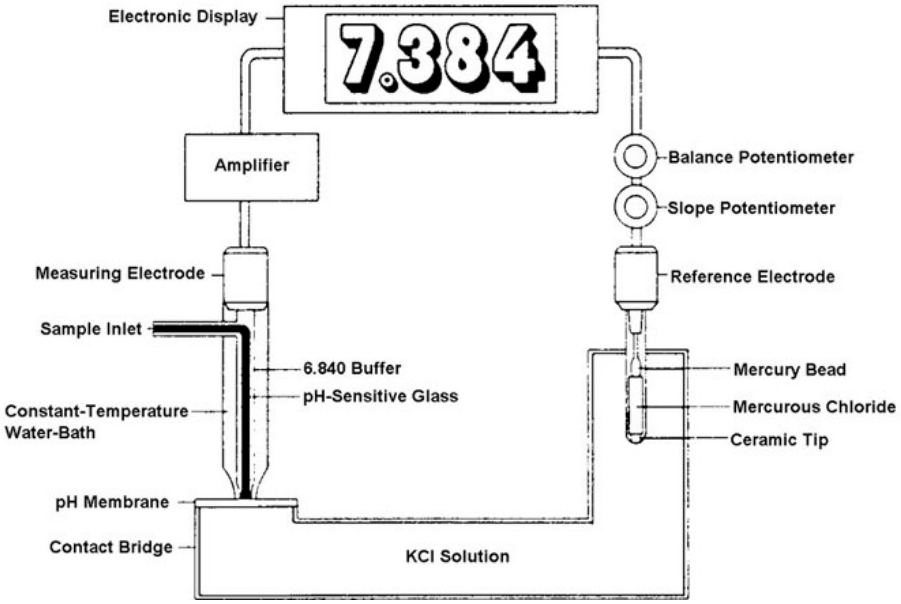

Figure 3–7. Illustration of an ultramicro pH electrode

PCO_2 electrode

Henry's law states that the amount of gas diffusing across a permeable membrane is directly proportional to the pressure gradient. As shown in figure 3–8 (A), if a CO_2 partial pressure gradient exists across a permeable membrane with an aqueous bicarbonate solution on the other side, CO_2 entering the solution undergoes the following chemical reaction:

$$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

The hydrogen ion concentration developed is directly proportional to the PCO_2 in contact with the membrane. When using aqueous bicarbonate chamber as the measuring half-cell, the pH change can be measured and utilized as an indirect measure of the PCO_2 of the blood.

A silicon elastic membrane separates the blood sample from the measuring half-cell (fig. 3–8, B). The pH-sensitive glass is separated from the membrane by a nylon spacer that allows an aqueous bicarbonate solution (electrolyte) to exist between the glass and permeable membrane. The measuring half-cell is silver-silver chloride, while the reference half-cell is another silver-silver chloride unit rather than calomel. The entire electrode is in a Lucite® jacket and bathed in an electrolyte solution. This electrolyte constantly replenishes the solution at the electrode tip and provides an electric contact bridge between the measuring and reference half-cells. The modern PCO_2 electrode was first introduced by Richard Stow and was further modified by John W. Severinghaus (commonly referred to as the Severinghaus electrode or Stow-Severinghaus electrode.

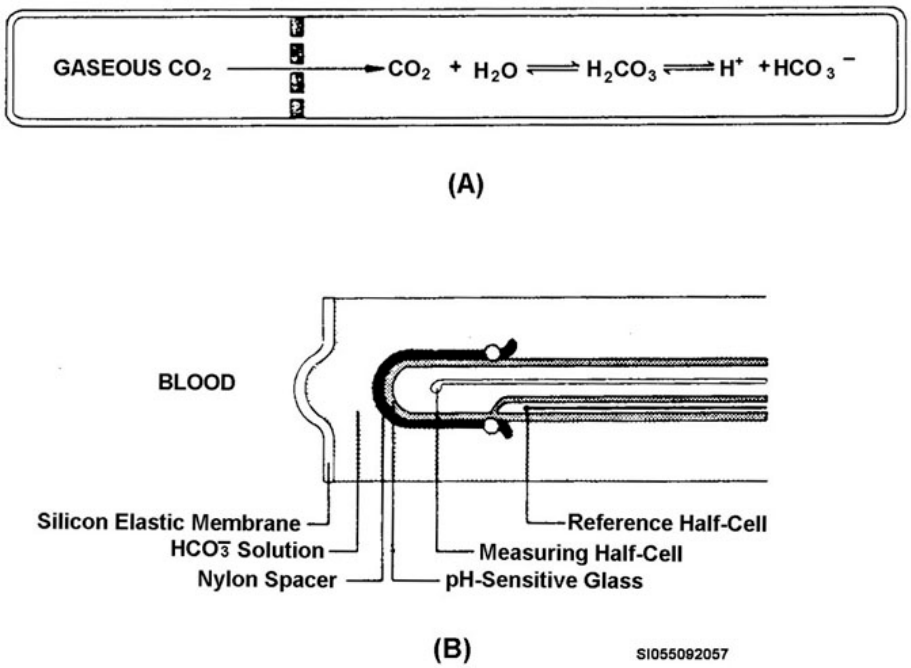

Figure 3–8. PCO_2 electrode.

PO_2 electrode

Gaining electrons in a chemical reaction is known as reduction and occurs at a cathode; the loss of electrons in a chemical reaction is known as oxidation and occurs at the anode. If O_2 is dissolved in an aqueous medium and exposed to a polarizing voltage at the cathode, the following reaction occurs:

$$O_2 = 2H_2O + 4 \text{ electrons (e-)} \longrightarrow 4OH^-$$

This chemical reduction of O_2 is the principle of the polargraphic electrode.

A silver anode immersed in a KCl electrolytic solution attracts anions (Cl-) to form silver chloride (AgCl) (fig. 3–9, A). This oxidation reaction produces a constant flow of current. An adjacent platinum electrode reacts chemically with O_2 to form hydroxyl ions (OH-)—a reduction reaction that uses electrons. In general, as electrons are consumed at the cathode, the anode reaction is accelerated.

Since the amount of O_2 reduced is directly proportional to the number of electrons used in the cathode reaction, we can determine the amount of O_2 in the electrode solution by measuring the change in current between the anode and cathode. An external polarizing voltage of approximately –0.6 volts is required to minimize the interference of other gases that can be reduced and to assure rapid O_2 reduction at the cathode.

The entire electrode system is usually covered by a polypropylene membrane, which allows a slow diffusion of O_2 from the blood into the electrode (fig. 3–9, B). A slow diffusing membrane is selected to prevent depletion of O_2 while the measurement is taking place. This negates the need for stirring the blood and significantly reduces electrode instability.

Although the first polargraphic electrodes were developed in the late 1930s, the development of the modern electrode is attributed to Leland C. Clark. For this reason, the PO_2 electrode is commonly referred to as the Clark electrode.

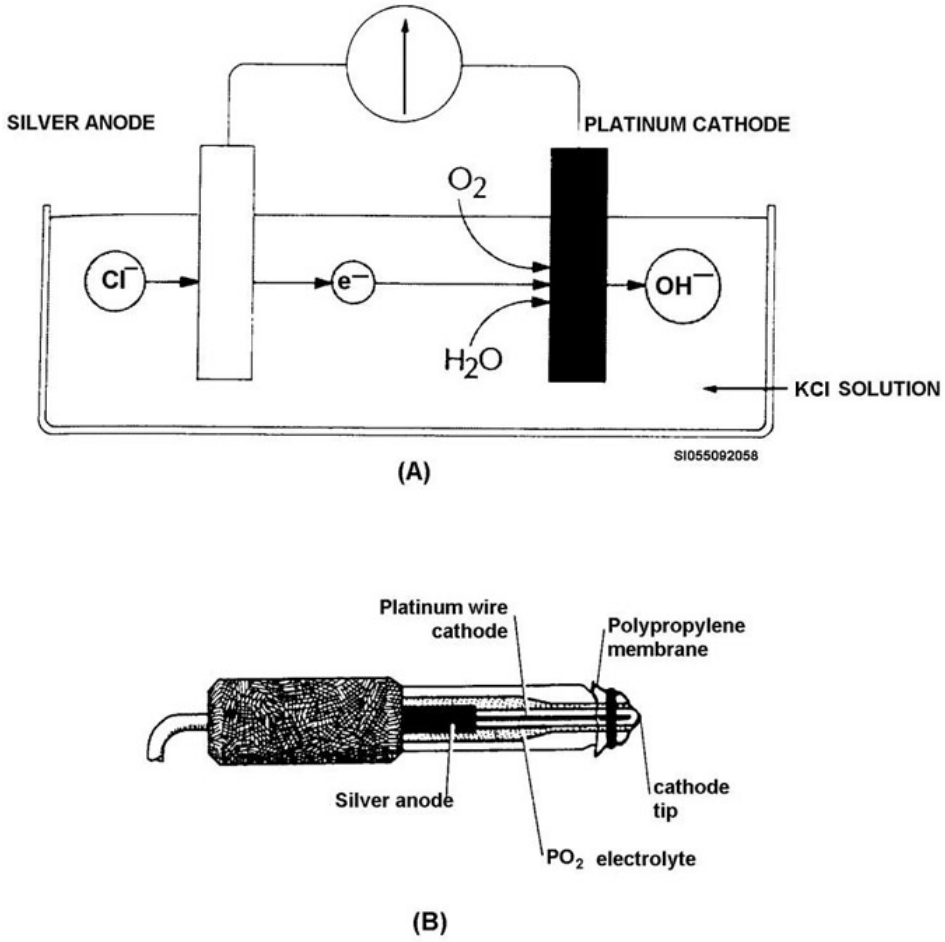

Figure 3–9. Polargraphic (Clark) electrode.

420. Chemistry analyzer

Clinical chemistry analyzers provide rapid analysis of serum/plasma for clinical chemistry analytes, such as electrolytes, glucose, Ca, and certain hematology values.

Methods of testing

There are three methods employed in chemistry analyzing:

1. Optical measurement – Every substance has a specific wavelength. Measuring the specific wavelength is measuring the specific substance. Photometers measure the amount of light transmitted through a sample. The principle is based on the Beer-Lambert Law, which states that a solution's absorbance of monochromatic transmitted light is proportional to the absorptivity, length of the light path, and concentration of the analyte in the solution. Reflectance photometry is employed by instruments that use dry reagent films and measure the amount of light reflected from the sample. This principle is based on the Williams-Clapper Formula, which is a derivation of the Beer-Lambert Law, but it pertains to reflectance instead of transmittance.
2. Electrochemistry – Ion-selective electrodes (ISE) measure analyte concentrations in solutions. These tests may be accomplished by dry and liquid reagent analyzers.
3. Kinetic assays – This technique measures the change in concentration of the monitored analyte over a given period of time, usually by making optical measurements during the reaction. Kinetic assays are commonly used to quantify enzymes.

These testing methods have been designed to be utilized in two ways—manually or automatically.

Manual

The term “manual” implies samples and reagent are manually inserted into the instrument for each test. This type of testing is accomplished through the use of dry reagent pads, films, or liquid reagents.

Batch analyzers

The instrument must be set up for each type of required test. Patient samples and standards are loaded onto a rotating tray. Then, the cycle is started and continues to completion without operator assistance. The instrument is then set up for the next procedure or next batch of samples. This system is considered manual because it requires set up by the operator and physical changing of the system to test for other items. It could easily be mistaken for automatic because once it is setup, it automatically tests all samples.

Automated chemistry analyzers

These units require the loading of the sample and the reagents, and starting of the unit. All dilutions, reactions, and measurements are done automatically. They can vary in size from single, one-shot instruments to large, multi-channel sequential analyzers. There are two types of automated chemistry analyzers: continuous flow and discrete.

Continuous flow analyzers

Continuous flow analyzers are instruments that continuously pump reagent through tubing and coils to form a flowing stream, and continuously pump samples into that stream (fig. 3–10). The essential part of a continuous flow system is a peristaltic pump composed of steel roller rods, which compress several pieces of plastic tubing by rolling on them. Fluids are drawn into the tubing and pushed through the system. Each test requires a manifold of plastic tubes—one for the sample and others for the reagents. The size of the inner diameter of the tubing employed determines the amount of each sample or reagent used.

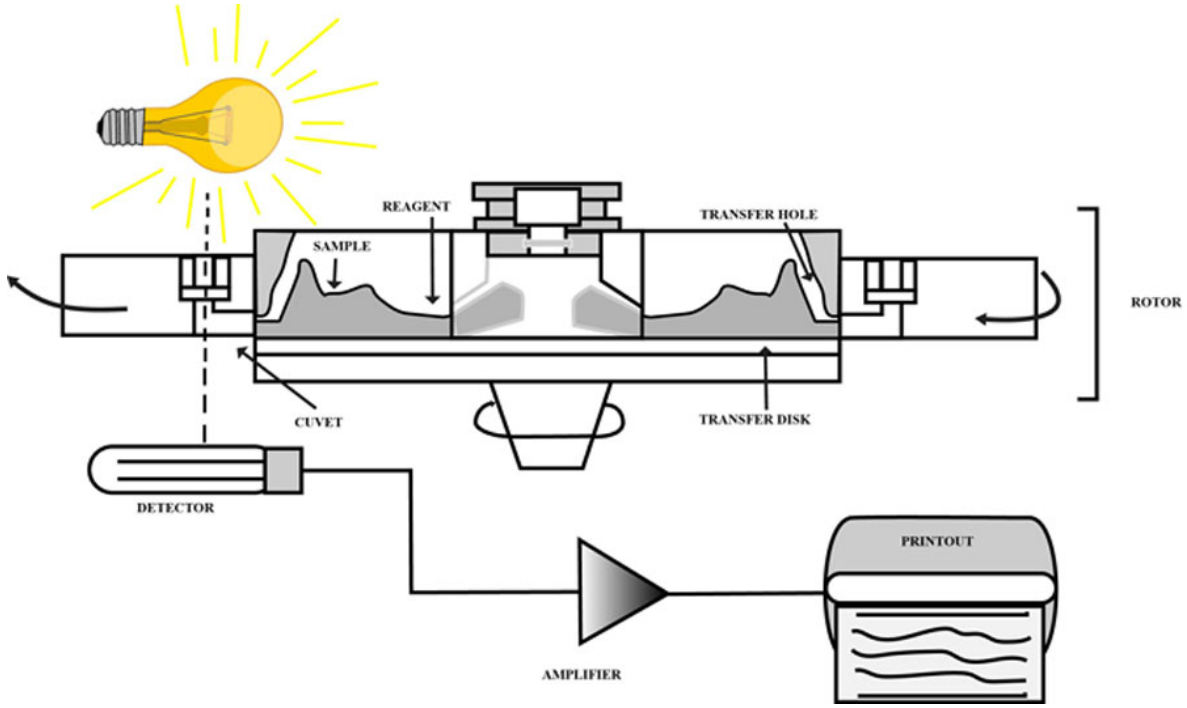

Figure 3–10. Illustration of a continuous flow system.

The samples are loaded into a rotating sample tray from which they are picked up in sequence by a probe attached to a manifold tube. Samples follow each other into the reagent streams, interspersed with a wash solution.

The success of the system depends entirely on small air bubbles injected into the sample and reagent streams at strategic points. These bubbles segment the stream and, through a squeeze-like action on the tubing, keep the segment intact. This ensures the sample does not mix with the one following it. Simultaneously, the efficiency of the mixing of reagents in each small segment is improved. Mixing is enhanced by directing the stream through glass coils. This creates a tumbling motion in each segment, resulting in the mixing of the reagents and sample. The description given thus far is used in all methods for introducing samples and reagents into the system. Following this, the stream flows through various fittings and modules designed to carry out the required chemical reactions and readings.

When deproteinization is required, the stream containing the sample is directed through a semicircular groove on one side of the dialysis membrane. A stream of recipient solution flows through a similar groove on the other side of the membrane. The solute that is of interest dialyzes into the recipient stream with the residual protein left behind.

If a period of time is required for a reaction to take place, the stream is directed through a time-delay coil. This coil is made of plastic or glass, the length and inner diameter of which determine the amount of time it will take the stream to pass through. If heating is required, a time-delay coil is immersed in a heating bath maintained at a desired temperature by a thermoregulator.

After the reaction is completed, the stream flows through an appropriate instrument for measurement. This usually is a spectrophotometer, photofluorometer, or flame photometer. A strip chart recorder pen is activated to give visual signals or peaks generated from the signals in these instruments. The size of these visual signals is related to the concentrations of the reactant in the samples. A series of standards accompanies each set of tests to give a standard curve. The concentrations of the tests are determined from a standard curve.

Discrete chemistry analyzers

Discrete analysis involves the treatment and measurement of samples in individual containers. Whereas the continuous flow system employs a proportioning system for measuring samples and reagents, discrete systems employ automatic pipetting devices. The samples are loaded into a sample tray and pipetted by the instrument into reaction tubes. The samples may be pipetted in sequence or in parallel, depending on the type of instrument used. The reaction tubes then move through various stations where more reagents are added and other operations are carried out, such as mixing and heating. A sample of the final solution is then removed automatically and measured using a spectrophotometer, photofluorometer, or flame photometer. The reaction vessel serves as a cuvette. The readout device may be a recorder or a printout of the final results.

The illustrated centrifugal fast analyzer in figure 3–11 differs from the types described in figure 3–10. In figure 3–11, the samples and reagents are measured by an automatic pipetter into separate compartments of a Teflon wheel (transfer disk). The disk is placed in the instrument where it rotates at a fixed speed. During the spinning period, the reagent flows by centrifugal force into the sample compartments. The treated samples then flow into cuvettes located in a rotor around the outside rim of the disk. The electronics of the instrument are designed so, as the cuvettes pass through the vertical light beam of a spectrophotometer, readings are made in rapid sequence and printed out as desired. This permits a single endpoint to be read a number of times or a kinetic reaction to be followed with almost continuous readings. This is only one style of discrete analyzer you will encounter.

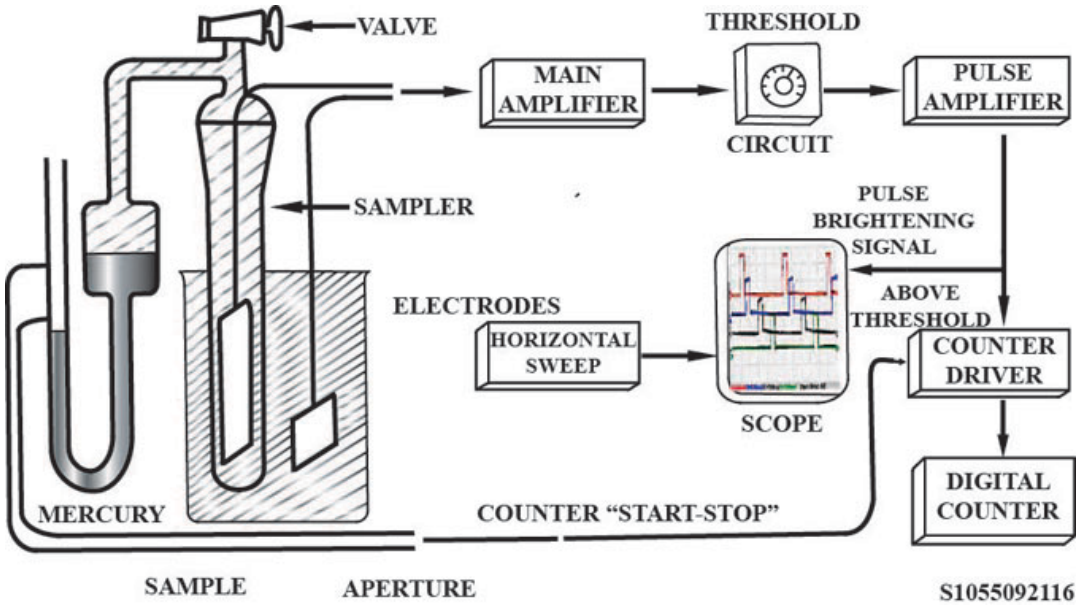

Figure 3–11. Illustration of a discrete type analyzer.

We use the automated discrete analyzer in larger MTFs. It can run up to 20 or more tests on an individual sample at rates of over 60 samples per hour (1,200 procedures per hour). All functions are controlled by a microcomputer. The system requires placing patient samples onto the rotary tray or belt, and "telling" the instrument what tests to run on each sample. The following table shows the advantages and disadvantages to this type of system:

Discrete Type Analyzer	
Advantages	• Better reproducibility than manual methods. • Lower operating costs (uses less reagent). • Saves operator time. • Can perform a variety of procedures very quickly.
Disadvantages	• Expensive. • Can be extremely complicated to operate due to many channels. • Upkeep and maintenance can be costly.

421. Electrolyte analyzer

Electrolyte levels must be tested when a person is sick or has a debilitating disease to ensure the body is maintaining a proper stasis.

Clinical applications

Electrolyte analyzers measure the important electrolytes in body fluids (serum and urine). Electrolytes are charged molecules or atoms (ions) that are essential for maintaining H_2O balance, acid-base balance, and overall balance of cellular function, since the body is made up of mostly H_2O.

The analyzer is designed to measure the following electrolytes as part of the normal electrolyte panel:

- Sodium (Na+) – Its normal serum level is 136-142 millimoles per liter (mM/L).
- Potassium (K+) – Its normal serum level is 4.0-4.8 mM/L.
- Chloride (Cl-) – Its normal serum level is 95-103 mM/L.
- Bicarbonate (HCO_3) – Its normal serum level is 24-30 mM/L.
- Lithium (Li+) – Its normal level 0.8-1.2 mM/L.

Other electrolytes (i.e., Ca and magnesium) exist but are not part of the routine electrolyte panel. Overall, the electrolytes should balance out as neutral (add all + and - ions).

Electrodes

ISEs are used in the clinical laboratory for the measurement of hydrogen (H+) ion, pH, Na+, K+, Ca++, fluoride (F-), and Cl-. Each electrode has a unique ion-selective phase intended to make the electrode respond to only one ion. However, interference ions do exist for all ISEs. A significant property of these electrodes is they are not absolutely specific. When dipped into a solution containing a specific ion, ISEs develop an electrical potential that is a function of the amount of that ion present. All ISEs require a reference electrode because two electrodes are required for any measurement. The unit will amplify and display the potential difference as compared to the reference electrode.

Na+

The Na+ electrode is used to measure the activity and concentration of Na+ in blood and urine. The Na+ electrode operates on the same principle as H+ ion electrode. The difference is in the contents of the glass membrane itself. Na+, as measured by ISEs, suffers from no interference of any significance in normal blood-derived samples. Along with ISEs, flame-emission photometry is another common way to measure Na+.

K+

K+ is measured similarly to Na+ using either ISE or flame-emission photometry methods. Although ISE is a less expensive route, urine K+ values greater than 50 milliequivalents per liter (mEq/L) in ISE may not be as reliable as compared to those using flame-emission photometry. This problem can be avoided by diluting urine samples that have such high values. A liquid ion-exchange membrane electrode using the antibiotic valinomycin as the K+ binder is most selective for K+.

Cl

Highly selective solid-state electrodes composed of AgCl were developed to measure Cl activities in serum and cerebrospinal fluid.

CO_2

HCO_3 is quantitatively the second most important anionic fraction in serum. CO_2 produced by cellular metabolism diffuses into the plasma and combines with H_2O inside RBCs to form H_2. The H_2 dissociates to form H+ and HCO_2. The CO_2 electrodes are ISEs placed behind a gas-permeable membrane. A typical CO_2 electrode consists of a pH electrode that has a flat surface, thin layer of a weak bicarbonate buffer, and silicone membrane covering the glass electrode surface.

The major advantage of such electrodes is that the measurement system is isolated from the sample and the reference; the electrode junction is inside the silicone membrane.

422. Deoxyribonucleic acid analyzer

While 99.9 percent of the deoxyribonucleic acid (DNA) from two people will be identical, it's the 0.1 percent of DNA code sequences that vary from person to person that make us unique. DNA testing is a powerful tool for identification and has many practical applications. Let's look at a few functions of a DNA analyzer.

Clinical application

Providers and researchers use DNA analyzers to identify a variety of characteristics within our genetic coding. Common uses include:

- Parental testing – To establish if someone is the biological parent of a child.
- Forensic testing – To help identify suspects or victims in a criminal investigation.
- Gene therapy – To test parents or fetuses for genetic conditions or birth defects.
- Genetic genealogy – To find out more about someone's ancestry.

Fragment analysis

Fragment analysis is a general term used to describe genetic marker analysis experiments which rely on detection of changes in the length of a specific DNA sequence to indicate the presence or absence of a genetic marker. Marker analysis is a general genetic technique in which the sequence of the gene is not directly analyzed, but the presence of a particular allele or mutant version of the allele of the gene is inferred from the presence or absence of a linked DNA sequence. This can serve as a marker for the allele. Using a marker analysis approach, we can trace inheritance patterns within a family and identify a mutant allele associated with a disease by comparing the alleles of affected and unaffected individuals. We can also trace inheritance patterns in populations of humans, animals, plants, and so forth, making genetic marker analysis quite useful in population biology and ecology studies.

We would use marker analysis instead of direct examination of a gene sequence for several reasons. A gene location may be known, but the gene sequence has not yet been determined and thus direct sequence comparison is not possible. If markers exist close to the gene locus, then the presence of mutant versions of the gene can be inferred through marker analysis. Marker analysis is much faster than direct gene sequencing. This is very helpful in population studies where the number of analyses needed can be very large.

Fragment analysis involves:

- Labeling oligonucleotides with fluorescent dyes or with a single dye. When using a labelled oligonucleotide, multiple different colored fluorescent dyes can be detected in one sample. One of the dye colors is used for a labeled size standard present in each sample. The size standard helps to extrapolate the base-pair sizes of the sample product peaks. When using a dye, you can visualize multiple fragments but only based on size
- Amplifying the fragments using polymerase chain reaction (PCR) on a thermal cycler.
- Separating the fragments by size using capillary electrophoresis.
- Analyzing the data using software to determine size and genotype.

DNA sequencing

Sequencing DNA means determining the order of the four chemical building blocks—called “bases”—that make up the DNA molecule. The sequence tells scientists the kind of genetic information that is carried in a particular DNA segment. For example, scientists can use sequence information to determine which stretches of DNA contain genes and which stretches carry regulatory instructions, turning genes on or off. In addition, and importantly, sequence data can highlight changes in a gene that may cause disease.

In the DNA double helix (fig. 3–12), the four chemical bases always bond with the same partner to form “base pairs.” Adenine (A) always pairs with thymine (T); cytosine (C) always pairs with guanine (G). This pairing is the basis for the mechanism by which DNA molecules are copied when cells divide, and the pairing also underlies the methods by which most DNA sequencing experiments are done. The human genome contains about 3 billion base pairs that spell out the instructions for making and maintaining a human being.

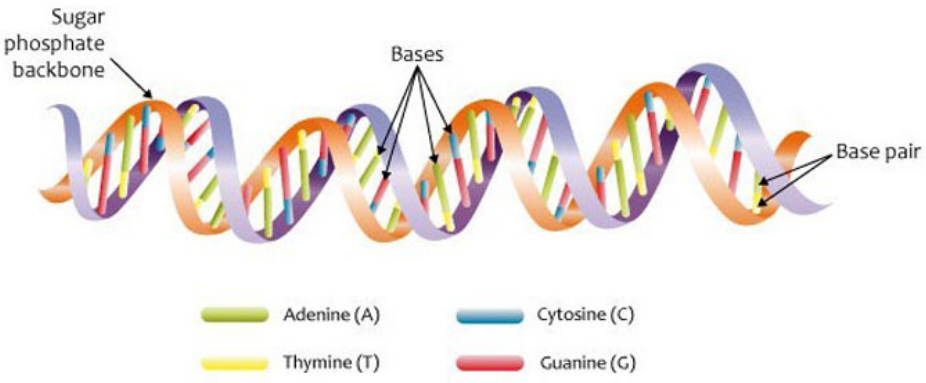

Figure 3–12. DNA double helix
(Licensed by CC-BY-2.0.)

Capillary electrophoresis

Historically, DNA sequencing products were separated using polyacrylamide gels that were manually poured between two glass plates. Capillary electrophoresis (CE) using a denaturing or non-denaturing flowable polymer has largely replaced the use of gel separation techniques due to significant gains in workflow, throughput, and ease of use. Fluorescently labeled DNA fragments separate according to molecular weight. Because you do not need to pour gels with CE, you can automate DNA sequence analysis more easily and process more samples at once.

During CE, the extension products of the cycle sequencing reaction enter the capillary as a result of electrokinetic injection. A high voltage charge applied to the buffered sequencing reaction forces the negatively charged fragments into the capillaries. Capillaries pass through the detection window, where the optical platform quantifies DNA fragments in real-time (fig. 3–13).

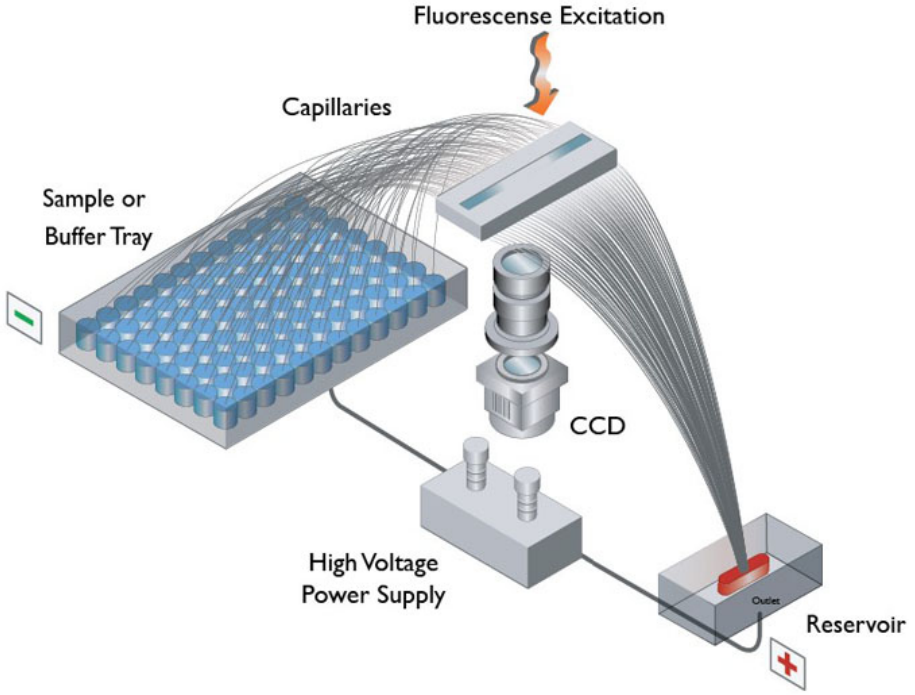

Figure 3–13. DNA analyzer capillary array.
(Copyright @ Advanced Analytical Technologies, Inc. 2017.)

Non-denaturing CE

Nucleic acid detection is accomplished with a rigorously designed optical platform comprised of an LED light source (470 nanometer [nm] excitation), camera lens, and charge-coupled device (CCD) detector. Fluorescent light passes from the LED through the array window. The emitted fluorescence from the intercalating dye then passes through the camera lens and specific band pass filters and spatially imaged onto the CCD detector. This system enables real-time detection of nucleic acid separations. Software converts the fluorescence signal to digital data, then records the data in a file. Because each dye emits light at a different wavelength when excited by the laser, we can detect and distinguish all four colors, and therefore all four bases, in one capillary injection.

Capillary arrays are the core of the DNA analyzer affecting all aspects of electrophoresis. Robust capillary array cartridges shorten time to results by reducing the amount of conditioning steps necessary between separation runs. This requires only a single conditioning step for multiple runs while maintaining resolution and quality

Denaturing CE

In denaturing CE, electrokinetically injected DNA fragments are separated by size through a denaturing gel polymer. Normally, a ladder is run in the same capillary as the fragments when fragment are being analyzed for size; while in sequencing, no ladder is used. For both fragment analysis and sequencing, the fragments are visualized based on the fluorescent label emission pattern. For sequencing, four different labels are required to visualize the four bases. With fragment analysis, up to five different labels can be used; this is called multiplex analysis. Post electrophoresis, data analysis software is used to evaluate the fragments and determine the DNA sequence.

423. Microscope

Similar to the slit lamp that we discussed in an earlier lesson, microscopes are effectively just tubes packed with lenses, or curved pieces of glass that bend light rays passing through them. The simplest microscope of all is a magnifying glass made from a single convex lens, which typically magnifies by about 5-10 times. Microscopes used in homes, schools, and professional laboratories are actually compound microscopes and use at least two lenses to produce a magnified image. There is a lens above the object (called the objective lens) and another lens near your eye (called the eyepiece or ocular lens).

The objective lens has a very small focal length, while the ocular lens (or eye piece) has a large focal length. The object under observation is placed on a platform of the microscope close to the objective lens, which makes an enlarged real image. This very image acts as an object for the eye lens, which in turn makes an enlarged virtual image. It is this virtual image that forms on the retina of the eye. Each lens, in fact, is made up of a series of different lenses. Most compound microscopes can magnify by 10, 20, 40, or 100 times, though professional ones can magnify by 1,000 times or more. For greater magnification than this, scientists generally use electron microscopes. Figure 3–14 shows the basic components of a compound microscope.

The ocular lens has interchangeable magnification properties of its own, generally five times (x) or 10x magnification. The total magnification strength multiplies the strength of the ocular lens with the strength of the selected objective lens. For instance, if you are using a 10x ocular lens and a 40x objective lens, then your viewing strength is essentially magnifying the object 400 times.

The light underneath the sample provides illumination for the sample with a light intensity control for optimal viewing conditions. More basic versions of a microscope will use an angled mirror that reflects ambient light or an external lamp source. When using a mirror setup, you can adjust the light intensity by adjusting the angle of the mirror. The condenser collects and then concentrates the light before passing it through the sample.

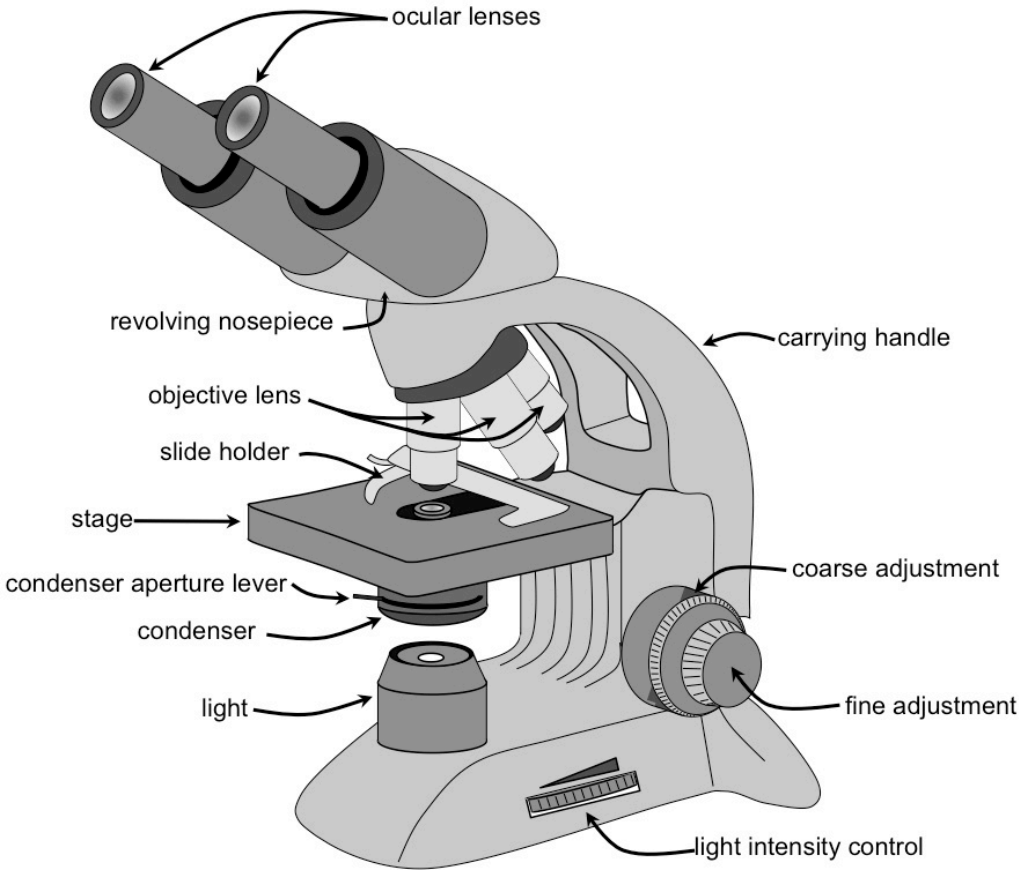

Figure 3–14. Parts of a microscope.
(Licensed by CC0 1.0.)

Course and fine adjustment controls change the distance between the stage and the objective lenses to bring the samples into view. Depending on your microscope, this is done by either raising or lowering the stage itself or the body tube which holds all of the lenses.

The following are common terms associated with microscope viewing properties:

- Depth of field – Vertical distance, from above to below the focal plane, that yields an acceptable image.
- Field of view – Area of the specimen that can be seen through the microscope with a given objective lens.
- Focal length – Distance required for a lens to bring the light to a focus (usually measured in microns).
- Focal point/focus – Point at which the light from a lens comes together.
- Magnification – Product of the magnifying powers of the objective and eyepiece lenses.
- Numerical aperture – Measure of the light-collecting ability of the lens.
- Resolution – The closest two objects can be before they're no longer detected as separate objects, usually measured in nm.

By using more lenses, microscopes can magnify by a larger amount but this doesn't always mean that you can see more detail. The amount of detail depends on the resolving power of a microscope or best resolution.

The resolving power of a microscope is ultimately limited by the wavelength of light (400-600 nm for visible light). To improve the resolving power, a shorter wavelength of light is needed, and sometimes microscopes have blue filters for this purpose (because blue has the shortest wavelength of visible light).

Light microscope

The light microscope, or compound microscope, is the oldest, simplest, and most widely-used form of microscopy. Specimens are illuminated with light, which is focused using glass lenses and viewed using the eye or photographic film. Specimens can be living or dead but often need to be stained with a colored dye to make them visible. Many different stains are available that stain specific parts of the cell such as DNA, lipids, cytoskeleton, and so forth. All light microscopes today are compound microscopes, which means they use several lenses to obtain high magnification. Light microscopy has a resolution of about 200 nm, which is good enough to see cells but not the details of cell organelles. There has been a recent resurgence in the use of light microscopy, partly due to technical improvements, which have dramatically improved the resolution far beyond the theoretical limit. For example, fluorescence microscopy has a resolution of about 10 nm, while interference microscopy has a resolution of about 1 nm.

Electron microscope

The electron microscope uses a beam of electrons, rather than electromagnetic radiation, to "illuminate" the specimen. This may seem strange, but electrons behave like waves and can easily be produced (using a hot wire), focused (using electromagnets), and detected (using a phosphor screen or photographic film). A beam of electrons has an effective wavelength of less than 1 nm, so it can resolve small sub-cellular ultrastructure. The development of the electron microscope in the 1930s revolutionized biology allowing us to see organelles such as mitochondria, endoplasmic reticulum, and membranes in detail for the first time.

The main problem with the electron microscope is that you must fix specimens in plastic and view them in a vacuum; therefore, we can only view dead specimen. Other problems are that the electron beam can damage specimens, and we must stain them using an electron-dense chemical (usually heavy metals like osmium, lead or gold).

There are two kinds of electron microscopes. The first is the transmission electron microscope (TEM), which works much like a light microscope, transmitting a beam of electrons through a thin specimen and then focusing the electrons to form an image on a screen or on film. This is the most common form of electron microscope and has the best resolution. The second kind is the scanning electron microscope (SEM), which scans a fine beam of electrons onto a specimen and collects the electrons scattered by the surface. This has poorer resolution but gives excellent 3-dimensional images of surfaces.

Microscope comparisons

The following chart will show some of the differences between functions of light microscope versus the electron microscope:

Feature	Light Microscope	Electron Microscope
Illumination and source	Light from lamp	Electrons from hot wire
Focusing	Glass lenses	Electromagnets
Detection	Eye or film	Phosphor screen or film
Magnification	1,500x	500,000 x
Resolution	200 nm	1 nm
Specimen	Living or dead	Dead
Staining	Colored dyes	Heavy metals
Cost	Cheap to expensive	Very expensive

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

416. Tissue processors

1. What are the four stages used in tissue processing?

2. What are the five major groups of fixative used to preserve tissue?

3. What is the most common form of fixative?

4. Water is removed from tissue through what process?

5. What is the final stage in tissue processing?

417. Centrifuge

1. Describe centrifugation.

2. Common laboratory centrifuges operate at approximately what speed?

3. Ultracentrifuges are used mostly in research labs for what purpose?

4. Cite two of the three devices that can be used to determine centrifuge rpm.

5. What is a blood cell washer used for?

6. What distinguishes a blood cell washer from other centrifuges?

7. What are the four stages in a wash cycle?

8. What are the concerns if a centrifuge or blood cell washer spins too slow or too fast?

9. Which kind of light does a non-contact laser tonometer use?

10. Explain how the tachometer measures rpm.

418. Electronic particle counter

1. Identify each of the column B items with the statements in column A. Each element in column B can be used once, more than once, or not at all.

Column A	*Column B*
____ (1) Based on the principle that blood cells are poor conductors of electricity and each passing cell momentarily decreases a flow of current between two electrodes.	a. Principle of resistance.
____ (2) As the diluted blood specimen enters the counting area, the sample is inspected by a reverse dark field microscope.	b. Impedance (resistance) counters.
____ (3) Scattering of the light beam due to the mass of each blood cell causes a light flash.	c. Devices with optical systems.
____ (4) As the blood cells pass through the aperture, the mass of the cell changes the resistance between electrodes.	d. Optical system.
____ (5) When the valve is open, the mercury falls, thus creating a vacuum in the sampler.	e. Coincidence passage.
____ (6) The higher the count, the greater the probability more than one cell will enter the aperture at one time.	

2. State the clinical application of the electronic particle counter.

419. Blood gas analyzer

1. What is the clinical application of a blood gas analyzer?

2. Upon what factors must you base the decision to purchase a blood gas analyzer?

3. Name the three electrodes common to all blood gas analyzers.

4. What is used to accurately measure the small potential differences accompanying blood pH variations?

5. What is the reference and measuring electrodes made of in a pH electrode?

6. What are the three conditions that a clinical measuring system must meet for pH measurement?

7. What is the principle gas law by which the PCO_2 electrode operates?

8. What is the measuring half-cell and reference half-cell composed of in a PCO_2 electrode?

9. Who first introduced and who further modified the modern PCO_2 electrode?

10. What is the principle of the polargraphic electrode?

11. What minimizes the interference of other gases that can be reduced in a polargraphic electrode?

12. Explain why a slow diffusing membrane is used to cover the PO_2 electrode.

13. To whom is the development of the modern PO_2 electrode attributed?

420. Chemistry analyzer

1. What are the three methods employed in chemistry analyzing?

2. What does a photometer measure?

3. What does a reflectance photometer measure?

4. What is the method used in measuring electrochemistry?

5. What does kinetic assays measure?

6. What does “manual” mean in reference to chemistry analyzers?

7. List the advantages and disadvantages of an automated discrete chemistry analyzer.

421. Electrolyte analyzer

1. What is the clinical application of the electrolyte analyzer?

2. For what are body electrolytes essential?

3. What electrolytes does a normal electrolyte panel test for?

4. What is required by all ISEs before a measurement will work?

5. What does the Na+ electrode measure?

6. What specific electrode measures K+?

7. What is the second most important anionic fraction in serum?

8. A typical CO_2 electrode consists of what?

9. What is the major advantage of ISEs?

422. Deoxyribonucleic acid analyzer

1. What percentage of DNA code sequences make us unique?

2. List the four common uses of DNA analyzers.

3. Explain what the term fragment analysis means.

4. Why would we use marker analysis instead of direct examination of a gene sequence in population biology and ecology studies?

5. What is DNA sequencing?

6. What are the two base pairs in a DNA double helix?

7. How many base pairs does the human genome contain?

8. What has largely replaced the use of gel separation techniques due to significant gains in workflow, throughput, and ease of use?

9. What components are used in nucleic acid detection?

423. Microscope

1. What is the simplest form of a microscope?

2. Explain the two types of lenses used in a microscope.

3. What is the magnifying strength of most compound microscopes?

4. If you are using a 5x ocular lens and a 40x objective lens, what is your magnification strength of the object?

5. What will a more basic version of a microscope use for sample illumination?

6. Explain the purpose of the condenser.

7. What determines the amount of detail that you can see in a microscope?

8. How does an electron microscope illuminate a specimen?

9. List the two types of electron microscopes.

3–3. Miscellaneous Support Equipment

Support equipment are valuable tools in any department, and often times can be the linchpin to the diagnostic equipment found throughout the MTF. The miscellaneous diagnostic support equipment found in this section support a mixture of clinics and departments. This section will highlight stress test systems and treadmills that support cardiac functions throughout the hospital, as well as fume hoods, which support many lab, pharmacy and dental sections.

424. Stress test systems and treadmills

In this lesson, you will learn about stress test systems and treadmills. We'll start off with some information about stress test systems, including the clinical applications; then, we'll explore more about treadmills.

Stress test systems

Some types of heart disease cannot be detected when a patient is at rest, because the patient's examination and ECG readings are entirely normal. However, when the patient's heart is stressed, such as during exercise, the problems become noticeable. In cases such as these, a cardiac stress test is performed using a stress test system. These systems are comprised of an exerciser (usually a treadmill or stationary bicycle), ECG with appropriate electrodes, computer, display, recorder, and printer.

Purpose of the test

We primarily use the cardiac stress test to diagnose coronary artery disease. This disease is basically a blockage in the coronary arteries, which supply blood to the heart muscle. If the patient has a partial blockage of the coronary arteries, the heart will likely get all the blood it needs when it is at rest. However, when the patient exercises, the partial blockage will keep the heart from receiving sufficient blood supply. When this happens, the heart muscle becomes ischemic (O_2 starved), the patient will experience chest pains (known as angina), and the ECG signal will also change accordingly. The cardiac stress test will allow the cardiologist to detect these problems brought on during exercise.

Cardiac stress testing can also help to determine the level of coronary artery disease. If a patient experiences problems at a very low level of exercise, it can be safely assumed there is significant blockage; however, if problems only occur during high levels of exercise, then the blockage is likely minor. Cardiologists may also perform the test periodically to assess the progression of a patient's coronary artery disease.

Finally, there are other problems the test will help to diagnose. For example, when a patient exercises, his or her adrenaline level naturally increases. This increased adrenaline level can sometimes cause certain arrhythmias. Again, this can only be detected during exercise.

Performing the test

To perform an exercise stress test, the patient is connected to the ECG leads. In addition, a blood pressure cuff is placed around the patient's arm and a pulse oximeter probe is placed on the finger. Before exercise begins, a baseline ECG, pulse rate, and blood pressure reading are obtained. Next, the patient begins an exercise routine that is graded—this means the workload is increased every three minutes. During each stage of the exercise routine, the patient's ECG, pulse, and blood pressure are recorded, along with any symptoms he or she is experiencing. The point at which the test is stopped depends upon which type of test is being performed.

Maximal stress test

In this test, the level of exercise gradually increases until the patient cannot keep up due to fatigue, or until symptoms, such as chest pain or shortness of breath, indicate the clinician should stop the test. The test may also be stopped if changes in the ECG signal indicate a problem. The maximal stress test is performed when the goal is to diagnose the presence or absence of coronary artery disease.

Submaximal stress test

In this test, the patient exercises until they reach a predetermined level. This test is performed on patients with known coronary artery disease; it will measure whether a specific level of exercise can be performed safely.

After either test is completed, the patient is monitored until any symptoms disappear, and the pulse rate, blood pressure, and ECG return to normal.

Test results

After performing a cardiac stress test, the unit analyzes the data from the ECG and prints a report. Like most other medical equipment, different stress test systems can perform different functions. While all systems will detect the ECG, others can perform more complex functions, such as automatically detecting arrhythmias or enlarging various parts of the ECG waveform. The cardiologist will analyze the results of the test to determine information about the patient's heart. The section can then print out the results from the test, or store them on a disk or other form of digital media.

If test results indicate a problem or are inconclusive, the physician can order further tests. One such test is a nuclear stress test. You will learn about nuclear medicine in the next volume of this CDC; in short, a radioactive substance is injected into a patient before they perform a stress test. Then, the physician will observe the flow of the substance by using a gamma camera. Next, the patient will begin exercising and a second injection of the radioactive substance will be given when a certain level of exercise is reached. After the exercise protocol is completed, the patient's heart will again be observed with the gamma camera. This test provides more information than the standard exercise stress test because it shows the actual flow of blood into the heart.

A second procedure that the doctor may order depending on the result of the stress test is cardiac catheterization. During this procedure, the doctor inserts a catheter into an artery or vein of the leg or arm. From there, the catheter is advanced to the coronary arteries and various tests can be performed, such as invasive blood pressure or injecting dye into the coronary arteries.

Treadmill

Now, you have learned all about the cardiac stress test, but we didn't cover very much about the actual stress test system. This is because the system itself is basically a fancy ECG that is computer controlled with some type of display and printer—covered thoroughly in the ECG lesson of the previous unit. However, there is one part of the system we haven't discussed—the exerciser. While some stress test protocols may call for the patient to ride a stationary bicycle, most call for the use of a treadmill so that is what we will focus on.

The treadmills used for cardiac stress testing are known as medical grade treadmills and, of course, cost significantly more than the one in your home gym. They also have many important features beyond an ordinary treadmill.

Treadmills used for cardiac stress testing are normally designed to interface with the rest of the stress test system through a serial data cable or other form of modern data transfer cable. This allows the physician to remotely control the treadmill while observing the readout. During the test, the doctor can increase and decrease the speed of the treadmill, and increase and decrease the incline.

Treadmills also have many extra features necessary due to the nature of their use. These units normally are larger and have a bigger walking/running surface for patient safety. They also have extended handrails and some type of safety switch that allows the patient or physician to immediately stop the treadmill at any sign of trouble. These units also have very accurate speed and incline controls, usually digitally controlled, to ensure test results are accurate. They also have very quiet motors to prevent disturbing other patients in the facility. Finally, these units may have a cushioned walking/running surface to decrease leg fatigue, and controls that allow the unit to start and stop very slowly and smoothly.

425. Fume hoods

A fume hood is typically a large piece of equipment enclosing five sides of a work area, the bottom of which is most commonly located at a standing work height.

Fume hood uses include:

- Protecting the user from inhaling toxic gases (fume hoods, biosafety cabinets, and glove boxes).
- Protecting the product or experiment (biosafety cabinets and glove boxes).
- Protecting the environment (recirculating fume hoods, certain biosafety cabinets, and any other type when fitted with appropriate filters in the exhaust airstream).

The fume hood is often the primary control device for protecting laboratory workers when working with flammable and/or toxic chemicals. Secondary functions of these devices may include explosion protection, spill containment, and other functions necessary for the work within the device.

Design elements and components

The front of the unit is a sash window, usually in glass, able to move up and down on a counterbalance mechanism. On educational versions, the sides and sometimes the back of the unit are also glass, so that several pupils can look into a fume hood at once. Low air flow alarm control panels are common.

For exceptionally hazardous materials, an enclosed glovebox may be used, which completely isolates the operator from all direct physical contact with the work material and tools. The enclosure may also maintain a negative air pressure to ensure that nothing can escape via minute air leaks.

One of the most important design features of a chemical fume hood is the entry. Basic principles of aerodynamics promote a smooth flow of air into the hood. The sides and the sill are shaped similar to the leading edge of an airplane wing (airfoil) to guide the airstreams into the hood with minimum turbulence. The idea is to maintain a laminar, attached flow. The sill is also raised slightly off the bottom or floor of the hood to create an air stream across this surface. Since a smooth entry is vital, placement of the hood in the laboratory merits careful consideration. They should not reside near doors, busy walkways, or near room air supply or return ducts. All of these can cause turbulence and disrupt laminar flow.

Another important design parameter is the velocity of the air flow entering the hood. The speed of the air needs to be just right. Too slow, and it will not pick up or push contaminates out. Too fast, and turbulence and eddies can lead to slipstreaming and dumping contaminates into the laboratory. The

air speed across the hood opening is referred to as “face velocity” and is a function of the total exhausted volume and the area of the opening. The basic relationship is velocity is equal to the volume divided by the area. So as the area increases, the velocity drops and vice versa. Also, if the volume reduces, so does the velocity. The hood sash, the sliding door or window on the front of the hood, controls the area open for flow and thus controls the face velocity. Different hood designs use this principle differently with the main types being standard hoods, bypass hoods, auxiliary air hoods, and variable air volume (VAV) hoods.

The third major design feature is the baffling or guiding of the hood flow. Chemical fume hoods can handle a wide variety of operations and contaminates. Typically, this is done with a series of baffles on the back wall and or top of the hood. These are slots with adjustable sliding covers, usually located near the bottom, center, and top of the hood’s back panel. By opening and closing the appropriate baffles, more flow can be guided across the bottom, in the center or towards the top of the hood.

Airflow into and within the hood should not be excessively turbulent, and hood face velocity should be adequate (typically 60-100 linear feet per minute [lfm]).

Types of fume hoods

There are two main types of fume hoods: ducted and recirculating (ductless). The principle is the same for both types; the unit draws air in from the front (open) side of the cabinet, and either expels it outside the building or makes it safe through filtration that feeds it back into the room.

Ducted

In most designs, the unit draws conditioned (i.e., heated or cooled) air from the lab space into the fume hood and then disperses it via ducts to the outside atmosphere.

The fume hood is only one part of the lab ventilation system. Because recirculation of lab air to the rest of the facility is not permitted, air handling units serving the non-laboratory areas are kept segregated from the laboratory units. To improve indoor air quality, some laboratories also utilize single-pass air handling systems, wherein the only use heated or cooled air once prior to discharge. Many laboratories continue to use return air systems to the laboratory areas to minimize energy and running costs, while still providing adequate ventilation rates for acceptable working conditions. The fume hoods serve to evacuate hazardous levels of contaminant.

To reduce ventilation energy costs, labs employ VAV systems, which reduce the volume of the air exhausted as the fume hood sash is closed. An automatic sash closing device will close the fume hood sash when the user leaves the fume hood face. The result is that the hoods are operating at the minimum exhaust volume whenever no one is actually working in front of them.

Since the typical fume hood in US climates uses 3.5 times as much energy as a home, the reduction or minimization of exhaust volume is strategic in reducing facility energy costs as well as minimizing the impact on the facility infrastructure and the environment. A major area of focus with ducted fume hoods is the exhaust discharge location, in order to reduce risks to public safety, and to avoid drawing exhaust air back into the building air supply system.

Ductless

Mainly for educational or testing use, these units generally have a fan mounted on the top of the hood or beneath the worktop. The unit sucks air through the front opening of the hood and then through a filter, before passing through the fan and feeding back into the workplace. With a ductless fume hood, it is essential that the filter medium be able to remove the particular hazardous or noxious material being used. As there are specific filter requirements for different materials, you should only use recirculating fume hoods when the hazard is well known and does not change.

Air filtration of ductless fume hoods is typically broken into two segments: pre-filtration and main-filtration.

Pre-filtration

This is the first stage of filtration and consists of a physical barrier, typically open cell foam, which prevents large particles from passing through. Filters of this type are generally inexpensive and last for approximately six months depending on usage.

Main filtration

After pre-filtration, the unit sucks fumes through a layer of activated charcoal which absorbs the majority of chemicals that pass through it. Ammonia and carbon monoxide will, however, pass through most carbon filters. Additional specific filtration techniques can help to combat chemicals that would otherwise pump back into the room. A main filter will generally last for approximately two years, dependent on usage.

Ductless fume hoods are often not appropriate for research applications where the activity, and the materials used or generated, may change or be unknown. A benefit of ductless fume hoods is that they are mobile, easy to install since they require no ductwork, and can be plugged into a 110 volt (V) or 220-V outlet.

Fume hood regulations

Because of the nature of safety hazards associated with fume hoods, they are one of the most highly regulated equipment items in the lab. The following table will outline a few of the governing bodies and their general area of responsibility concerning fume hoods:

Organization/Regulation	Area of Responsibility
Occupational Safety and Health Administration (OSHA): Code of Federal Regulations Volume 29 Part 1910.1450, Occupational Exposure to Hazardous Chemicals in Laboratories.	This code addresses several aspects of laboratory design and operation. Regarding hoods, it is primarily concerned with airflow at the face of the hood, monitoring, maintenance, and exhaust.
American National Standards Institute (ANSI) and the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE): ANSI/ASHRAE 110–1995, Method of Testing Performance of Laboratory Fume Hoods	This standard concerns itself primarily with methods of testing fume hoods to check their operation.
ANSI and the American Industrial Hygiene Association (AIHA): ANSI/AIHA Z9.5, Laboratory Ventilation Standard	This standard covers a variety of lab ventilation issues including hood monitoring, face velocities, and exhaust.
National Fire Protection Association (NFPA): NFPA 45, Standard on Fire Protection for Laboratories Using Chemicals	This standard recommends hood construction, location, fire protection, specialty hoods, identification, inspection, testing and maintenance and exhaust.
Scientific Equipment and Furniture Association (SEFA): SEFA 1.2–1996, Laboratory Fume Hoods Recommended Practices	This publication covers design requirements of hoods, face velocities and testing.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

424. Stress test systems and treadmills

1. Why is exercise stress testing performed?

2. What disease is cardiac stress testing primarily used to detect?

3. Briefly describe how an exercise stress test is performed.

4. What is the difference between a maximal and submaximal stress test?

5. Name two additional procedures the cardiologist may order based on the results of an exercise stress test.

6. How do treadmills interface with the stress test system?

425. Fume hoods

1. Name some of the common fume hood uses.

2. List some of the secondary functions of a fume hood.

3. Why would you use an enclosed glove box?

4. Where should you avoid installing a fume hood? Why?

5. What are the two main types of fume hoods?

6. What are the two types of air filtration used by ductless fume hoods?

Answers to Self-Test Questions

414

1. An instrument used to look within the body.
2. (1) Rigid.
   (2) Flexible.
3. (1) Through a natural body orifice.
   (2) Through a tiny surgical incision.
4. Any six of the following:
   (1) Arthroscopy – Joints.
   (2) Bronchoscopy – Trachea and bronchial tree.
   (3) Colonoscopy – Colon and large intestine.
   (4) Colposcopy – Vagina and cervix.
   (5) Cystoscopy – Bladder, urethra, urinary tract, and male prostrate.
   (6) Duodenoscopy – Duodenum.
   (7) EGD – GI tract.
   (8) Gastroscopy – Esophagus, stomach, and duodenum.
   (9) Laparoscopy – Stomach, liver, and female reproductive organs.
   (10) Laryngoscopy – Larynx.
   (11) Sigmoidoscopy – Rectum, colon, and large intestine.
   (12) Thorascopy – Pleura.
5. (1) Fiberoptic endoscopes.
   (2) Videoscopes.
6. (1) Control body.
   (2) Insertion tube.
   (3) Bending section at the distal tip.
   (4) Light-guide connector unit.
7. (1) Objective lens.
   (2) Telescope.
   (3) Light post.
   (4) Eyepiece.
8. Any four of the following:
   (1) Light source.
   (2) Camera.
   (3) Video processor.
   (4) Monitor.
   (5) Digital capture system.
   (6) Insufflator of fluid pump.
   (7) Operative instrumentation.
9. By transmitting light to the tip of the endoscope via a fiberoptic bundle.
10. By expanding the cavities with gas (CO_2) from an insufflator or clear fluid from a fluid pump.

415

1. To ensure there are no cracks, tears, or holes in the scope.
2. Because endoscopes are specialized and can be quite expensive; therefore, a department may not have a lot of endoscopes on hand and will need a rapid reprocessing turnaround.
3. (1) High-pressure steam.

(2) EtO gas.
(3) Plasma sterilization.
(4) Liquid chemical germicide.

4. (1) Each LCG must remain in contact with a scope's surface for a specific amount of time.
(2) Each LCG must remain at a specific temperature range to sterilize effectively.
5. High-level disinfection is the killing of all vegetative bacteria, fungi, and viruses, but possibly leaving some bacterial endospores. Sterilization is the killing of all microorganisms.
6. Any five of the following:
(1) Basin.
(2) Channel tubing with adapters.
(3) Electronics section.
(4) Fluid reservoir(s).
(5) Water filter.
(6) Fume containment.
(7) Alarms.
7. (1) Disinfecting.
(2) Rinse.
8. A soft cloth dampened with 70% isopropyl alcohol.
9. Increase the frequency of scheduled maintenance.
10. To filter the incoming potable water prior to reaching the unit.
11. A 0.1-micron pharmaceutical sterilizing-grade filter to provide filtered water to rinse processed instruments, as well as a sterile air filter.
12. Run a diagnostic cycle to ensure each component in the system is working as intended. Check that the unit passes through each stage at the appropriate time, and check for any water or air leaks during all cycle phases.

416

1. (1) Fixation.
(2) Dehydration.
(3) Clearing.
(4) Embedding.
2. (1) Aldehydes.
(2) Mercurials.
(3) Alcohols.
(4) Oxidizing agents.
(5) Picrates.
3. Formalin (10 percent formaldehyde in water).
4. Dehydration.
5. Embedding.

417

1. The process by which substances of different densities separate from one another by centrifugal force.
2. 3,000 rpm.
3. Separation of proteins and nucleic acids.
4. Any two of the following:
(1) Strobe light or Jaquet™.
(2) Worm gear.
(3) Vibrating reed tachometer.

5. To separate and prepare cells for *in vitro* diagnostic testing.
6. The wash cycle.
7. (1) Fill.
   (2) Spin.
   (3) Decant.
   (4) Agitate.
8. Spinning too slowly may give inadequate results, while spinning too fast may damage cell structures.
9. Infrared.
10. The infrared light from the tachometer falls on the surface and reflects back to the detector on the tachometer. The amplitude of the returning signal, reflected alternately by the object surface and the contrast spot, determines what a "pulse" is. The frequency of pulses per unit of time gives the speed of rotation of the object in rpms.

418

1. (1) a, b.
   (2) c.
   (3) c.
   (4) b.
   (5) b.
   (6) e.
2. Enumerating (counting) the formed elements in the blood.

419

1. Accurately and reliably measure pH, PCO_2 and PO_2 on samples as small as 65 µl, but they are also able to self-calibrate and self-diagnose malfunctions, and have computer capability for measuring plasma bicarbonate, base excess or deficit, temperature corrections, and other algorithms.
2. Primarily on the performance of the analyzer in basic blood gas measurements and secondarily on the manipulation of these measurements.
3. (1) pH.
   (2) PCO_2.
   (3) PO_2.
4. Chemical half-cells.
5. Mercury-mercurous chloride; silver-silver chloride.
6. (1) The blood sample must remain anaerobic.
   (2) The measuring cycle must require a minimal volume of blood.
   (3) It must maintain a constant temperature.
7. Henry's law, which states that the amount of gas diffusing across a permeable membrane is directly proportional to the pressure gradient.
8. Silver-silver chloride.
9. Stow; Severinghaus.
10. Chemical reduction of O_2.
11. An external polarizing voltage of approximately –0.6 volts.
12. To prevent depletion of O_2 while the measurement is taking place; this also negates the need for stirring the blood and significantly reduces electrode instability.
13. Clark.

420

1. (1) Optical measurement.
   (2) Electrochemistry.
   (3) Kinetic assays.

2. The amount of light transmitted through a sample.
3. The amount of light reflected from the testing sample.
4. ISE.
5. The change in concentration of the monitored analyte over a given period of time.
6. Implies samples and reagent are manually inserted into the instrument for each test.
7. Advantages include better productivity, lower operating cost, saves operator time, and can perform a variety of procedures very quickly.

   Disadvantages include expensive, can be extremely complicated to operate, and upkeep and maintenance can be costly.

421

1. Used to measure the important electrolytes in body fluids (serum and urine).
2. Essential for maintaining H_2O balance, acid-base balance, and over-all balance of cellular function.
3. Na+, K+, Cl-, HCO_3, and Li+.
4. Reference electrode.
5. The activity and concentration of Na+ in blood and urine.
6. A liquid ion-exchange membrane electrode using the antibiotic valinomycin as the K+ binder.
7. HCO_3.
8. A pH electrode that has a flat surface, thin layer of weak bicarbonate buffer, and silicone membrane covering the glass electrode surface.
9. The measurement system is isolated from the sample and the reference; the electrode junction is inside the silicon membrane.

422

1. 0.1%
2. (1) Parental testing.
   (2) Forensic testing.
   (3) Gene therapy.
   (4) Genetic genealogy.
3. Is a general term used to describe genetic marker analysis experiments which rely on detection of changes in the length of a specific DNA sequence to indicate the presence or absence of a genetic marker.
4. A gene location may be known, but the gene sequence has not yet been determined and thus direct sequence comparison is not possible. If markers exist close to the gene locus, then the presence of mutant versions of the gene can be inferred through marker analysis. Marker analysis is much faster than direct gene sequencing. This is very helpful in population studies where the number of analyses needed can be very large.
5. Determining the order of the four chemical building blocks—called “bases”—that make up the DNA molecule. The sequence tells scientists the kind of genetic information that is carried in a particular DNA segment.
6. Adenine (A) always pairs with thymine (T); cytosine (C) always pairs with guanine (G).
7. About 3 billion.
8. Capillary electrophoresis using a denaturing flowable polymer.
9. An optical platform comprised of an LED light source (470 nm excitation), camera lens, and CCD detector.

423

1. A magnifying glass made from a single convex lens, which typically magnifies by about 5-10 times.
2. There is a lens above the object (called the objective lens) and another lens near your eye (called the eyepiece or ocular lens).
3. 10, 20, 40, or 100 times, though professional ones can magnify by 1000 times or more.
4. 200 times.
5. An angled mirror, using the reflection of ambient light or an external lamp source.

6. It collects and then concentrates the light before passes it through the sample.
7. The resolving power of a microscope, or best resolution.
8. It uses a beam of electrons rather than electromagnetic radiation.
9. (1) TEM.
   (2) SEM.

424

1. Because some forms of heart disease cannot be detected when a patient is at rest.
2. Coronary artery disease.
3. The patient is connected to the ECG leads, blood pressure cuff, and pulse oximeter probe. A baseline ECG, pulse rate, and blood pressure reading are obtained before beginning the exercise. Next, the patient begins a graded exercise routine with the workload increasing every three minutes. During each stage of the exercise routine, the patient's ECG, pulse, and blood pressure are recorded, along with any symptoms he or she is experiencing. The point at which the test is stopped depends upon which type of test is being performed.
4. In a maximal stress test, the level of exercise increases until the patient cannot continue; in the submaximal test, the patient exercises until they reach a predetermined level.
5. (1) Nuclear stress test.
   (2) Cardiac catheterization.
6. Through a serial data cable or other form of modern data transfer cable.

425

1. Protecting the user from inhaling toxic gases, protecting the product or experiment, and protecting the environment.
2. Explosion protection, spill containment, and other functions necessary for the work within the device.
3. For exceptionally hazardous materials, which completely isolates the operator from all direct physical contact with the work material and tools. The enclosure may also maintain a negative air pressure to ensure that nothing can escape via minute air leaks.
4. Near doors, busy walkways, or near room air supply or return ducts. All of these can cause turbulence and disrupt laminar flow.
5. (1) Ducted.
   (2) Recirculating or ductless.
6. (1) Pre-filtration.
   (2) Main-filtration.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

61. (414) What are the two *basic* ways a scope is introduced into the body?
    a. Natural body orifice and major surgical incision.
    b. Natural body orifice and tiny surgical incision.
    c. Skin graft and major surgical incision.
    d. Skin graft and tiny surgical incision.

62. (414) The four *basic* parts of a *flexible* scope are the control body, insertion tube, bending section at the distal tip, and
    a. light-guide connector unit.
    b. light source.
    c. insufflator.
    d. monitor.

63. (414) The *most fragile* part of a rigid endoscope is the
    a. objective lens.
    b. light post.
    c. telescope.
    d. eyepiece.

64. (415) What is *not* a basic feature found on an automated scope processor?
    a. Basin.
    b. Alarms.
    c. Monitor.
    d. Water filter.

65. (416) The four stages in *automated* tissue processing are fixation, dehydration,
    a. clearing, and decalcification.
    b. clearing, and embedding.
    c. staining, and embedding.
    d. staining, and clearing.

66. (416) What is the *most common* form of fixative?
    a. Mercurial.
    b. Aldehyde.
    c. Formalin.
    d. Picrates.

67. (416) Paraffins are purchased according to level of hardness preferred and
    a. fire rating.
    b. climate.
    c. speed.
    d. cost.

68. (417) What is *not* a factor in developing centrifugal force?
    a. Distance from the center of rotation.
    b. Speed of rotation.
    c. Volume.
    d. Density.

69. (417) What does the centrifuge time include?
    a. Acceleration, time, and deceleration.
    b. Acceleration and time.
    c. Deceleration and time.
    d. Time only.

70. (417) The wash cycle in an automated cell washer takes *approximately*
    a. 10–15 seconds.
    b. 25–30 seconds.
    c. 35–40 seconds.
    d. 60–85 seconds.

71. (417) What does a non-contact tachometer use to measure the speed of rotation of a centrifuge?
    a. Red light.
    b. Infrared light.
    c. Ultraviolet light.
    d. Ultrasonic pulses.

72. (418) Complete blood cell counts are a function of
    a. kinetic assay.
    b. blood gas analyzers.
    c. electrolyte analyzers.
    d. electronic particle counters.

73. (418) What are two *automated* methods of counting blood cells?
    a. Optical and impedance.
    b. Optical and radioactive.
    c. Discrete and continuous.
    d. Impedance and radioactive.

74. (419) What is used to measure the small potential differences accompanying blood potential hydrogen variations?
    a. Cell half-life.
    b. Chemical half-cells.
    c. Electronic resistance.
    d. Electronic impedance.

75. (419) Who modified Richard Stow's work on the partial pressure of carbon dioxide electrode?
    a. Blaise Pascal.
    b. Leland Clark.
    c. William Henry.
    d. John Severinghaus.

76. (420) What are the three methods employed for chemistry analyzing?
    a. Electrochemistry, reagents, and standards.
    b. Radioisotopes, optical measurement, and staining.
    c. Optical measurement, kinetic assays, and radio tagging.
    d. Optical measurement, electrochemistry, and kinetic assays.

77. (420) Which equipment uses the principle of *reflectance*, instead of transmittance?
    a. Photometer.
    b. Spectrophotometer.
    c. Reflectance photometer.
    d. Reflectance spectrophotometer.

78. (420) Ion-selective electrodes are used with which method of chemistry analyzing?
    a. Photometry.
    b. Kinetic assay.
    c. Electrochemistry.
    d. Optical measurement.

79. (420) What are the two types of *automated* chemistry analyzers?
    a. Discrete and continuous flow.
    b. Batch and continuous flow.
    c. Individual and discrete.
    d. Individual and batch.

80. (421) Charged molecules or atoms essential for maintaining water balance, acid-base balance, and overall balance of cellular function are called
    a. nutrients.
    b. minerals.
    c. electrolytes.
    d. potential hydrogen.

81. (421) What material is used in the ion-selective electrodes for measuring chloride in serum?
    a. Mercury.
    b. Silver chloride.
    c. Silver-silver chloride.
    d. Ion exchange membrane with antibiotic.

82. (422) The percentage of DNA code sequences that vary from person to person and make us unique is
    a. 0.01 percent.
    b. 0.1 percent.
    c. 1.0 percent.
    d. 10 percent.

83. (422) In a deoxyribonucleic acid (DNA) double helix, which base pair would be a correct bond?
    a. Adenine (A) with thymine (T).
    b. Guanine (G) with thymine (T).
    c. Cytosine (C) with adenine (A).
    d. Thymine (T) with cytosine (C).

84. (423) What is the *minimum* number of lenses that a compound microscope uses to produce a magnified image?
    a. One.
    b. Two.
    c. Three.
    d. Four.

85. (423) The distance required for a microscope lens to focus light, usually measured in microns, is known as the
    a. focal length.
    b. field of view.
    c. depth of field.
    d. focal point/focus.

86. (423) What is needed to improve the resolving power of a microscope?
    a. Shorter depth of field.
    b. Higher lens magnification.
    c. Longer wavelength of light.
    d. Shorter wavelength of light.

87. (424) A cardiac stress test is *primarily* used to diagnose
    a. liver disease.
    b. kidney disease.
    c. stomach disease.
    d. coronary artery disease.

88. (424) What test is *not* obtained during an exercise stress test?
    a. Baseline electrocardiogram.
    b. Blood pressure.
    c. Temperature.
    d. Pulse.

89. (425) Which component of a fume hood is designed to guide the airstreams into the hood with minimum turbulence?
    a. Sash.
    b. Airfoil.
    c. Baffles.
    d. Plenum.

90. (425) The speed of air traveling across the opening of a fume hood is referred to as
    a. face velocity
    b. airfoil velocity.
    c. variable air flow.
    d. laminar flow speed.

Glossary

Abbreviations and Acronyms

λ	wavelength
°	degree
µl	microliter
A	adenine
AC	alternating current
AgCl	silver chloride
AIHA	American Industrial Hygiene Association
AM	amplitude modulation
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
AV	atrioventricular
aVF	augmented voltage foot
aVL	augmented voltage left arm
aVR	augmented voltage right arm
BIS	bispectral index
BMET	biomedical equipment technician
bpm	beats per minute
C	cytosine
Ca	calcium
CBC	complete blood count
cc	cubic centimeter
CCD	charged-coupled device
CCU	critical care unit/coronary care unit
CDC	career development course
CE	capillary electrophoresis
Cl	chloride
Cl-	anion
cm	centimeter
CO	cardiac output
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
CVP	central venous pressure

daPa	decapascal
dB	decibel
DC	direct current
DMLSS	Defense Medical Logistics Standard Support
DNA	deoxyribonucleic acid
DVD	digital versatile disc
ECG	electrocardiogram/electrocardiograph
ED	emergency department
EEG	electroencephalogram
EGD	esophageal-gastroduodenoscopy
EKG	electrocardiogram/electrocardiograph
ER	emergency room
ERV	expiratory reserve volume
EtO	ethylene oxide
F	fluoride
FCC	Federal Communications Commission
FECG	fetal electrocardiogram
FHR	fetal heart rate
FRC	functional residual capacity
G	guanine
GI	gastro-intestinal
H	hydrogen
H_2O	water
HCO_3	bicarbonate
HL	hearing level
HR	heart rate
Hz	Hertz
i	angles of incidence
i’	angles of reflection
IBP	invasive blood pressure
ICU	intensive care unit
IOP	intraocular pressure
IRV	inspiratory reserve volume
ISE	ion-selective electrode
IV	intravenous
K	potassium

KCl	potassium chloride
kHz	kilohertz
KVM	keyboard, video, mouse
L/m	liters per minute
LCG	liquid chemical germicide
LED	light-emitting diode
lfm	linear feet per minute
Li	lithium
LVDT	linear variable differential transformer
mA	milliampere
MAP	mean arterial pressure
mEq/L	milliequivalent per liter
MHz	megahertz
mL	milliliter
mm	millimeter
mM/L	millimole per liter
mmHg	millimeters of mercury
MTF	medical treatment facility
mV	millivolt
mW	milliwatt
N	nitrogen
Na	sodium
NCT	non-contact tonometry
NFPA	National Fire Protection Association
NIBP	non-invasive blood pressure
nm	nanometer
O_2	oxygen
OH-	hydroxyl ion
OR	operating room
OSHA	Occupational Safety and Health Administration
PAP	pulmonary artery pressure
PCG	phonocardiography
PCO_2	partial pressure of carbon dioxide
PCR	polymerase chain reaction
PCW	pulmonary capillary wedge
PFT	pulmonary function tester

pH	potential of hydrogen
PICU	pediatric intensive care unit
PM	preventive maintenance
PO_2	partial pressure of oxygen
PPE	personal protective equipment
psi	pounds per square inch
PTT	pure tone threshold
PVC	premature ventricular contraction/polyvinyl chloride
QRS	Q-wave, R-wave, and S-wave
RBC	red blood cell
RCF	relative centrifugal force
rpm	revolutions per minute
RV	residual volume
SaO_2	arterial blood oxygen saturation
SEFA	Scientific Equipment and Furniture Association
SEM	scanning electron microscope
SpO_2	oxygen saturation determined by pulse oximetry
SPR	scheduled parts replacement
SV	stroke volume
T	thymine
TEB	thoracic bioimpedance
TEE	transesophageal echocardiography
TEM	transmission electron microscope
TLC	total lung capacity
toco	tocodynamometer
TV	tidal volume
UPS	uninterruptable power supply
USB	universal serial bus
USCOM	ultrasonic cardiac output monitor
UV	ultraviolet
V	volt
VAV	variable air volume
WBC	white blood cell
WMTS	Wireless Medical Telemetry Service
x	times

Student Notes

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