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Blood Pressure, Heart Tones, and Diagnoses

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1. BLOOD PRESSURE

Fundamental to providing comprehensive care to patients is the ability to obtain an accurate medical history and carefully perform and interpret a physical examination. The optimal selection of further tests, treatments, and use of subspecialists depends on well-developed skills for taking patient history and a physical diagnosis. An important part of a normal physical examination is obtaining a blood pressure reading and auscultation of the heart tones, which both represent critical cornerstones in evaluating a patient’s hemodynamic status and diagnosing and understanding physiological and anatomical pathology.

Naive ideas about circulation and blood pressure date as far back as ancient Greece. It took until the 18th century for the first official report to describe an attempt to measure blood pressure, when Stephen Hales published a monograph on “haemastatics” in 1733. He conducted a series of experiments involving cannulation of arteries in horses and invasive direct blood pressure measurement; unfortunately, his method was not applicable for humans at that time. There were many subsequent contributions to the art of measuring and understanding blood pressure during the next two centuries. One of the greatest of these was described in a publication in Gazetta medica di Torino called “A New Sphygmomanometer” by Dr. Riva-Rocci in 1896; it is recognized as the single most important advancement in practical noninvasive methods for blood pressure estimation in humans.

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In 1916, French physician Rene Laennec invented the first stethoscope, which was constructed from stacked paper rolled into a solid cylinder. Prior to his invention, physicians around the world would place one of their ears directly on the patient’s chest to hear heart or lung sounds. After Dr. Laennec’s initial success, several new models were produced, primarily of wood. His stethoscope was called a “monaural stethoscope.” The “binaural stethoscope” was invented in 1829 by a physician named Camman in Dublin and later gained wide acceptance; in the 1960s, the Camman stethoscope was considered the standard for superior auscultation.

It is essential that health care professionals and bioengineers understand how these important diagnostic parameters are obtained, their sensitivities, and how best to interpret them.

1.1. Physiology of Blood Pressure

Blood pressure is the force applied on the arterial walls as the heart pumps blood through the circulatory system. The rhythmic contractions of the left ventricle result in cyclic changes in the blood pressure. During ventricular systole, the heart pumps blood into the circulatory system, and the pressure within the arteries reaches its highest level; this is called systolic blood pressure. During diastole, the pressure within the arterial system falls and is called diastolic blood pressure.

The mean of the systolic and diastolic blood pressures during the cardiac cycle represents the time-weighted average arterial pressure; this is called mean arterial blood pressure. Alternating systolic and diastolic pressures create outward and inward movements of the arterial walls, perceived as arterial pulsation or arterial pulse. Pulse pressure is the difference between systolic and diastolic blood pressures.
Blood pressure is measured in units called millimeters of mercury (mmHg). A "normal" systolic blood pressure is less than 140 mmHg; a "normal" diastolic blood pressure is less than 90 mmHg. Blood pressure higher than normal is called hypertension, and one lower than normal is called hypotension. Hence, normal mean arterial pressure is between 60 and 90 mmHg. Mean arterial pressure is normally considered a good indicator of tissue perfusion and can be measured directly using automated blood pressure cuffs or calculated using the following formulas:

\[
\text{MAP} = \frac{\text{DBP} + \text{PP}/3}{2} \text{ or } \text{MAP} = \frac{\text{SBP} + (2 \times \text{DBP})}{3}
\]

where PP = SBP - DBP; MAP is mean arterial pressure, DBP is diastolic blood pressure, PP is pulse pressure, and SBP is systolic blood pressure.

Blood flow throughout the circulatory system is directed by pressure gradients. By the time blood reaches the right atrium, which represents the end point of the venous system, pressure has decreased to approx 0 mmHg. The two major determinants of blood pressure are: (1) cardiac output, which is the volume of blood pumped by the heart per minute; and (2) systemic vascular resistance, which is the impediment offered by the vascular bed to flow. Systemic vascular resistance is controlled by many factors, including vasomotor tone in arterioles, terminal arterioles, or precapillary sphincters. Blood pressure can be calculated using the formula

\[
\text{BP} = \text{CO} \times \text{SVR}
\]

where BP is blood pressure, CO is cardiac output, and SVR is systemic vascular resistance.

Blood pressure decreases by 3–5 mmHg in arteries that are 3 mm in diameter. It is approx 85 mmHg in arterioles, which accounts for approx 50% of the resistance of the entire systemic circulation. Blood pressure is further reduced to around 30 mmHg at the point of entry into capillaries and then becomes approx 10 mmHg at the venous end of the capillaries.

The speed of the advancing pressure wave during each cardiac cycle far exceeds the actual blood flow velocity. In the aorta, the pressure wave speed may be 15 times faster than the flow of blood. In an end artery, the pressure wave velocity may be as much as 100 times the speed of the forward blood flow.

As the pressure wave moves peripherally through the arterial system, wave reflection distorts the pressure waveform, causing an exaggeration of systolic and pulse pressures. This enhancement of the pulse pressure in the periphery causes the systolic blood pressure in the radial artery to be 20–30% higher than the aortic systolic blood pressure and the diastolic blood pressure to be approx 10–15% lower than the aortic diastolic blood pressure. Nevertheless, the mean blood pressure in the radial artery will closely correspond to the aortic mean blood pressure.

1.2. Methods of Measuring Blood Pressure

Arterial blood pressure can be measured both noninvasively and invasively; these methods are described next.

1.2.1. Noninvasive Methods

1.2.1.1. Palpation

Palpation is a relatively simple and easy way to assess systolic blood pressure. A blood pressure cuff containing an inflatable bladder is applied to the arm and inflated until the arterial pulse felt distal to the cuff placement disappears. Then, the pressure in the cuff is released at a speed of approx 3 mmHg per heartbeat until the arterial pulse is felt again. The pressure at which the arterial pulsations start is the systolic blood pressure. Diastolic blood pressure and mean arterial pressure cannot be readily estimated using this method. Furthermore, the measured systolic blood pressure using the palpation method is often an underestimation of the true arterial systolic blood pressure because of the insensitivity of the sense of touch and the delay between blood flow below the cuff and the appearance of arterial pulsations distal to the cuff.

1.2.1.2. Doppler Method

The Doppler method is a modification of the palpation method and uses a sensor (Doppler probe) to determine blood flow distal to the blood pressure cuff. The Doppler effect is the shift of the frequency of a sound wave when a transmitted sound wave is reflected from a moving object. When a sound wave shifts (e.g., as caused by blood movement in an artery), it is detected by a monitor as a specific swishing sound. The pressure of the cuff, at which blood flow is detected by the Doppler probe, is the arterial systolic blood pressure.

This method is more accurate (less subjective) in estimating systolic blood pressure compared to the palpation method. It has also been quite a useful method in detecting systolic blood pressure in patients who are in shock, have low-flow states, are obese, or are pediatric patients. Disadvantages of the Doppler method include: (1) inability to detect diastolic blood pressure; (2) necessity for sound-conducting gel between the skin and the probe (because air is a poor conductor of ultrasound); (3) likelihood of a poor signal if the probe is not applied directly over an artery; and (4) potential for motion and electrocautery unit artifacts.

1.2.1.3. Auscultation (Riva–Rocci Method)

The auscultation method uses a blood pressure cuff placed around an extremity (usually an upper extremity) and a stethoscope placed above a major artery just distal to the blood pressure cuff (e.g., the brachial artery if using the cuff on the upper extremity). Inflation of the blood pressure cuff above the systolic blood pressure flattens the artery and stops blood flow distal to the cuff. As the pressure in the cuff is released, the artery becomes only partially compressed, which creates conditions for turbulent blood flow within the artery and produces the so-called Korotkoff sounds, named after the individual who first described them. Korotkoff sounds are caused by the vibrations created when blood flow in partially flattened arteries transforms from laminar into turbulent, and they persist as long as there is an increased turbulent flow within a vessel. Systolic blood pressures are determined as the pressures of the inflated cuffs at which Korotkoff sounds are first detected. Diastolic blood pressures are determined as the cuff pressure at which Korotkoff sounds become muffled or disappear.

Sometimes, in patients with chronic hypertension, there is an "auscultatory gap" that represents disappearance of the normal Korotkoff sounds in a wide pressure range between the systolic and the diastolic blood pressures. This condition will lead to inaccurately low blood pressure assessments. Korotkoff sounds