EXERCISE PHY. LAB. MANUAL G. Adams

CHAPTER 16

Resting Blood Pressure

Numerous researchers have reported an inverse (negative) relationship between physical activity or fitness and morbidity (disease rate) or mortality (death rate), not only from coronary heart disease[4,5,11,32,39,41,44] but from all causes.[5,6] Thus, physical activity and fitness are associated with a reduced risk of cardiovascular disease (CVD), as well as reduced deaths from CVD and all causes. In light of such evidence it seems prudent that the student of exercise physiology be knowledgeable about cardiovascular tests.

Blood pressure measurement is one of the most common clinical tests. It is recommended that all persons over 3 y of age check their blood pressure annually.[45,46]

Because blood pressure screening or monitoring is such an important part of many physical fitness clinics, the technique of measuring blood pressure should be learned by many types of allied health personnel. Dr. H. K. Hellerstein, a renowned cardiologist, speaking as a member of the American Medical Association's Committee on Exercise, said, "Certainly every physical educator should know how to take blood pressure and record it."[20] Additionally, every physical educator should know how to interpret blood pressure.

Purpose of Blood Pressure Measurement

Millions of Americans are hypertensive, with more men than women, until older adulthood, and more blacks than whites classified as hypertensive. *Primary hypertension* means that the cause of hypertension is not known; *secondary hypertension* means that it is caused by known endocrine or structural disorders.[1] Although the cause of hypertension (high blood pressure) in at least 90 % of adults is unknown, it is associated with a high risk for future cardiovascular morbidity and mortality.[15] Hypertensive persons are more likely to accelerate atherosclerosis (hardening of arteries) that may cause vascular occlusions and ruptures about 20 y earlier than in normotensives.[27] If there were obvious symptoms (e.g., pain, nausea) associated with high blood pressure, there would be less need to measure the actual pressure. However, high blood pressure may not be noticed outwardly until a fatal or near-fatal heart attack or stroke occurs. Thus, the primary clinical purpose of measuring blood pressure is to determine the potential risk of cardiovascular disease; if the pressure is high, then appropriate medications or lifestyle changes are recommended. Periodic monitoring of the blood pressure is done in order to check the efficacy of such recommendations.

Another purpose of measuring resting blood pressure is to establish a baseline by which to compare the effect of exercise on blood pressure. Thus, the effects of different types, intensities, or durations of exercise may be compared by noting their effects upon the baseline value. For example, blood pressure comparisons may be made between (1) static versus dynamic exercise, (2) different intensities of muscle actions (e.g., 30 % vs. 80 % maximal forces), and (3) short versus long durations of exercise.

Physiological Rationale

High blood pressure is unhealthy; blood pressure, per se, is not unhealthy. Without blood pressure there would be no blood flow. Blood pressure is primarily dependent upon the volume of blood and the resistance of the blood vessels. The blood pressure that is commonly measured is that of the arteries. Thus, blood pressure may be defined for laboratory purposes as the force of blood distending the *arterial* walls. Typically, the brachial artery is sampled because of convenience and its position at heart level. The brachial artery (Figure 16.1) is a continuation of the axillary artery and extends medially alongside the humerus; it gradually moves centrally as it nears the antecubital fossa (anterior crease of the elbow), where it divides into the radial and ulnar arteries.[22]

Korotkoff Sounds

The determination of blood pressure in the typical laboratory setting is based upon the sounds made by the vibrations from the vascular walls. These sounds are referred to as Korotkoff sounds (named after their discoverer in 1905) (Figure 16.2). In brief, when there is no blood flow (as when a tourniquet is applied), there will be no vibrations and thus no sound. Paradoxically, when there is completely nonobstructed flow of the blood, there is also no vibration and thus no sound; this is due to the streamlined flow of the blood. When blood flow is restricted by the application of a tourniquet or by any kind of pressure, and then gradually released, there will be a bolus of blood escaping at the peak point of blood pressure coinciding with left ventricular contraction (systole). This bolus of blood will cause vascular vibrations which result in a faint sound (phase 1); this is **systolic pressure.** As the restriction or pressure continues to be released, more blood escapes, causing even greater vibration and louder sounds. Phases 2

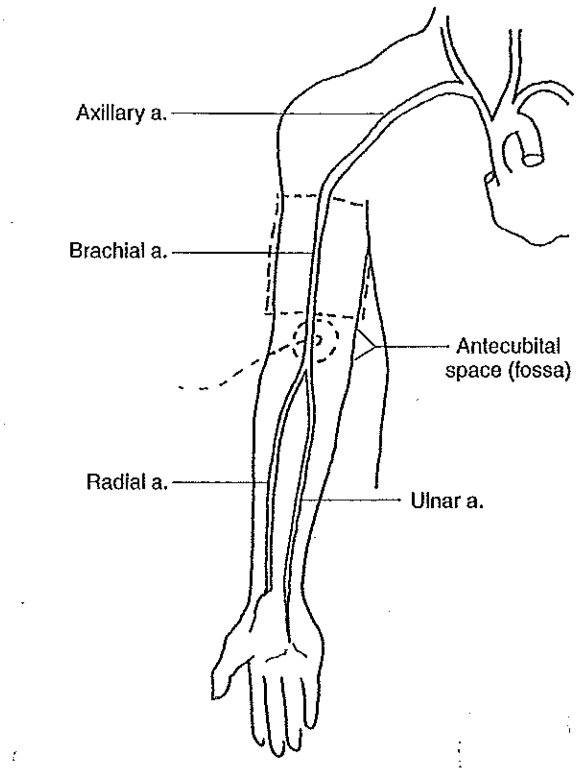

Figure 16.1 An internal view of the brachial artery and its origins and branches; the dotted diaphragm of the stethoscope is at the antecubital fossa (a. = artery).

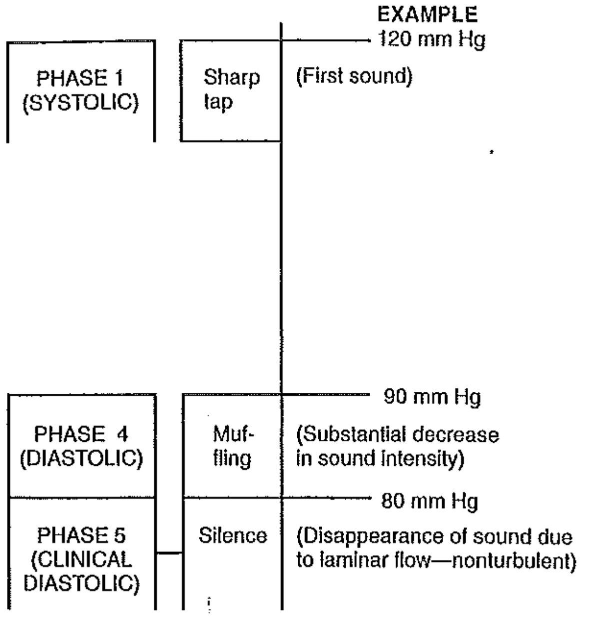

Figure 16.2 The three major phases of Korotkoff sounds when systolic pressure (first phase) is 120 mm Hg and diastolic pressures (fourth and fifth phases) are 90 and 80 mm Hg, respectively. Phase 2 (swishing sound) and phase 3 (crisp and intense) are not shown.

and 3 are not commonly used in recording blood pressures and, therefore, have been deleted in Figure 16.2. More blood escapes as the cuff pressure continues to decrease. However, after phase 3, as the blood flow becomes more streamlined due to less compression, there is a reduction of vibrations, causing a muffling sound (phase 4). The fourth phase is sometimes difficult to distinguish. The American Heart Association describes it as ". . . a distinct, abrupt, muffling of sound (usually of a soft, blowing quality) . . . ".[15] Identifying phase 4 is more difficult than identifying phase 5.[14] When blood flow is completely streamlined (laminar flow), there is a disappearance of sound (phase 5). The disappearance denotes **diastolic pressure,** the lowest pressure that exists in the arteries. However, the fourth phase is closer to the actual invasive diastolic pressure; hence, it is sometimes referred to as the true diastolic pressure. The fifth phase is often referred to as the clinical diastolic pressure because it is the reference for normative classification.

The Task Force on Blood Pressure Control in Children[45,46] recommends that both the point of muffling (phase 4) and the point of disappearance (phase 5) of the sound be recorded when taking blood pressure in children. Because of the frequency of these occurring simultaneously or of the fifth phase's not occurring at all in children, the Task Force and the American Heart Association use the fourth phase to interpret children's norms and the fifth phase for all persons above 12 y of age. Occasionally, phase 4 should be used for adults whose sounds remain very faint to near zero levels.[48] Usually, the fourth phase is significantly higher than the fifth phase by about 5 mm of mercury (Hg).[10] Rarely do true diastolic pressures reach less than 40 mm Hg.[12] Thus, for any person whose sounds can be heard below this level, it seems logical to use the fourth phase instead of the fifth phase as the true diastolic pressure. Exercise technicians are encouraged to practice recording the fourth phase in all persons because of the fourth phase's importance during exercise (Chapter 17).

Pulse Pressure and Mean Pressure

Pulse pressure (PP) is the difference between systolic and diastolic pressures. High pulse pressures—that is, large differences between SP and DP—may indicate increased risk of heart attack (myocardial infarction).[35] Pulse pressure reflects the vascular compliance (distensibility) in large arteries. Pulse pressure is used to calculate mean blood pressure (MBP).

MBP is based upon the actual pressure that the arteries would sustain if blood flow were not pulsating. Because arterial blood pressure under resting conditions is at systolic level only about one-twentieth of the time during a cardiac cycle, mean pressure is always closer to diastolic pressure than it is to systolic pressure. Resting MBP is usually estimated as one-third the distance between fifth-phase diastolic pressure and systolic pressure[43] (Eq. 16.1), or, similarly, by multiplying the difference between SP and DP—that is, PP, by 0.33[51] (Eq. 16.2). MBP is typically between 90 mm Hg and 100 mm Hg at rest.

$$MBP = (PP/3) + DP \qquad \text{Eq. 16.1}$$

where:

PP = pulse pressure; SP – DP

$$\text{Example: MBP (mm Hg)} = \frac{130 - 80}{3} + 80$$
$$= (50 / 3) + 80$$
$$= 17 + 80$$
$$= 97 \text{ mm Hg}$$

or:

$$MBP = (0.33 \times PP) + DP \qquad \text{Eq. 16.2}$$

$$\text{Example: MBP (mm Hg)} = [0.33 \times (130 - 80)] + 80$$
$$= (0.33 \times 50) + 80$$
$$= 17 + 80$$
$$= 97 \text{ mm Hg}$$

Method

The accuracy of blood pressure measurements is described in Box 16.1. Many types of instruments exist for measuring blood pressure. The original instrument in 1733, water in a glass tube, was used to measure the blood pressure of a horse.[3] Due to water's light weight (lower density) in comparison with mercury—the liquid now being used—a ladder was needed to enable the investigator to read the water column, which had risen about 10 ft. Mercury, being nearly 14 times heavier than water, enables the measurement of blood pressure with a glass tube, which can be about one-fourteenth the length of the original water-filled glass tubes. If we still used water to measure human blood pressure, the tube would have to be a minimum of six feet tall, and the column of water would oscillate by more than one foot with each heartbeat.[21]

The International System's unit of measure for pressure is the hectopascal. However, due to the traditional use of mercury in blood pressure instrumentation, the unit of measure for blood pressure recordings is millimeters of mercury (mm Hg; Hg = hydrargyrum; g = j sound). Regardless of the type of blood pressure method or instrument, the unit of measure remains mm Hg. The graduations on the sphygmomanometer gauge are in 2 mm divisions and extend to 300 mm Hg.

The methods of blood pressure measurement may be divided into two categories—invasive and noninvasive. The *invasive* method is the more valid of the two methods and is usually reserved for clinical settings or precise research investigations. A thin teflon tube, called an endhole catheter or cannula, is connected on one end to a pressure transducer. The sensor end of the catheter is inserted into the brachial artery or ascending aorta while the transducer end is connected to a recorder. Although the invasive method is accurate for mean and diastolic pressures in the ascending aorta,[16] it is expensive, elaborate, and traumatic, compared with the noninvasive method.

BOX 16.1 Accuracy of Blood Pressure Measurements

Validity

The cuff method of measuring systolic and fifth-phase diastolic blood pressure is usually lower than the more accurate invasive method of measuring blood pressure by about 10 mm Hg (8 %) and 5 mm Hg (6 %), respectively; the fourth phase, however, is not significantly different from the invasive measurement of diastolic pressure.[43] Thus, the fourth phase appears to be the most valid indicator of diastolic pressure, although the fifth phase is commonly used for calculating mean pressures during a resting body state.

Reliability

The ability of the human ear to hear sounds is dependent upon the frequency (Hz) and decibels (dB) of the sounds. Unfortunately, Korotkoff sounds are neither of high frequency nor high decibel—both being less than the optimal hearing of the human ear.[33] Acceptable reliability coefficients can be obtained for the test-retest values of systolic (r = .89) and diastolic (r = .83) blood pressures.[a] The diastolic values of the fifth phase may be more repeatable than those of the fourth phase due to greater difficulty in determining muffling points of fourth phases versus disappearance points of fifth phases. In fact, one investigator encourages the use of the fifth phase for this reason, although it may not be hemodynamically justified for all persons.[29]

[a]Adams, G. M. (1968). Blood pressure reliability in the elderly. Unpublished raw data.

Two major methods are used to measure *noninvasive blood pressure*—cuff manometry and ultrasound Doppler. The cuff manometry method uses an instrument called a sphygmomanometer (*sphygmo* = pulse; pronounced sfig-mo-ma-nóm-a-ter); it is more easily referred to as a manometer. Both aneroid and mercury methods of manometry require a cuff with an air bladder; thus, the method is sometimes referred to as the cuff method (Figure 16.3). Although aneroid manometers are not favored over mercury manometers,[1,24] if the aneroids are calibrated routinely (Box 16.2), they are acceptable. Validated electronic devices can be used also, but finger sphygmomanometers are not recommended.[24] The aneroid manometers use a metal bellows device that drives tiny gears that move the dial's pointers. Commercial electronic automated blood pressure instruments have not been endorsed by the American Heart Association, partly because of the difficulty in checking their accuracy and their infrequent use by health personnel. The safety and performance requirements of nonautomated[42] and automated[49]

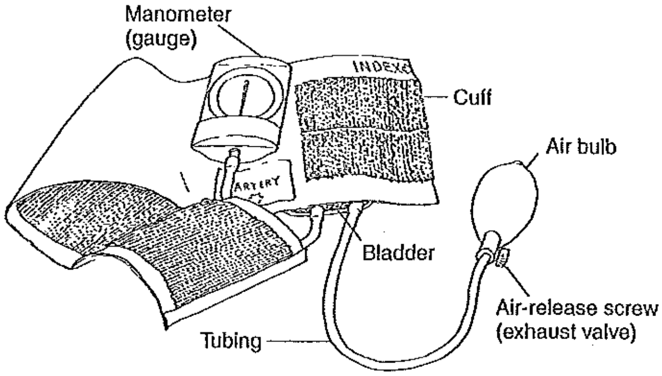

Figure 16.3 The main parts of an aneroid sphygmomanometer are the gauge, tubing, cuff, bladder, air bulb, and air-release screw.

sphygmomanometers have been reported by the American Standards Institute.

Mercury and aneroid sphygmomanometers require a stethoscope to auscultate the Korotkoff sounds; when this is done, the noninvasive method may be referred to as the **auscultatory method.** Surprisingly, experienced participants can sense their blood pressure fairly accurately while the technician or clinician is auscultating it.[13] Ambulatory blood pressure monitors can be programmed to take readings every 5 min to 120 min throughout a 24 h period. The pressures can be analyzed after being downloaded on a computer.[13]

Procedures

Certain preparations, such as calibration and participant orientation, should be made in order to facilitate blood pressure measurement. **Calibration** of aneroid manometers, using a mercury manometer, should be done at six-month[24,27] to annual[28,46] intervals (Box 16.2).

Participant orientation includes such preparatory rules that were suggested for the stepping test (Chapter 13) and cycling test (Chapter 14). Whereas those tests prescribed abstaining from smoking and caffeine for 3 h prior to testing, the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure prescribes only a 30 min abstention.[24] The participant should relax for at least five minutes in a comfortable environment prior to the blood pressure measurement.[15,24] Also, sleeveless shirts/blouses or loose-fitting sleeves are recommended attire; if the sleeve appears to fit tightly around the person's arm when the sleeve is rolled up, the shirt or sweater should be removed. The cuff and stethoscope should not be placed over cloth. Most of the following procedures for measuring blood pressure are the recommendations of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (1997).[24]

BOX 16.2 Calibration of Aneroid Sphygmomanometer

Assumption: The method of calibrating the aneroid sphygmomanometers assumes that the mercury sphygmomanometer is accurate. A good sphygmomanometer will not shift its indicating pointer or mercury column when the air-release screw is closed.

Zero

Most pointers on the dials of the aneroid sphygmomanometers are designed to rest at the zero when no air has been inserted into the bladder. However, some aneroid sphygmomanometers are not designed to return to the zero. Thus, the return of the indicator to zero is not an infallible criterion for accuracy in all aneroid manometers. Those that are designed to rest at zero should be returned to the manufacturer if they do not do so.

Range

Equipment: (1) Mercury sphygmomanometer; (2) a "Y" connector; the Y section joining the binaurals of some stethoscopes may be used; (3) a short (about 4 in.) piece of surgical tubing; (4) (optional) a can or bottle that approximates the circumference of a person's upper arm.

Configuration: (1) Wrap the cuff around the can or bottle; (2) connect the tube of the cuff's bladder to one end of the "Y" connector; (3) connect the tube of the mercury sphygmomanometer to another end of the Y; and (4) connect the tube of the air bulb to the third end of the Y connector (Figure 16.4).

Procedure: (1) Inflate the cuff's bladder until the aneroid dial reads 40 mm Hg; (2) read the dial on the mercury sphygmomanometer; (3) record actual mercury reading; (4) deflate the bladder; (5) repeat the same procedure at increments of 20 mm Hg; (6) if necessary, devise a mathematical correction based upon the readings or return the aneroid to the manufacturer if values disagree.

Procedural Steps

1. The participant should sit comfortably in a chair with a backrest for at least 5 min. The arm bared is at heart level and resting on the armrest of a chair or on a table (Figure 16.5).
2. The manometer should be clearly visible to the technician; mercury gauges should read so that the meniscus (top of mercury) is at eye level.
3. For persons with suspected small or large arm circumferences, the technician measures the circumference of the participant's upper arm.
   a. The appropriate cuff size is selected based on the arm circumference guidelines in Table 16.1.
   b. Some cuffs have index lines that indicate if the cuff is too small or too large (Figure 16.6). In general the *bladder* should wrap around at least 80 % of the arm.

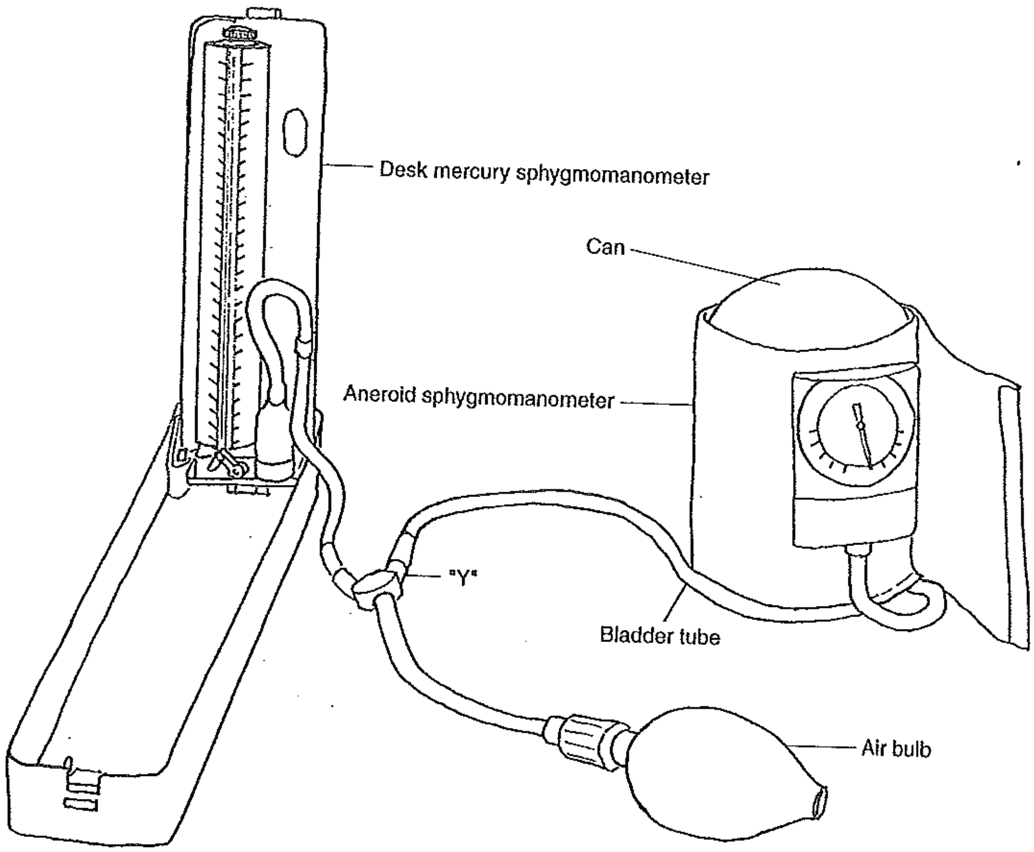

Figure 16.4 The configuration for aneroid sphygmomanometer calibration.

4. The technician snugly places the blood pressure cuff so that the lower edge is approximately 2.5 cm (1 in.) above the antecubital space.[30]
   a. The center of the bladder should be over the brachial artery.
   b. Some cuffs have a mark to line-up with the brachial artery. To assure alignment, it may be helpful to palpate the brachial artery along the medial side of the antecubital space.[15]
5. The technician places the diaphragm, or bell, of the stethoscope firmly, but not tight enough to indent the skin, over the nonvisible brachial artery in the antecubital space.
6. After turning the air-release screw clockwise, the technician quickly inflates the cuff to any of the three following levels:
   a. 160 mm Hg
   b. 20 mm Hg above expected or known SP
   c. 20 mm Hg to 30 mm Hg above the disappearance of the palpated radial pulse[15]
7. The technician turns the air-release screw counterclockwise so that the cuff pressure decreases at a rate of about 2 mm Hg to 3 mm Hg per second.[24]
8. The technician listens carefully and mentally notes the first Korotkoff sound of two consecutive beats—systolic pressure (first phase)—then fourth phase (muffling)—then fifth phase (disappearance)—at the nearest 2 mm mark on the manometer, respectively.
9. The technician continues listening for 10 mm Hg to 20 mm Hg below the last sound heard to confirm disappearance.
10. The technician rapidly deflates the cuff.
11. The technician records the values in even numbers according to the accepted format: e.g., systolic/fourth phase DP/fifth phase DP. Thus, a hypothetical recording would appear as 128/92/86 mm Hg.
12. The technician notes the presence or absence of auscultatory gaps and/or irregular pulse rhythm.
13. The technician repeats the measurement after 2 min, then averages the two readings unless they differ by more than 5 mm Hg—in which case, additional readings are made.[24,27] If more than two readings are necessary, the technician averages them all.
14. The technician uses the first and fifth phases to classify persons according to Tables 16.2 and 16.4.

Comments on Blood Pressure Procedures

Body and Arm Position

There is no *practical* difference in blood pressure measured in the seated position versus that measured in the supine position. However, *statistically,* slightly higher values occur for systolic (6 to 7 mm Hg) and diastolic (1 mm Hg) in the supine position.[31,47] The standing position increases diastolic pressure but not systolic pressure.[18]

The sitting position should automatically place the person's antecubital space of the arm at heart level. Blood pressures are higher if the arm is below the heart versus above the heart (nearly 1 mm Hg for each centimeter above or below heart level). Erroneously higher systolic and diastolic pressures occur if the arm is allowed to hang at the person's side rather than supported at heart level.[47]

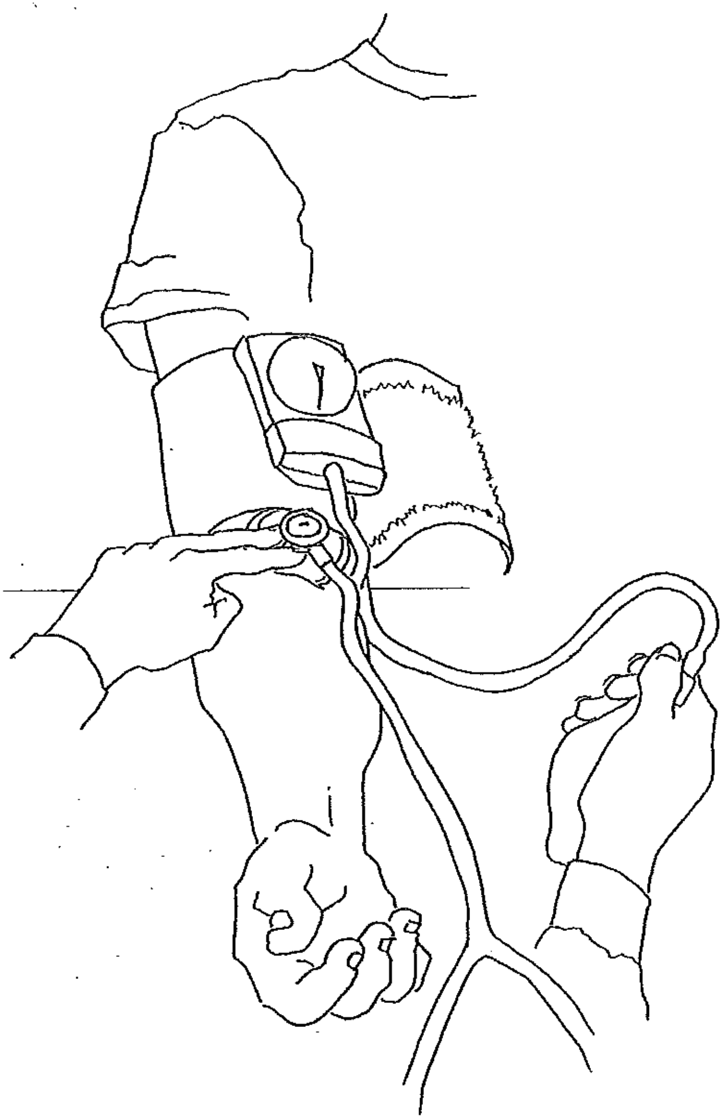

Figure 16.5 The bottom border of the cuff is placed about 1 in., or 2.5 cm, above the antecubital space and diaphragm of the stethoscope.

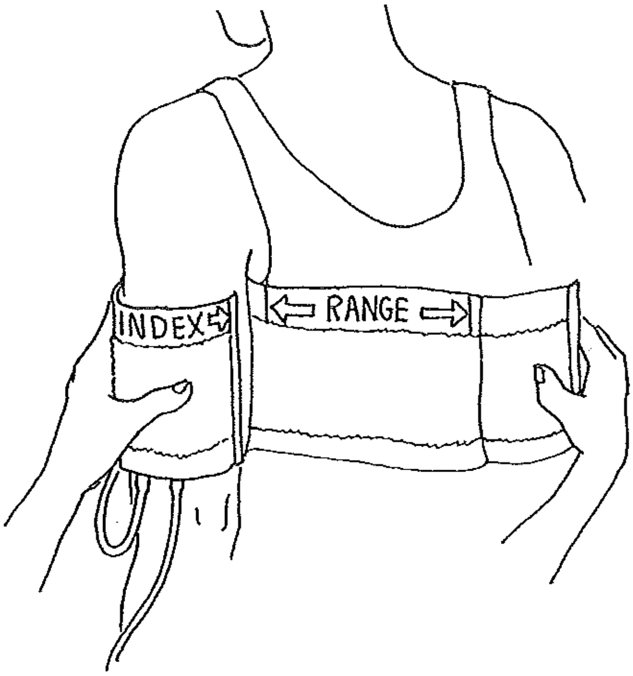

Figure 16.6 The cuff's index and range lines determine the appropriate cuff size for some sphygmomanometers.

Table 16.1 Guidelines for Type of Blood Pressure Cuff According to Limb Circumference (cir.)

Limb Size (cm)	Type of Cuff[a]	Bladder Size (cm)	
Upper Arm Cir.		Length	Width
32–42	Large adult	33 or 42	15
24–32	Adult (standard)	24	12.5
18–24	Child	21.5	10
	(3 y to 12 y)	18	8
Thigh Cir.			
42–50	Thigh	37	18.5

Note: [a]Other types of cuffs are newborn and infant.

Table 16.2 Blood Pressure (mm Hg) Criteria for Various Categories and Follow-Up Recommendations

Category	Criteria (mm Hg)		
	Systolic	Diastolic (5th phase)	Follow-Up
Optimal	< 120	< 80	Recheck in 2 y
High normal	130–139	85–89	Recheck in 1 y
Hypertension			
Stage 1	140–159	90–99	Confirm within 2 mo
Stage 2	160–179	100–109	Evaluate or refer to care within 1 mo
Stage 3	≥ 180	≥ 110	Evaluate or refer to care immediately or within 1 wk depending on clinical situation

Source: Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure. (1997). The sixth report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (JNC VI). NIH Publication No. 98-4080.

For best exposure of the antecubital position, it helps to have the person's palm upward with the thumb-side rotated outwardly (the anatomical position) and to have the arm nearly straight while resting on a platform (e.g., table). This provides the best contact with the brachial artery. The antecubital space should be left clear for the stethoscope's diaphragm.[7]

Various authorities recommend that the right arm be chosen for the blood pressure measurement.[8,46] This is partly because of the remote possibility that the genetic anomaly of coarctation (abnormal narrowing) between the aorta and subclavian artery will cause an elevated blood pressure. If the pressure in the right arm is normal, it is likely to be normal everywhere. However, higher right-arm values were not confirmed by some investigators,[10,17] nor did the investigators in the famous epidemiological study in Framingham, Massachusetts, measure blood pressure in the right arm.[25] In older patients, one group of investigators found that the systolic pressure in the right arm was not more than a few millimeters higher than in the left arm and that the diastolic pressure was virtually the same in both arms.[19] The American Heart Association recommends that both arms be measured at the initial examination and the arm with the higher pressure be measured in subsequent examinations.[15] Another consideration should be the comfort and convenience of both the technician and the participant.

Table 16.3 Age Prevalence Rates for Hypertension

	Percent
Total Adult Population[a]	25 to 33
Age-Specific Estimates[b]	
18 y to 29 y	4
30 y to 39 y	11
40 y to 49 y	21
50 y to 59 y	44
60 y to 69 y	54
70 y to 79 y	64
80+ y	65

Sources: [a]Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure. (1993). The fifth report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (JNCV). *Archives of Internal Medicine, 153,* 154–183. [b]National High Blood Pressure Education Program Working Group. (1993). Report on primary prevention of hypertension. *Archives of Internal Medicine, 153,* 186–208.

Cuff Size

Special cuff sizes are available for small or large arms. Cuffs that are too small will overestimate blood pressure, whereas cuffs that are too large will underestimate blood pressure. The average overestimation by narrow cuffs is about 9 mm Hg and 5 mm Hg for SP and DP, respectively.[36] The ideal cuff size is when the cuff is 20 % wider than the diameter of the arm and bladder length is 80 % of arm circumference.[24]

Some cuff manufacturers print a criterion index line by which to determine proper cuff size (review Figure 16.6). For example, the cuff is placed so that the vertical arrow printed on the cuff is over the brachial artery. After the cuff encircles the arm, the index line should fall within the two horizontal range lines, otherwise, the cuff is too small. These index lines can vary considerably among manufacturers. Thus, lab personnel are encouraged to mark a line on the interior surface of the cuff at a distance of 32 cm from the standard cuff's left border.[36] Table 16.1 provided the proper guidelines for cuff size. Either the larger or smaller cuff may be used for overlapping values found in that table. A distended, bulging, or balooning bladder is a sign that something is wrong with the manometer.

Controlling the Manometer and Stethoscope

No air spaces should be allowed between the skin and the diaphragm of the stethoscope. By not pressing heavily on

Table 16.4 Percentile Norms for Blood Pressure in Active Men and Women, Ages 20 y to 39 y

	Men				Women			
	Systolic		Diastolic		Systolic		Diastolic	
	Age (y)				Age (y)			
%ile	20–29	30–39	20–29	30–39	20–29	30–39	20–29	30–39
99th	94	96	60	60	90	90	56	60
90	110	108	70	70	99	100	63	65
80	112	110	72	74	101	104	68	70
70	118	116	78	78	106	110	70	70
60	120	120	80	80	110	110	72	74
50	121	120	80	80	112	114	75	76
40	128	124	80	81	118	118	78	80
30	130	130	84	85	120	120	80	80
20	136	132	88	90	122	122	80	82
10	140	140	90	92	130	130	82	90
1st	158	168	110	110	141	160	90	110
n	367	1615			118	301		

Source: Data from Pollock, M. L., Wilmore, J. H., & Fox, S. M. et al., *Health and Fitness Through Physical Activity,* 1978. Copyright © 1978 John Wiley & Sons, Inc., New York, NY.

the bell or diaphragm, the technician can avoid turbulent blood flow induced by the diaphragm. Turbulence can lower the diastolic pressure reading but is unlikely to distort systolic.[34] The technician should clear the cuff bladder's tubing away from the diaphragm because when they touch each other it sounds much like the Korotkoff sounds.

The technician should place the air bulb deep in the palm of the hand so that the thumb and index finger control the air-release screw. Although an effective method for knowing when to stop inflating the cuff is by palpating the person's radial artery, it can be an awkward procedure. The technician has to take one hand off the stethoscope's diaphragm while palpating the pulse. Often, technicians decrease the pressure too fast. Low systolic and high diastolic readings may occur when the rate of deflation is too fast.[15] Very slow deflation rates should be avoided in order to prevent prolonged discomfort, apprehensiveness, and fidgeting in the participant, all of which may increase the individual's blood pressure. If the person requires a repeated measurement for any reason, the pressure cuff should remain deflated for about 2 min between determinations.[24] This will allow the blood in the venous circulation to return to normal.[15]

The meniscus level (the peak of the "hump") at the top of the column of mercury is the measuring point when using **mercury** manometers. The indicating pointer is used for the **aneroid** gauge. If using the mercury manometer, the observer's eyes should be level with the meniscus in order to avoid parallax (angle distortion). When reading the aneroid dial, the observer's eyes should be directly in front of the gauge. Inexperienced technicians have a tendency to record pressures in deca-rounded numbers, such as 130/80/70.

Results and Discussion

The interpretation of blood pressure is based upon the criteria that have been established by various professional medical groups. These criteria are established from large-scale studies that indicate the norms for that particular population and/or subpopulation, such as, African Americans, males, females, and children.

Blood pressure criteria are based upon the contribution of blood pressure to the risk of death from cardiovascular disease—heart attacks, strokes, and congestive heart failure—and kidney damage, blindness, and dimentia.[24] The authoritative study groups on blood pressure such as the American Heart Association,[2] the Task Force on Blood Pressure,[45,46] the Joint National Committee,[24] and National High Blood Pressure Program[38] indicate that the criteria for systolic hypertension and diastolic hypertension are equally important. However, the Joint National Committee indicates that systolic pressure in older adults is a superior predictor of cardiovascular events.[24] Because blood pressure may be affected by nonpathological (nondisease) factors, such as emotions, it is recommended that no one be classified as hypertensive on the basis of only one day's measurements. A person should be classified as hypertensive only when measurements taken on two separate visits are over the established hypertension criteria.[24]

Hypertension The classification criteria listed in Table 16.2 are based on the Korotkoff sounds of the first and fifth phases. The criterion of 140/90 mm Hg is the recognized criterion for hypertension.[24,50] All that is necessary to meet the criterion is for either systolic or diastolic pressure to reach the respective value, not necessarily both of them. When only one of the pressures exceeds the criterion it is often referred to as *isolated* systolic (or diastolic) hypertension. Various authorities have suggested a category of high normal for younger persons with systolic pressure between 130 and 139 mm Hg, and diastolic pressure between 85 and 89 mm Hg.[24,26,45] The persons in the high normal category of Table 16.2 have an increased risk for future hypertension and target organ damage despite their seemingly benign blood pressures of 130–139/85–89 mm Hg.[24] Subdivisions of the hypertension category are Stages I, II, and III. Age prevalence percentages are presented in Table 16.3.[23,38]

Average BP The average pressures of over 5000 men, ages 20 y to 60+ y, who were tested at a fitness clinic were 125/82 mm Hg.[40] These values are probably less than in a random sample because they are men who have been tested at a fitness clinic, presumably with the intention of planning to exercise or to evaluate their existing exercise programs. The women's averages (119/78 mm Hg) are from the same investigators and include 914 active women the same ages as the men—that is, between 20 y and 60+ y.

Optimal BP Although the Joint National Committee[24] categorizes optimal as blood pressures < 120/< 80, the exact criteria for optimal SP and DP may not exist. For example, if the criteria were less than 120/80, then criteria would also have to consider the person's symptoms.[24] Thus, the lowest blood pressure may be the best as long as symptoms such as lightheadedness, dizziness, and/or faintness (syncope) are absent.

Hypotension There are no increased risks for cardiovascular disease in hypotensive persons; in fact, lower pressures reduce the cardiovascular risk.[15] A hypotension criterion of 90 mm Hg is meant only for systolic pressure; there is no accepted criterion for diastolic pressure with respect to hypotension, although less than 60 mm Hg is unusual.[37] As with optimal blood pressure, hypotensive criteria really should be based upon symptoms. Thus, if an individual is experiencing dizziness, syncope, coldness, pallor, nausea, low urine output, and high arterial blood lactates when blood pressure decreases to a certain point, then that point should be the criterion for hypotension for that person.[9]

Norms are based on the average and standard deviation of blood pressures from a large population. Norms for active persons of both sexes between the ages of 20 y and 39 y are found in Table 16.4.[40] In general, women have lower blood pressures than men; younger persons have lower pressures than older persons.

The *mean blood pressure* of 507 healthy men and women at an average age of 35 y (± 13.2 y) was 85 mm Hg (± 9.0).[52] These persons were sedentary and included 166 Blacks among the Whites. Their blood pressures were taken with a calibrated automated device.

Lifestyle Modification of Hypertension Prevention

The Joint National Committee lists seven lifestyle changes that could prevent or control hypertension.[24]

- Lose weight if overweight.
- Limit alcohol to one drink per day.
- Increase aerobic activity to 30 + min most days of the week.
- Reduce sodium to < 2.4 g/d or NaCl to < 6 g/d.
- Maintain dietary potassium of ≈ 90 mmol/d.
- Maintain dietary calcium and magnesium.
- Stop smoking and reduce saturated fat and cholesterol.

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Form 16.1

Individual Data for Resting Blood Pressure

Name ☐ Date ☐ Time ☐ A.M. ☐ P.M. ☐

Age ☐ y Gender (M or W) ☐ Ht ☐ cm Wt ☐ kg ☐ N Tech. Initials ☐

Meteorological Data

Temperature (*T*) ☐ °C RH ☐ % P_B ☐ mm Hg

Blood Pressure Data

Arm circumference ☐ cm Cuff type: Large adult ☐ Adult ☐ Child

Body position: Seated ☐ Supine ☐ Standing ☐ Arm: Rt ☐ Left ☐

Auscultatory Method of Sphygmomanometry

	Aneroid: (Rt. arm)	**(Left arm)**	**Mercury: (Rt. arm)**	**(Left arm)**
	1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg
Additional measurement If first two differ > 5mm Hg:		1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg
Average of two or more measurements:		1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg;	1st / 4th / 5th mm Hg

Auscultatory gap: ☐ Yes ☐ No Irregular pulse: ☐ Yes ☐ No %tile ☐ Table 16.4

PP = SP [1st] – DP [5th] = ☐ mm Hg (use highest average of arms)

MBP = [(SP [1st] – DP [5th])/3] + DP [5th] mm Hg

SP – DP (or PP)

= (☐)/3 + DP [5th]

(SP – DP)/3

= ☐ + DP [5th] = ☐ mm Hg

Form 16.2

Group Data for Resting (Sitting) Blood Pressure (mm Hg)

MEN

Initials	Systolic	Diastolic	
		4th	5th
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
M			
Minimum			
Maximum			

WOMEN

Initials	Systolic	Diastolic	
		4th	5th
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			
M			
Minimum			
Maximum			

CHAPTER 17

Exercise Blood Pressure

It is just as important to measure blood pressure at exercise as it is to measure heart rate. If only heart rate is measured, blood pressure is neglected as a contributor to the total power output of the heart. The consideration of both heart rate and blood pressure provides a better estimate of myocardial oxygen consumption than heart rate alone, and the calculation of the rate-pressure product provides an indication of the heart's power output.[10,37]

The measurement of systolic pressure during progressive exercise may provide input toward diagnosing heart disease[56] and may reveal potential problems in those persons who show exaggerated increases in exercise blood pressure despite being normotensive under a resting state.[18,35,36] Conversely, decreases in systolic blood pressure, despite increases in exercise intensity, may be clinically significant if accompanied by cardiac ischemia or pectoris angina (chest pain).[2]

The pulse pressure—the difference between systolic and diastolic pressure—provides the basis for calculating mean pressure at exercise (Figure 17.1). Last, the measurement of blood pressure during recovery from exercise may lead to the prevention of syncope (fainting) in the performer.

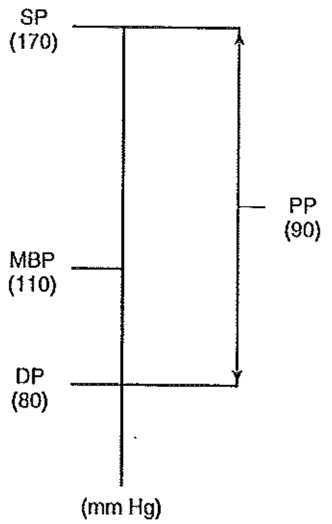

Figure 17.1 Mean blood pressure (MBP) is one-third of pulse pressure (PP) plus diastolic pressure (DP). For example, a blood pressure during exercise of 170/80/80 mm Hg produces a pulse pressure of 90 mm Hg and a mean pressure of 110 mm Hg.

Physiological Rationale

Numerous factors may affect blood pressure at exercise. These include characteristics of the performers, such as their age, muscle mass, fitness level, and smoking status. Also, the type of exercise may affect blood pressure.[57] For example, weight lifting in five 22- to 28-year-old body builders increased intra-arterial blood pressure during leg presses to 355 mm Hg over 281 mm Hg.[11] This is higher than in rhythmical aerobic exercise, such as cycling or walking. Differences are found even among types of aerobic exercise; cycling, for example, elicits higher blood pressures than treadmill exercise.[31,48] Additionally, the exercise protocol itself may affect the rate of increase and absolute levels of blood pressure during exercise.

Blood pressure is mainly a function of cardiac output and peripheral resistance. The increase in blood pressure during exercise is due to the increased cardiac output. Despite a decrease in peripheral resistance due to dilation of muscle arterioles, the large increase in cardiac output more than makes up for the decreased peripheral resistance.

Blood Pressure During Aerobic Exercise

Systolic pressure is expected to increase rather linearly,[3,54] and diastolic pressure changes very little, if at all, during progressive aerobic exercise (Figure 17.2)[9,13,16] when measured by noninvasive sphygmomanometry.

As mentioned in Chapter 16, mean blood pressure (MBP) is calculated from pulse pressure (PP). The traditional equation is recommended, although one group of investigators concluded that it may be more valid to use one-half the distance between cuff-determined fifth-phase diastolic pressure and systolic pressure, as the mean pressure.[54]

The traditional mean pressure as one-third the distance between systolic and diastolic pressure appears to be justified until further research confirms otherwise.

The Power Output of the Heart

The heart is affected by both its rate of pumping (b·min^{-1}) and the force or resistance (mm Hg) it has to pump against. This power output of the heart is often referred to as either the **double product** or the **rate-pressure product (RPP)** because of the multiplication of the two factors,

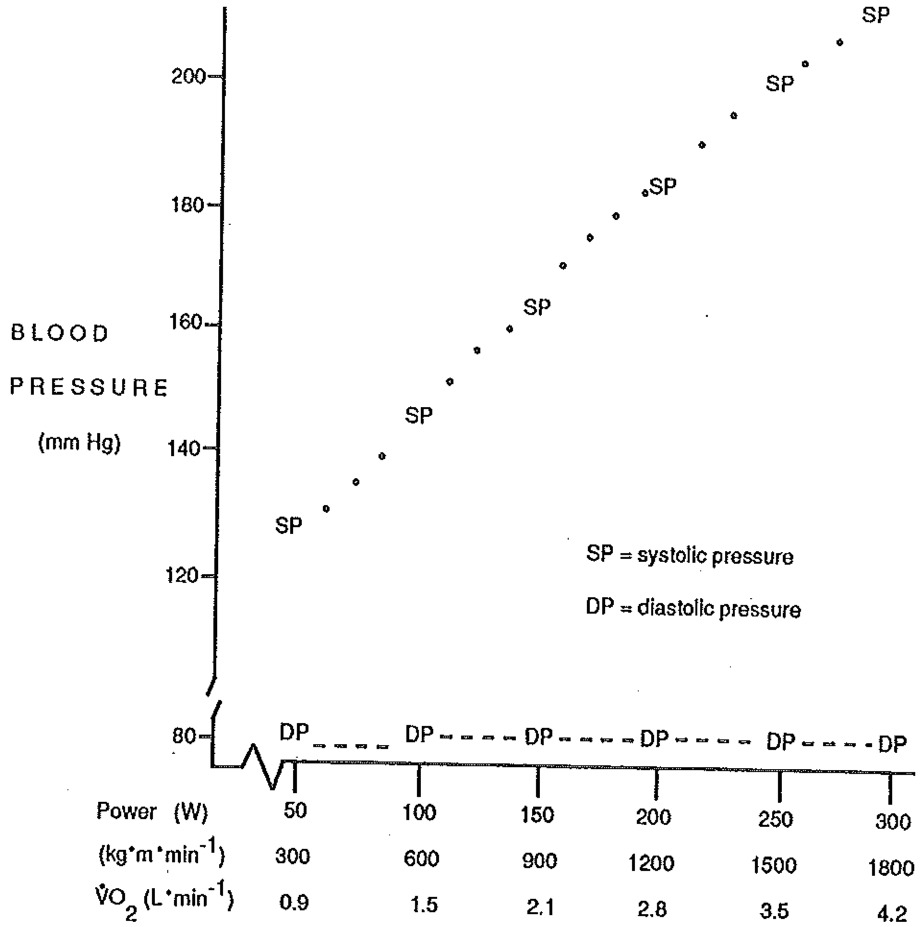

Figure 17.2 Relationship between systolic and fifth-phase diastolic blood pressures versus exercise intensity in a typical 70 kg man.

heart rate (HR) and systolic pressure (SP). The RPP, as calculated from Equation 17.1, is not meant to reflect differences in stroke volumes between individuals but is an accurate reflection of the myocardial oxygen requirement.[2,20,40] The product of HR and SP is divided by 100 in order to reduce the value to a convenient unit[53] and to agree closely with the oxygen consumption ($mL{\cdot}min^{-1}$) of the heart. The *rate* of myocardial fiber shortening, an important factor in the contractility of the heart, is not included in the derived RPP.[24]

$$RPP = (HR \times SP) \div 100 \qquad \text{Eq. 17.1}$$

where:

HR = heart rate ($b{\cdot}min^{-1}$)

SP = systolic pressure (mm Hg)

For example, if the heart rate is 150 $b{\cdot}min^{-1}$ and systolic pressure is 200 mm Hg during exercise, then the RPP may be calculated as

$$(150 \times 200) \div 100 = 30\,000 \div 100 = 300$$

Method

The measurement of blood pressure during exercise is one of the most common measurements in an exercise laboratory. However, the technique is one of the most difficult to master, requiring many trials before the technician becomes confident. Although standards exist for measuring *resting* blood pressure, no such standards exist for *exercise* blood pressure.[25]

As expected, there are many similarities between the measurement of blood pressure at rest and at exercise. The differences include minor adjustments to the blood pressure technique and a more intense concentration on the fourth phase (muffling). During exercise it is not unusual for the vibrations to be heard even near zero levels[43] due to enhanced vasodilation at exercise.[22] Thus, the fifth phase is not a valid indicator of diastolic pressure during exercise tests in some people. For this reason, the American Heart Association recommends the recording of the fourth phase for exercise testing.[23] See Box 17.1 for a discussion on the accuracy of exercise blood pressure measurements.

BOX 17.1 Accuracy and Calibration of Exercise Blood Pressure Measurements

Validity

The ability to measure exercise blood pressure accurately is complicated by the noise of the equipment and movement of the performer. Although the indirect noninvasive measurement of systolic pressure has been reported to be satisfactory,[47] it appears that the noninvasive cuff method of measuring systolic pressure underestimates the invasive direct measure of systolic pressure anywhere from 8 mm Hg[30,45] up to 11 mm Hg[54] or 15 mm Hg[30] during aerobic exercise.

One group of investigators[54] found that the intra-arterial diastolic pressures exceeded the noninvasive fourth and fifth phases for diastolic pressure by 5 mm Hg and 13 mm Hg, respectively. This supports the use of the indirectly measured fourth phase as the most valid diastolic pressure during exercise. Their correlations between intra-arterial pressures and cuff pressures were .95 and .84 for systolic and diastolic (fourth phase) pressures, respectively. However, the fourth phase is not as clearly distinguishable as the fifth phase.

One group of reviewers recommended manual or automated sphygmomanometry to measure systolic pressure if the goal is to estimate the rate-pressure product.[25]

Reliability

Although various investigators have not supported high reliabilities in automated blood pressure methods,[4,5,41,50] including the measurement of diastolic blood pressure during recovery,[36] some have concluded that a few automated devices are a suitable alternative to human auscultatory methods.[25,42]

Calibration of Automated Blood Pressure Instruments

Automated blood pressure instruments are more widely accepted for research if they have been calibrated. For example, the heralded HERITAGE Family Study investigators use an automated device (Colin-STBP-780™, San Antonio, TX) after calibrating it with a mercury manometer and verifying the readings by listening with headphones. They calibrate it at mercury manometer pressures of 0, 50, 100, 150, and 200 mm Hg.[59]

If the performer tenses the arm while the technician is taking the blood pressure, it will cause large oscillations in the aneroid pointer or the mercury column. Presumably, this is due to the changes in upper arm circumference as the muscles contract and relax. Thus, it is very important to promote muscle relaxation of the performer's arm (Figure 17.3). Also, it is important to clear the antecubital space for the placement of the stethoscope's diaphragm. Sometimes the cuff will slide toward the elbow during exercise, or the bladder's rubber tubes will interfere with the antecubital space. Some researchers advise placing the cuff so that the tubing runs along the back of the upper arm rather than the front, especially during treadmill exercise.

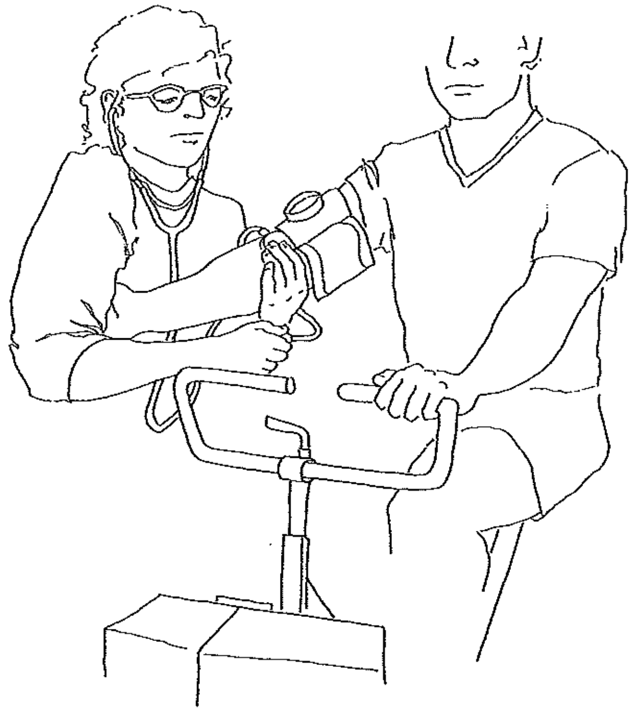

Figure 17.3 An appropriate position for the technician and performer while blood pressure is being measured at pre-exercise or during exercise.

Contraindicative Blood Pressure

Another consideration in measuring blood pressure at exercise is whether to perform the exercise test in the first place. The term *contraindicative* means that for some people "the risks of exercise testing outweigh the potential benefits."[2] For example, the risk is greater than the benefit of exercise testing for someone who has just had a heart attack or someone with uncontrolled erratic heart rhythm accompanied by disturbing symptoms. Some authorities suggest that exercise testing is contraindicated if systolic is greater than 180 mm Hg or diastolic greater than 100 mm Hg.[51] The American College of Sports Medicine (2000) takes a more liberal view by having no **absolute** contraindication criteria for blood pressure but providing **relative** contraindicative criteria. This means that, if resting systolic pressures are greater than 200 mm Hg or diastolic pressures are greater than 110 mm Hg, then the risk-benefit ratio must be evaluated before exercise testing.[2]

Relative Contraindicative Blood Pressure

SP > 200 mm Hg   DP > 110 mm Hg

Table 17.1 Cycling Protocols for Exercise Blood Pressure

Pre-exercise			
Seated on cycle ergometer			
		Exercise[a]	
	Low-Power	Moderate-Power	High-Power
$\dot{V}O_2max$ (L·min⁻¹) history	< 2.1	2.1–2.9	> 2.9
Time		Power Prescription (W)	
0:00–3:00	50	75	100
3:00–6:00	100	125	150
6:00–9:00	150	175	200
		Recovery	
9:00–12:00 Cooldown on ergometer	25	50	75
11:00–14:00	Seated in chair		

Note: Treadmill protocols are in Chapters 15 and 19. [a]The three columns of exercise protocols represent three different fitness levels based on a person's maximal oxygen consumption.

Protocol for Exercise Blood Pressure

Three multistage cycling protocols are presented in Table 17.1. Technicians usually find it easier to measure blood pressure when performers cycle than when they walk or run on a treadmill. In order to prescribe an appropriate exercise protocol, consideration should be given to the performer's fitness level. The prescription can be based upon prior tests of aerobic or physical power on the prospective performer. An exercise interval of 3 min should assure a steady state at each stage.[43] The exercise period starts at 50, 75, or 100 W (300, 450, or 600 kg·m min⁻¹), depending upon the fitness level of the performer. Power levels are increased by 50 W after each 3 min interval. Until the technician gains considerable confidence, repeated measures should be taken throughout the test; only the pressures measured at the last 30 s of each power level, however, need to be recorded.

In order to calculate the rate pressure product (RPP), the heart rate must be measured by either another technician with a stethoscope or by heart-rate monitor.

Summary of Procedures

The major differences in the technique for measuring blood pressure at exercise versus that at rest are the following: (a) the technician must support the exerciser's arm; (b) greater listening concentration is required due to the noise of the ergometer; and (c) the muffling point (fourth phase) is used sometimes as the primary indicator of diastolic pressure at exercise.[54,58] The procedural steps for measuring blood pressure are as follows.

Pre-Exercise

1. Obtain baseline blood pressures by measuring first-, fourth-, and fifth-phase pressures while the performer is resting on the cycle ergometer (or standing on the treadmill if it is the chosen mode).
   a. With the cuff around the performer's arm, place that arm between your elbow and the side of your body (Figure 17.3).
   b. Instruct the performer to relax the arm as much as possible.
   c. While taking the pressure, maintain the performer's arm in an extended position.
   d. Especially for treadmill exercise, tape or strap the stethoscope's diaphragm and the BP cuff to the performer's arm; you may need to remove the air bulb intermittently.

Exercise

2. Use Step #1 procedures for taking blood pressure during exercise, but allow cuff pressure to fall faster at about 5 to 6 mm Hg per second.[49]
3. Follow the exercise protocol for cycle ergometry (Table 17.1 or any of the Treadmill protocols in Chapters 15 and 19).
4. Record the blood pressure that was taken during the last 30 s of each exercise stage. Remeasure immediately if systolic pressure has decreased from prior stage's reading.
5. Take auscultatory or telemetered heart rate during these times in order to calculate rate-pressure product.

Recovery

6. Measure blood pressure during the last 30 s of each minute of the cooldown period while the performer pedals at 25 W, 50 W, or 75 W.
7. Measure blood pressure during the last 30 s of each minute during the recovery period while the performer is seated in a chair. Continue monitoring until blood pressure stabilizes.

Graph

8. Graph blood pressures (mean pressure optional) on Form 17.3.

Table 17.2 Comparative Blood Pressure Values at Submaximal Exercise, Maximal Exercise, and Recovery

	Systolic (mm Hg)	Diastolic (mm Hg)	
		4th Phase	5th Phase
Submaximal Exercise			
Cycling			
Normotense:	< 200	≈ ↑ from resting	↔ ≈ ↑ ≈ ↓ from resting
	10–18 per 50 W↑	7–11 per $\dot{V}O_2$ L·min^{-1}↑	
	30 per $\dot{V}O_2$ L·min^{-1}↑	≈ 5 per 50 W↑	
Hypotense:	↓ with P increase		
	↓ > 15 at given P		
Hypertense:	> normotense ↑		↑ > 10–15 from resting
Treadmill			
Normotense:	7–10 per MET↑	↑ < cycling ↑	
Hypertense:	> 20 per MET↑		
Maximal Exercise			≈ ↑ from resting
Normotense:			
General population	150–250		
Young adults:	150–250; 200		
Treadmill			
Active M (44 y)	190 ± 23		
Sedentary M (45 y)	185 ± 22		
Active W (42 y)	159 ± 19		
Sedentary W (48 y)	166 ± 23		
Hypertense:	220–230; ↑ > 96 from rest	95; ↑ > 15	
Hypotense:	↓ with P ↑; ↑ < 33 from rest to max		
Recovery	Return to pre-exercise level within 5 min to 8 min; possibly < pre-exercise up to 60 min to 90 min		

Note: ≈ = slight; ↑ = increase; ↔ = no change; ↓ = decrease; P = power level; M = men; W = women or watts.

Results and Discussion

Various criteria and expectations for exercise blood pressure are presented in Table 17.2 for comparative purposes. The table is organized into submaximal and maximal levels of exercise intensity, in addition to recovery from exercise.

Blood Pressure at Submaximal Aerobic Exercise

Even before exercise begins, persons anticipating the exercise test may have a systolic pressure about 10 mm Hg higher than their normal resting pressure.[14] Theoretically, **systolic pressure** is expected to increase somewhat linearly during aerobic cycling by approximately 10 mm Hg[44] or 15 mm Hg[3] for each 50 W (300 kg·m min^{-1}) increase in cycling power level. One group of investigators reported a rate of increase of 18 mm Hg per 50 W based on a 30 mm Hg increase per liter increase in oxygen consumption on less active persons monitored by intra-arterial catheter.[54]

During treadmill exercise, one might expect a 10 mm Hg (± 2) increase per MET increase.[2] It would be unusual for exercise heart rate to exceed systolic pressure in young adults. A hypertensive response in treadmill exercise may be indicated when systolic pressure increases at a rate greater than 20 mm Hg per MET,[19] or per 0.25 L·min^{-1} oxygen consumption. If systolic pressure fails to increase at all with progressive exercise, or actually decreases, it may be a sign of coronary artery disease[56] or a high risk indication.[1,2,21]

More controversy exists regarding **diastolic pressure** changes than systolic pressure changes during exercise. Fifth-phase diastolic pressure usually decreases or stays the same in healthy persons.[2] Part of this controversy may be attributed to the method of measuring diastolic pressure. One group concluded that the noninvasive fifth-phase diastolic pressure decreases slightly from rest to heavy cycling by only 3 mm Hg, but the fourth-phase cuff pressure and intra-arterial diastolic pressure increases from rest through maximal cycling by about 7 to 11 mm Hg per liter of oxygen consumed.[54]

Some report decreases in fifth-phase diastolic pressure with progressive exercise in highly fit persons.[9,46] Others claim that a normal fifth-phase diastolic pressure response to exercise is one that does not increase by more than 10 mm Hg[18] to 15 mm Hg.[56] During treadmill exercise, many healthy persons show slight increases in diastolic pressure of no more than 10 mm Hg during the first couple of minutes, followed by a progressive reduction into the peak exercise period.[12] Others report a slight decrease or no change in diastolic pressure in healthy men during treadmill exercise.[60]

The **mean blood pressures (MBP)** of healthy sedentary males and females (17 y to 29 y) were determined at 50 W and 60 % $\dot{V}O_2max$, respectively. The 95 males averaged a MBP of 94 (± 9.1) mm Hg and 105 (± 9.9) mm Hg, respectively. The 134 females' MBP were 90 (± 9.7) mm Hg and 101 (± 12.0) mm Hg, respectively.[59]

Blood Pressure at Maximal Aerobic Exercise

Quite often it is impossible to get a technically reliable blood pressure measurement while the performer is exercising at or near maximal intensity. In these cases, the blood pressure should be taken immediately after exercise with

Table 17.3 Peak Systolic and Diastolic Blood Pressures of Apparently Healthy Men and Women during Maximal Treadmill Testing[a]

Age y	Men		Women	
	Systolic *M (SD)*	Diastolic *M (SD)*	Systolic *M (SD)*	Diastolic *M (SD)*
20–29	182 (21)	71 (12)	156 (20)	70 (12)
30–39	184 (20)	76 (12)	160 (22)	74 (11)
40–49	188 (21)	80 (12)	167 (23)	78 (11)
50–59	193 (23)	83 (12)	177 (24)	81 (12)
60–69	197 (24)	84 (12)	186 (24)	81 (13)
70–79	196 (27)	84 (13)	185 (25)	83 (10)

Note: [a]Bruce protocol in 7863 men and 2406 women during the years 1988 to 1992. Adapted with permission from Daida, H., Allison, T. G., Squires, R. W., Miller, T. D., & Gau, G. T. (1996). Peak exercise blood pressure stratified by age and gender in apparently healthy subjects. *Mayo Clinic Proceedings, 71*, 445–452.

precautions taken to avoid postural (orthostatic) syncope in the performer; usually, this would mean easy walking on the treadmill (or in place) or easy pedalling on the ergometer. The peak blood pressure may be slightly underestimated by waiting to take blood pressure immediately after exercise, rather than during exercise.[32]

Maximal systolic pressure can be quite variable, ranging from 150 mm Hg to 250 mm Hg in men and women,[9] with an average in a normal young adult about 182 mm Hg[15] up to 200 mm Hg.[28] This concurs with other investigators who reported a maximal systolic pressure of 194 (± 20) mm Hg for running on the treadmill.[17] Normotensive middle-aged persons reach maximal systolic pressures between 180 mm Hg and 190 mm Hg.[10] Table 17.3 provides the mean systolic and diastolic pressures at peak exercise during treadmill testing of males and females from 18 y to 79 y of age. Men's pressures were higher than women's pressures and were positively related to age.[15] If systolic blood pressure exceeds 240 mm Hg, it may indicate a susceptibility for developing resting hypertension.[38]

Sometimes during an exercise test, the blood pressure reaches a level that calls for termination of the test. A systolic pressure greater than 260 mm Hg is a **general** indication by ACSM for stopping the test in a low-risk person.[2] Ruptures have occurred in the blood vessels of experimental animals when systolic pressures were between 260 and 280 mm Hg.[29] Others suggest caution and consider it a hypertensive response if the systolic pressure exceeds 220 mm Hg.[8,12] Some consider the exercise response as hypertensive if the systolic pressure increases by more than 96 mm Hg from the resting level, and as hypotensive if the systolic pressure does not increase more than 33 mm Hg at maximal exercise.[52]

Caution may be prudent when the performer's exercise **diastolic pressure** reaches 95 mm Hg.[8] However, the ACSM's indication for halting the test for low-risk adults is when DP exceeds 115 mm Hg.[2]

STOP Test!*

SP > 260 mm Hg DP > 115 mm Hg

*The ACSM criteria for stopping a test performed by a high-risk person under a clinical setting are ≥ 250 mm Hg and ≥ 110 mm Hg.[2]

Typical **mean** arterial pressures at maximal exercise are approximately 130 mm Hg, but may reach as high as 155 mm Hg.[9] A large group (n = 95) of 17- to 29-year-old males' MBP averaged 122 mm Hg of maximal cycling exercise. The average MBP for the females (n = 134) of the same age was 117 mm Hg.[59]

Blood Pressure during Recovery from Aerobic Exercise

Blood pressure often returns to the pre-exercise level within 5 min to 8 min after the cessation of moderate exercise.[34,44,55] It is not unusual for systolic pressure to drop slightly lower than the pre-exercise systolic pressure[6,27,28,39] and remain lower for several hours.[2] For example, from the 5th to the 60th,[38] or up to the 90th min[6] of recovery from treadmill walking, systolic blood pressure was slightly lower (8 to 12 mm Hg) than it was preceding exercise, possibly due to endorphin-like (opioid) effects.[7]

Usually, diastolic pressure during recovery remains similar to pre-exercise. The return of blood pressure to resting levels is affected by the type, intensity, and duration of the original exercise in addition to the type of recovery. For example, it requires more than 3 min for blood pressure to return to normal after heavy cycling exercise (85 % $\dot{V}O_2max$) if the cyclist recovers with unloaded pedaling at a slow rate.[54] However, if the performer were to stand upright immediately after the same exercise, it is quite possible that blood pressure would drop rapidly and drastically. Venous pooling of blood in the legs would reduce the blood flow to the brain and possibly lead to syncope. Post-exercise hypotensive symptoms are most likely after bouts of exercise lasting 30 min or more. Recovery hypotension is due to various factors besides venous pooling, such as cessation of muscle pump during passive recovery, loss of plasma volume due to sweating, reduced venous return, and reduced vasoconstriction.[26]

Rate-Pressure Product (RPP)

The mean resting rate pressure product in 1623 healthy men and women ranging from 20 y to 70 y of age was 75 ± 17.5 mm Hg. At maximal exercise of the Bruce treadmill protocol, the RPP averaged 328 ± 44.6.[33] The assumed myocardial oxygen consumption ($\dot{V}O_2$myo) at maximal exercise more than quadrupled the resting $\dot{V}O_2$myo. The men's maximal RPP was higher than the women's maximal RPP. Rate-pressure products at maximal exercise in active men and active women of a wide age range were 341 ± 55 and 281 ± 37 respectively.[10]

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Form 17.1

Individual Data for Exercise Blood Pressure

Name ______ Date ______ Time ______ A.M. ☐ P.M. ☐

Age ______ y Gender (M or W) ☐ Ht ______ cm Wt ______ kg Tech. Initials ☐

Meteorological Data

T ______ °C (closest 0.1 °C) RH % ______ P_B ______ mm Hg × 1.333 = ______ hPa

Mode (check): Cycle ☐ Other ☐ Cycle Model ☐ Seat Ht ☐

Prior Test Score(s): $\dot{V}O_2max$ ______ L·min^{-1} ______ L·min^{-1} Predicted (P) or Direct (D) $\dot{V}O_2max$ (check) ☐ P ☐ D

Time	Power W	Systolic Pressure (SP)	Diastolic Pressure 4th Phase (DP-4th)	Diastolic Pressure 5th Phase (DP-5th)	Pulse Pressure (PP)	Heart Rate (HR)	Rate-Pressure Product (RPP)
Pre-exercise (on bike)							
Exercise							
2:30–3:00							
5:30–6:00							
8:30–9:00							
Recovery: Cooldown							
9:30–10:00							
10:30–11:00							
11:30–12:00							
Chair Recovery							
12:30–13:00							
13:30–14:00							
14:30–15:00							

Mean Blood Pressure (MBP)

Body State	Time	Pulse Pressure (PP)	PP ÷ 3	+ DP	= MBP
Pre-exercise				+	=
Peak Exercise	8:30–9:00			+	=
Recovery	11:30–12:00			+	=
Recovery	14:30–15:00			+	=