



Arterial Blood Pressure Measurement: Physiology, Tools, and Techniques

Lydia Love, DVM

The Humane Society of the United States Rural Area Veterinary Services
Memphis, Tennessee

Ralph Harvey, DVM, MS, DACVA

The University of Tennessee

ABSTRACT: Blood pressure monitoring in dogs and cats is important because both hypotension and hypertension can occur and have significant effects on patient outcome. Awareness of the advantages and disadvantages of available monitoring devices is essential for practitioners. Although direct arterial monitoring is the most accurate method available, it is invasive and technically demanding. Indirect measurements are comparatively easy to obtain but are typically less accurate. Because precision and efficiency are often the most important characteristics of a diagnostic test, indirect techniques are preferred in daily practice. Blood pressure measurement is an accessible technique that can enhance the quality of care provided by general practitioners.

Blood pressure (BP) was first measured in horses in the early 18th century. In his seminal work *Haemastatics*, Stephen Hales described a technique in which measurement of the height of a column of blood in a glass tube inserted into the femoral artery of a horse could be used to determine BP.¹ The first noninvasive method for humans was reported in 1834,² and almost two centuries of study have produced a variety of BP measurement techniques. In humans, BP is often referred to as *the fourth vital sign* accompanying temperature, pulse, and respiration. Unlike veterinarians, physicians enjoy the comparative luxury of a typically coop-

erative patient; in addition, various anatomic differences render BP measurement in humans more straightforward than in animals.³⁻⁵ However, BP measurement is indispensable in contemporary veterinary practice because pressure derangements are common and potentially life-threatening in small animals.

CLINICAL RELEVANCE

Hypotension is more readily recognized than hypertension because the clinical presentation of hypotension is usually acute. The three basic pathophysiologic mechanisms that lead to hypotension are decreased vascular tone, decreased cardiac output, and hypovolemia.⁶ Certain disease states, particularly those related to anaphylaxis, blood loss, sepsis, and neoplasia,

Send comments/questions via email
editor@CompendiumVet.com
or fax 800-556-3288.

Visit CompendiumVet.com for
full-text articles, CE testing, and CE
test answers.

can lead to potentially devastating hypotension. Iatrogenic causes of hypotension, including anesthesia and pharmacologic vasodilation, are also common.⁴ Anesthetized patients are particularly at risk for severe and possibly life-threatening hypotension because many injectable and inhalant anesthetics depress cardiac output (CO) and/or peripheral vascular resistance.^{7,8} Monitors that simply amplify respiratory and cardiac sounds do not identify hypotensive states or impending cardiovascular collapse.^{9,10} Hypotension is the most common perianesthetic complication in small animal practice; therefore, BP monitoring may expose dangerous cardiovascular trends before they are realized clinically.¹¹ The American College of Veterinary Anesthesiologists recommends BP monitoring during anesthesia, at a minimum, for patients with moderate to severe systemic disease.¹²

Autoregulation of blood flow refers to the ability of regional vasculature beds to compensate for systemic arterial pressure changes.¹³ Autoregulation is limited in the presence of severe hypotension, which can therefore compromise adequate perfusion of the kidneys, heart, and brain and lead to organ dysfunction and failure.^{6,14,15} The renal vascular bed actually appears to lose the ability to autoregulate BP at a mean arterial pressure (MAP) of approximately 80 mm Hg, whereas the brain and heart can maintain perfusion down to an MAP of approximately 40 to 50 mm Hg.¹⁴ To preserve organ function, maintaining normal BP during both anesthesia and disease is a desirable goal. Although BP monitoring is not an exact indicator of CO or organ perfusion, it is a fast and reliable indicator of cardiovascular function.^{7,8}

Hypertension in veterinary patients has become more widely recognized. Development of hypertension results from complex interactions between the endocrine, renal, vascular, and autonomic nervous systems. Essential hypertension, defined as elevated BP without an established cause, is thought to be rare in veterinary patients but is the most frequent form of hypertension in humans.^{16,17} It is frequently associated with renal disease and hyperthyroidism in cats and with renal disease, hyperadrenocorticism, and other endocrinopathies in dogs.^{18–22} Autoregulation also fails with sustained hypertension, causing direct damage to many organs, including the eyes, brain, and kidneys.^{20,21} Systemic hypertension often complicates the clinical picture in various chronic disease states in animals, most notably renal failure.^{16,18,19,23–26} One of the most commonly recognized clin-

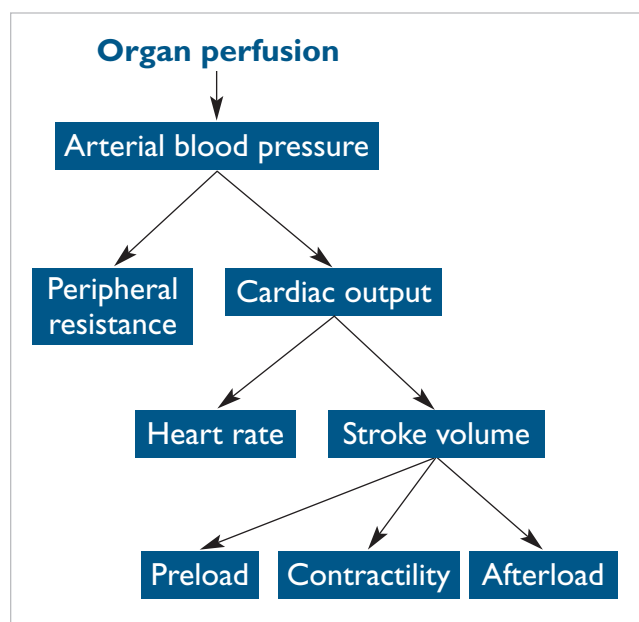


Figure 1. The relationship of various cardiovascular parameters to arterial blood pressure and organ perfusion.

ical presentations of hypertension in cats is acute onset of blindness due to retinal detachment.^{16,20,25} Although it may not be practical to measure BP in every animal, geriatric patients and those with certain disease states should be evaluated for hypertension.

In addition to diagnostic investigation for hypo- and hypertension, BP measurement in dogs and cats can direct therapy, such as the use of vasoactive medications, and therapeutic endpoints during resuscitation from shock.

PHYSIOLOGY

Arterial BP is defined as the force exerted by flowing blood on arterial walls.^{4,27,28} This force is pulsatile due to intermittent contractions of the heart, creating a forward-moving waveform. The determinant factors of BP are cardiac output (CO), peripheral vascular resistance, and blood volume as described by the following equations^{4,13,27–29}:

$$BP = CO \times \text{Peripheral vascular resistance}$$

$$CO = \text{Heart rate} \times \text{Stroke volume}$$

Stroke volume is the volume of blood ejected by the heart during systole.^{4,13,27–29} Stroke volume is influenced by cardiac contractility, preload, and afterload²⁹ as shown in Figure 1.

Comparative Terminology

To evaluate the different methods of measuring BP, the following terms are used:

- **Accuracy** is the proximity of a measured value to the actual value.
- **Precision** is the ability to obtain a repeatable measurement.
- **Efficiency** is the ratio of the number of successful attempts to the number of overall attempts at obtaining a measurement.
- **Sensitivity** is the probability of obtaining a positive test in patients with that disease (e.g., detecting low BP in a hypotensive patient).
- **Specificity** is the probability of obtaining a negative test in unaffected patients (e.g., obtaining a normal reading in a normotensive animal).

Systolic BP is the maximum arterial BP measurement during systole (ventricular contraction), whereas diastolic BP is the minimum measurement taken during diastole (cardiac relaxation). MAP is the time-weighted average of pressure exerted during the cardiac cycle and is the major determinant of organ perfusion.^{4,27,30} Because the duration of diastole is normally longer than that of systole, MAP cannot be directly averaged and the following equation³¹ is used to approximate it:

$$\text{MAP} = \text{Diastolic BP} + \frac{1}{3}(\text{Systolic BP} - \text{Diastolic BP})$$

The difference between systolic and diastolic pressures is the pulse pressure, which creates the palpable pulse.^{4,27,28} However, manual palpation of the pulse does not provide

painful, inexpensive, automatic, reliable, accurate, and precise over a wide range of conditions, including patient and situational factors.

Direct Measurement

Direct arterial BP is the standard to which all other methods are compared. This measurement is obtained by placing a catheter into an artery and connecting it to a pressure transducer. Like most clinical skills, the technique for placing arterial catheters is not difficult but does require sufficient practice. The most common sites for arterial catheter placement in small animals are the dorsal metatarsal artery, which lies between the second and third metatarsal bones, or, for smaller patients, the femoral artery.^{6,8,32–34} However, any accessible artery can be used, including the lingual, auricular, and carotid.^{8,29,33} Although methods using only local anesthetics in conscious research dogs have been described,^{4,35} direct arterial catheter placement virtually necessitates a patient that is minimally responsive or nonresponsive because of either sedation or a disease state.

After wide depilation and sterile preparation over the catheter site, a 18- to 24-gauge sterile over-the-needle catheter primed with heparinized saline should be placed using methods similar to venous catheterization.^{8,33} Lidocaine is often injected at the insertion site to decrease arteriospasm when the catheter is positioned.⁴ If possible, the pulse should be palpated (Figure 2) and the catheter inserted in the same direction as the vessel at a 45° angle. Because pulses may be nonpalpable in severely hypotensive or hypovolemic patients, a cut-down technique can be used if necessary. Pulsatile, rapid

Direct arterial blood pressure monitoring should be considered for any hemodynamically unstable patient.

reliable information about MAP. This is an important point because it is possible to have a significant derangement in MAP, and therefore organ perfusion, while maintaining a subjectively adequate pulse pressure.^{8,27}

CLINICAL MEASUREMENT

BP may be determined via direct or indirect techniques. Each method has its own set of advantages and disadvantages that should be considered when evaluating clinical options. An ideal technique would be non-

blood flow through the catheter indicates successful placement within the artery. The catheter should then be advanced into the artery (Figure 3) and the stylet removed. A T-piece should be placed and the catheter flushed with 1 to 2 ml of heparinized saline. The catheter should be secured similarly to venous catheters and labeled to avoid inadvertent arterial injection. The catheter should then be connected with noncompliant tubing primed with heparinized saline to a pressure transducer placed at the level of the heart. The trans-



Figure 2. Palpating the arterial pulse to prepare for insertion of an intraarterial catheter.



Figure 3. An intraarterial catheter in the dorsal pedal artery before it is secured with tape.

ducer converts the mechanical signals into electrical energy, which is displayed on the monitor as a continuous pressure waveform as well as a numeric reading of the systolic, mean, and diastolic BPs. A typical display monitor is shown in Figure 4. It is also possible to connect the tubing to an aneroid manometer, which greatly decreases the expense but provides only an MAP reading.^{7,8} The catheter and tubing should be flushed frequently, either continuously or at least every 4 hours to avoid thrombus formation.^{4,6,33} Telemetric monitoring is a specialized form of direct arterial measurement that uses an indwelling catheter and transmission of radio signals from a conscious, unrestrained patient.^{30,32} This technique is primarily used in research settings.

Direct BP measurement is not infallible. Direct arterial readings can be affected by clots within the catheter and by contact of the catheter with the vessel wall.³⁴ In addition, the catheter itself can obstruct blood flow in smaller arteries and artificially increase pressure readings.^{4,36} Tubing that is kinked, is too long or compliant, or contains air bubbles can alter BP readings.^{4,34} Therefore, use of connections and the length of the tubing should be minimized. Care must be taken to ensure that the transducer is at the same level as the heart.^{4,34} Examination of the arterial waveform can give some indication of the accuracy of the measurement. The upstroke registered during systole should be steep, and the presence of the dicrotic notch, indicating closure of the aortic valve and subsequent elastic recoil within the vascular system, should be noted.^{4,27,31,37} Artifactual changes can be produced by the measuring and recording components, and, as with any vital monitor, readings must be integrated into the clinical picture.



Figure 4. Display monitor for intraarterial pressure measurement.

Complications of arterial catheter placement may include thromboembolization, hemorrhage, hematoma formation, ischemic necrosis of adjacent tissues, infection, and accidental intraarterial drug injection.^{33,34,38} Disadvantages include expense of equipment, invasiveness, need for technical proficiency with placement, and frequent maintenance of the catheter and tubing.^{8,33,34} In addition, the time required to place the arterial catheter may increase anesthesia time. Intraarterial catheter placement may be contraindicated in patients with hemostatic disorders or in areas with overlying dermatitis. Advantages include accurate readings under all pressure conditions, continuous measurement, the ability to accomplish waveform analysis, and the presence of

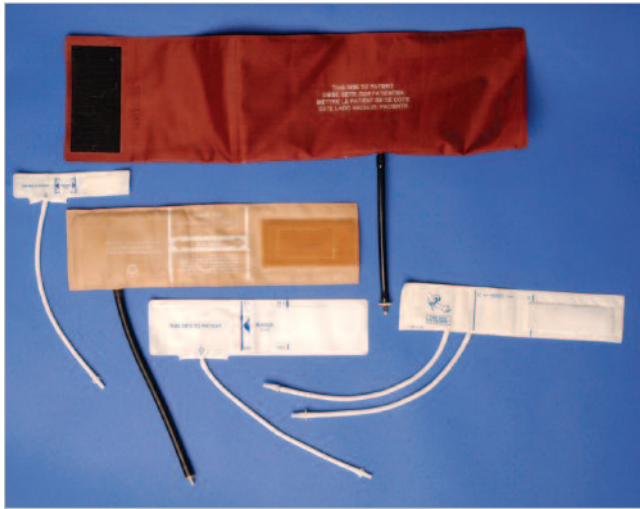


Figure 5. Various inflatable cuffs used with Doppler and oscillometric indirect blood pressure monitors.

established arterial access for blood gas measurements.^{27,33,34} Arterial catheterization should be considered for any hemodynamically unstable or critically ill patient because indirect techniques may be inaccurate in these situations.^{33,34}

Indirect Measurement

BP readings can be obtained via several noninvasive methods. These indirect techniques are generally considered less accurate than intraarterial measurements but also require less technical skill, pose less risk to the patient, and are more routinely practical.^{4,17,27} The most common methods of indirect measurement require a superficial artery of sufficient size that can be compressed easily. These techniques rely on detection of the return of pulsatile blood flow after occlusion of the artery with an inflatable cuff.²⁷ Several sizes of inflatable cuffs for use with the most common indirect methods are shown in Figure 5.

Cuff width is important for accurate readings and should be approximately 40% of the circumference of the limb.^{4,39–41} One study³⁶ recommends a 30% ratio for cats. If the cuff is too large, pressures may be underestimated; if the cuff is too small, pressures may be overestimated.^{40–44} If a correctly sized cuff is unavailable, it should be noted that the magnitude of error is greater with a small cuff; therefore, the wider cuff should be chosen.^{4,41,42} If the inflatable part of the cuff does not encircle the entire limb, care should be taken to place the inflatable bladder over the artery to be compressed.

The cuff should fit snugly, and the limb should be positioned so that the air hoses are not kinked.⁴⁵ Ideally, the cuff should be positioned at the same level as the heart.²⁷ Most authors indicate that accuracy of indirect methods is improved by averaging readings from multiple measurements after discarding outliers.^{22,32,46–50}

Indirect methods are generally more straightforward and less invasive than direct BP monitoring but are less accurate because of intrinsic differences in methodology.^{8,27} Indirect techniques are typically registered in more peripheral and, therefore, narrower parts of the vascular tree that are inherently susceptible to the dictates of waveform mechanics, including distal amplification, reflection, and impedance.^{4,45,51,52} The Association for the Advancement of Medical Instrumentation, a group that sets forth standards for indirect BP monitors in humans, designates 5 ± 8 mm Hg as the maximum mean error and standard deviation acceptable for these devices compared with direct arterial measurement.⁴² It should be noted that few noninvasive devices used in veterinary medicine have been evaluated by the Association for the Advancement of Medical Instrumentation standards, and none has been shown to fully meet the criteria.^{42,45,50–52}

Doppler Ultrasonography

The Doppler effect refers to detection of a shift in frequency of waves relative to an observer. A Doppler BP transducer uses a piezoelectric crystal (i.e., one that acquires a charge when distorted) to emit and receive ultrasonic waves. Reflection of the waves produced by erythrocyte flow within the artery is converted into the audible range and amplified.^{8,30}

The probe is placed over an artery distal to an inflatable cuff with an attached aneroid manometer. The most common sites are the caudal metatarsal region, caudal metacarpal region, and ventral tail, with the cuff placed just proximal to the probe.^{27,29,43,53} The area over the artery is frequently shaved; however, application of alcohol to the haircoat may be adequate. Ultrasonic coupling gel is placed in the depression of the probe, which is aligned parallel to the blood flow. Once the sound of the blood flow is detected, the probe can be taped in place for repeated measurements, such as during surgical procedures, or held in place by hand. The cuff should then be inflated until the pulse can no longer be heard and then slowly deflated while the attached manometer is observed. The pressure at which the pulse first becomes audible is read as the systolic pressure.^{27,30,33,43,51,52}

Diastolic readings cannot be reliably obtained via this method because wide interobserver variation has been reported.^{27,30,33,54} Figure 6 demonstrates the use of a Doppler BP device.

The Doppler method has been investigated in conscious^{16,50,54} and anesthetized cats^{36,50,51,53} as well as conscious^{35,52} and anesthetized dogs.⁵⁵ Compared with direct BP measurement, Doppler measurement tends to underestimate systolic pressure.^{35,36,50–53} This tendency is especially pronounced in cats. One study⁵³ reported that Doppler readings may more closely reflect MAP than systolic arterial pressure (SAP) in this species, although others^{36,51} have not validated this finding. In hypotensive situations, Doppler ultrasonography may be more accurate and precise than other indirect methods^{51,53} and maintains the ability to obtain a reading in low-pressure states.^{51,53,55} Doppler measurements correlate well with direct analysis and are therefore useful in detecting trends.^{51–53,55}

Disadvantages of the Doppler method include the inability to reliably determine diastolic arterial pressure (DAP) and therefore MAP.^{8,53} In addition, Doppler methodology is operator-driven (i.e., it is not automatic) and requires some practice and patience to locate the vessel with the probe.

Advantages of the Doppler method include relatively low cost and technical ease (compared with direct meas-



Figure 6. A Doppler BP monitor on the forelimb of a dog.

urements). Oscillometric monitors have been investigated for use in both anesthetized^{5,9,46,47,55–57} and conscious dogs,^{22,32,35,52} with significant differences in accuracy and efficiency reported. The accuracy of oscillometric technology varies between individual makes and models because of software differences.^{9,46,56} However, in general, oscillometric techniques tend to underestimate direct arterial pressure at normo- and hypertensive values,^{32,35,52,56} with the divergence between direct and oscillometric mea-

Doppler BP monitors tend to underestimate direct BP measurements.

urements), noninvasiveness, and portability. In addition, Doppler methodology is applicable to animals of any size.^{4,8,51,54}

Oscillometric Measurement

Oscillometric BP monitors consist of an appropriately sized cuff, transducer, microprocessor, and display unit. These automatic devices work by detecting oscillations (periodic fluctuations) within the cuff produced by arterial wall motion. As the cuff is deflated, oscillations rapidly increase at the systolic pressure, reach a maximum at the MAP, and then rapidly decrease at the diastolic pressure.^{8,27} The attached electronic monitor displays SAP, MAP, and DAP as well as pulse rate. For most devices, MAP is most closely measured, whereas SAP and DAP are calculated via programmed algorithms.^{4,27,42} Oscillometric devices are available from the manufacturers listed in the box on p. 456.

surements more pronounced at higher pressures.^{9,32,46,52} During hypotension, systolic pressures are often overestimated and precision may be compromised.^{5,58} If sequential values are averaged, oscillometric methods have been shown to be both sensitive (100%) and specific (91%) for hypotension in dogs.⁴⁷

The site of cuff placement can affect accuracy, and every attempt should be made to standardize measurement protocols.^{32,50,52,54} Restraining conscious animals in lateral recumbency to use a limb may be difficult, but placing the cuff at the base of the tail in standing dogs allows satisfactory measurements and is usually well tolerated.^{30,32,52,54,59} The latter technique may be best used in conscious animals because during surgical procedures, the tail may not be readily accessible and blood flow could be compromised to the caudal region.⁹

Oscillometric devices have been studied in both conscious^{50,54} and anesthetized cats.^{42,50,51,53} In this species,

Resources

Oscillometry

CardioCommand, Inc.

Phone 800-231-6370
www.cardiocommand.com

Digicare Biomedical Technology, Inc.

Phone 561-689-0408
www.digicarebiomedical.com

Dinamap (GE Healthcare)

Phone 800-558-5120
www.gehealthcare.com/euen/patient_monitoring/products/imm-monitoring/dinamap

DRE Medical Equipment

Phone 800-462-8195 or 502-244-4444
www.dremed.com

Grady Medical Systems, Inc.

Phone 800-800-2585
www.gradymedical.com

S&B medVet

www.submedvet.com

Sharn Veterinary, Inc.

Phone 800-325-3671
www.sharnvet.com

SurgiVet

Phone 262-513-8500 or 888-745-6562 (United States only)
www.surgivet.com

Doppler ultrasonography

DRE Medical Equipment

Phone 800-462-8195 or 502-244-4444
www.dremed.com

Jorgenson Labs

Phone 800-525-5614
www.jorvet.com

Parks Medical Electronics, Inc.

Phone 800-547-6427
www.parksmmed.com

Vmed Technology, Inc.

Phone 800-926-9622
www.vmedtech.com

Pressure plethysmography

VetSpecs

Phone 678-493-3555 or 800-599-2566
www.vetspecs.com

oscillometric methods also tend to underestimate direct pressure readings, with the error increasing with increasing pressures.^{42,45,50,51,53} Some studies^{42,53} have demonstrated improved accuracy of the oscillometric device in cats compared with other indirect techniques, but other studies^{50,51,54} have not demonstrated this. However, efficiency in obtaining readings, especially during hypotensive states, is low, making the use of this method time-consuming.^{45,51,53,54} Clipping the fur where the cuff will be placed can sometimes allow recording of a previously unobtainable reading but does not improve accuracy of the measurement.⁴⁵

It is generally agreed that oscillometric techniques are most appropriate for use in animals weighing more than 11 lb (5 kg). These methods are less efficient than Doppler techniques because they may not be able to obtain readings as easily, especially in patients with a fast or rapidly changing heart rate, in low-flow conditions, and in cats and small dogs.^{4,45,50,51} Modification of the algorithms used by the processor might make oscillometric techniques more accurate and efficient for animals less than 11 lb (5 kg).^{45,51}

Disadvantages of oscillometric BP monitoring include inconsistency between different devices, decreased efficiency in the presence of shivering or muscle movement,^{47,57} and limited use in small patients. The major advantage of oscillometric technology is that its use requires the least training and clinical skill. In addition, this method is automated, is portable, has alarm capabilities, and provides SAP, DAP, and MAP as well as pulse rate.^{27,57}

Photoplethysmography

In contrast to Doppler and oscillometric methods, photoplethysmography uses transmission of infrared light to detect arterial volume. A constant arterial blood volume is maintained by an inflatable cuff so that the measured cuff pressure equals the intraarterial pressure.^{51,60} The cuff is placed around the metatarsal region just distal to the hock. There have been few veterinary studies, but this technique has been shown to have accuracy similar to that of the Doppler method compared with direct measurements in anesthetized cats.⁵¹ At higher pressures, a slight tendency toward overestimation was noted. This same study⁵¹ demonstrated considerable variability in the data, indicating that each reading must be interpreted cautiously. In addition, the authors had difficulty obtaining readings in darkly pigmented patients. A small study⁶⁰ involving anesthetized dogs demonstrated good correlation and accuracy compared with directly obtained measurements. The major disadvantage of this technology is that its use is restricted to animals weighing less than 22 lb (10 kg) because it was developed for use on human fingers.⁶⁰

Advantages of photoplethysmography include continuous pressure measurements, waveform visualization, and low susceptibility to motion artifact.^{27,30,51,60}

Other Methods

Stethoscopic auscultation has been described in dogs⁶¹ but is generally impractical in clinical practice.⁸ This is the most common method in human medicine and relies on compression of a superficial artery via an inflatable cuff and recognition of pulsatile arterial sounds using a stethoscope over the artery just distal to the cuff. As cuff pressure is reduced, systolic pressure is identified as the cuff pressure at which pulsatile sounds are first heard. As cuff pressure is further reduced, loss of pulsatile sounds indicates the diastolic BP. These Korotkoff sounds are thought to originate from a combination of turbulent blood flow and oscillations of the arterial wall. In domestic animals, the arteries of sufficient size are not superficial enough for routine use.^{4,27} In addition, Korotkoff sounds are soft and low-pitched in dogs and cats.^{8,62}

Ultrasonic kinearteriography involves the use of a Doppler transducer imbedded in a pressure cuff to detect arterial wall motion versus erythrocyte movement as described earlier.⁸ Several investigations^{62–64} of the use of the Doppler shift have used these devices. Older literature^{62,63} indicates that diastolic pressure can be detected with this technology. These devices are not commercially available at this time.

Optical plethysmography involves placement of a pulse oximeter probe distal to a pressure cuff. The probe is connected to a monitor, and return of blood flow after releasing the pressure in the cuff is detected by return of a pulse-oximetry signal. A continuous waveform is displayed as with direct-pressure monitoring. This method has been studied⁵¹ only in cats; the accuracy and precision are similar to those of Doppler sphygmomanometry.

GUIDELINES FOR CLINICAL INTERVENTION

The literature describing normal values for BP in dogs and cats is abundant and quite diverse.^{18,19,22,25,35,36,43,49,62,65} Most studies of both conscious and anesthetized companion animals have yielded normal values higher than those documented in humans. Tables 1 and 2 summarize the literature.

Hypotension

It is generally agreed in the veterinary literature that a systolic pressure of 80 mm Hg or less and an MAP of

60 mm Hg or less are the values at which intervention treatment of hypotension should be considered.^{6,8,11,29} Hypotension that occurs during anesthesia can generally be corrected by reducing the amount of anesthetic gas and thereby decreasing the plane of anesthesia.^{8,29} Increasing the rate of crystalloid fluid administration or adding a colloid may also be indicated and is often the first line of defense in hypotension caused by trauma and sepsis.^{6,66} Hypotension that is nonresponsive to aggressive volume expansion may require the use of vasoactive medications such as dopamine, dobutamine, norepinephrine, epinephrine, or phenylephrine.^{6,29}

Hypertension

When BP is measured in a conscious patient, care should be taken to keep the patient relaxed and calm; this may necessitate the presence of the owner. The upper limits of normal BP in dogs and cats are debatable. It is important to note that detection of a value consistent with hypertension does not necessarily justify intervention. Hypertension isolated from evidence of end-organ damage should be viewed critically because cutoff values are simply guidelines.¹⁹ Investigators have proposed that clinicians be suspicious of a systolic pressure of 150 to 180 mm Hg and a diastolic pressure of 100 mm Hg in cats and dogs.^{20,21,25,26,67} A recent statistical comparison of Doppler and oscillometric techniques versus direct arterial puncture in dogs demonstrated appropriate detection of hypertension with the following values⁶⁸:

- A sensitivity of 71% and a specificity of 86% with a forelimb Doppler reading of 160 mm Hg or higher
- A sensitivity of 65% and a specificity of 85% with a systolic reading of 160 mm Hg or higher via an oscillometric cuff on the distal hindlimb
- A sensitivity of 84% and a specificity of 75% with a systolic reading of 150 mm Hg or higher via an oscillometric cuff on the tail

It is helpful to note that a large epidemiologic study⁶⁹ of dogs conducted over several years demonstrated that although BP can vary greatly between patients, individuals tend to maintain their rank order over time. The cornerstone of controlling hypertension is management of the underlying cause. Various classes of pharmacologic agents are used as necessary, including calcium channel blockers, angiotensin-converting enzyme inhibitors, direct-acting vasodilators, β -blockers, and diuretics.^{21,23}

Table 1. Suggested Normal Blood Pressure Ranges in Dogs

Method	Trade Name	Investigator	Subjects	Systolic (mm Hg)	Diastolic (mm Hg)	Mean (mm Hg)
Direct (Telemetry)	Data Science Co. Transmitter TL10M2-D70	Mishina et al ⁶⁵	Seven conscious dogs	123.4 ± 7.9	74.5 ± 4.9	91.1 ± 5.6
Direct	Eagle 4000 GE	Stepien and Rapoport ³⁵	27 conscious dogs	154 ± 20	84 ± 9	107 ± 11
Doppler	Arteriosonde 1022	Remillard et al ⁶⁷	102 conscious dogs	147 ± 27.7	82.6 ± 15.1	104.1 ± 17.1
Doppler	Parks Model 811-AL	Stepien and Rapoport ³⁵	27 conscious dogs	151 ± 27	Not measured	Not measured or calculated
Oscillometric monitor	Dinamap 1846sx	Bodey et al ³²	1,782 conscious dogs	133 ± 0.49	75.5 ± 0.37	98.6 ± 0.41
Oscillometric monitor	Dinamap 1255	Coulter and Keith ⁴⁹	73 conscious dogs	144 ± 27	110 ± 21	91 ± 20
Oscillometric monitor	USM-700GTM	Mishina et al ²²	102 conscious dogs	118 ± 10.7	67.4 ± 14.4	93.8 ± 15
Oscillometric monitor	Eagle 4000 GE	Stepien and Rapoport ³⁵	27 conscious dogs	150 ± 20	71 ± 18	108 ± 15

Table 2. Suggested Normal Blood Pressure Ranges in Cats

Method	Trade Name	Investigator	Subjects	Systolic (mm Hg)	Diastolic	Mean
Oscillometric monitor	Dinamap 1846sx	Sansom et al ²⁵	94 conscious cats	≤168	Not reported	Not reported
Doppler	Parks Model 811-BTS	Grandy et al ³⁶	16 anesthetized cats	79 ± 20	Not reported	Not reported
Doppler	Parks Model 811	Sparkes et al ⁴³	50 conscious cats	162 ± 19	Not reported	Not reported

CONCLUSION

BP measurement is a valuable tool in small animal practice; however, all methods of BP evaluation have limitations. Table 3 compares the most common methods. Direct arterial pressure is considered the gold standard but is painful, invasive, and relatively time-consuming. Direct measurements are recommended for clinically unstable patients that would benefit from continuous monitoring. On a routine basis, noninvasive measurements are preferred because they are relatively inexpensive, easy to obtain, and fairly accurate. As a group, indirect measurements tend to underestimate direct measurement of BP. However, correlation between direct and indirect methods is typically good and

allows detection in trends. Doppler methodology is reasonably accurate, very efficient, and applicable to patients of any size but can be time-consuming because it is not automated. Oscillometric monitors can also be fairly accurate, have alarm systems, and are automated but tend to fail to obtain readings more often than do other indirect methods. Although each approach to BP measurement has limitations, the principal requirements for any routine procedure are precision and practicality. Intervention should be based on multiple inputs, and any given BP value should be integrated into the clinical picture. BP measurement can be easily performed in general practice and can enhance quality of care on a daily basis.

Table 3. Comparison of Blood Pressure Monitoring Methods

Method	Accuracy ^a	Precision ^b	Efficiency ^c	Ease of Use	Patient Weight
Direct	High	High	High	Low	Any
Doppler	Moderate	Operator dependent	High	Moderate	Any
Oscillometric monitor	Varies	Varies	Often low	High	>11 lb (5 kg)
Photoplethysmography	Moderate	High	High	High	<22 lb (10 kg)

^aAccuracy = proximity of a measured value to the actual value.

^bPrecision = the repeatability of a given measurement.

^cEfficiency = ratio of the number of successful attempts to the number of overall attempts.

REFERENCES

- Hoff HE, Geddes LA, McCrady JD: The contributions of the horse to knowledge of the heart and circulation. 1. Stephen Hales and the measurement of blood pressure. *Conn Med* 13(11):795–800, 1965.
- Naqvi NH, Blafox MB: *Blood Pressure Measurement: An Illustrated History*. Pearl River, NY, Parthenon Publishing Group, 1998, p 4.
- Garner HE, Hahn AW, Hartley JW, et al: Indirect blood pressure measurement in the dog. *Lab Anim Sci* 25(2):197–202, 1975.
- Kittleson MD, Olivier NB: Measurement of systemic arterial blood pressure. *Vet Clin North Am Small Anim Pract* 13(2):321–336, 1983.
- Gains MJ, Grodecki KM, Jacobs RM, et al: Comparison of direct and indirect blood pressure measurements in anesthetized dogs. *Can J Vet Res* 59:238–240, 1995.
- Macintire DK: Hypotension, in Ettinger SJ, Feldman EC (eds): *Textbook of Veterinary Internal Medicine: Diseases of the Dog and Cat*, ed 5. Philadelphia, WB Saunders, 2000, pp 183–186.
- Haskins SC: Monitoring the anesthetized patient, in Thurman JC, Tranquilli WJ, Benson GJ (eds): *Lumb and Jones' Veterinary Anesthesia*, ed 3. Philadelphia, Williams & Wilkins, 1996, pp 409–423.
- Wagner AE, Brodbelt DC: Arterial blood pressure monitoring in anesthetized animals. *JAVMA* 210(9):1279–1285, 1997.
- Sawyer DC, Guikema AH, Siegel EM: Evaluation of a new oscillometric blood pressure monitor in isoflurane-anesthetized dogs. *Vet Anaesth Analg* 31:27–39, 2004.
- Dyson DH: Assessment of three audible monitors during hypotension in anesthetized dogs. *Can Vet J* 38:564–566, 1997.
- Gaynor JS, Dunlop CI, Wagner AE, et al: Complications and mortality associated with anesthesia in dogs and cats. *JAAHA* 35:13–17, 1999.
- American College of Veterinary Anesthesiologists: Anesthesiology guidelines developed: Suggestions for monitoring anesthetized veterinary patients. *JAVMA* 206(7):936–937, 1999.
- Guyton AC, Hall JE: *Textbook of Medical Physiology*, ed 10. Philadelphia, WB Saunders, 2000.
- Bellomo R, Giantomasso DD: Noradrenaline and the kidney: Friends or foes? *Crit Care* 5(6):134–138, 2001.
- Muir WW, Mason D: Cardiovascular system, in Thurman JC, Tranquilli WJ, Benson GJ (eds): *Lumb and Jones' Veterinary Anesthesia*, ed 3. Philadelphia, Williams & Wilkins, 1996, pp 62–114.
- Littman MP: Spontaneous systemic hypertension in 24 cats. *J Vet Intern Med* 8(2):79–86, 1994.
- Kaplan NM: Systemic hypertension: Mechanisms and diagnosis, in Braunwald E, Zipes DP, Libby P (eds): *Heart Disease: A Textbook of Cardiovascular Medicine*, ed 6. Philadelphia, WB Saunders, 2001, pp 941–971.
- Bodey AR, Sansom J: Epidemiological study of blood pressure in domestic cats. *J Small Anim Pract* 39:567–573, 1998.
- Bodey AR, Mitchell AR: Epidemiological study of blood pressure in domestic dogs. *J Small Anim Pract* 37:116–125, 1996.
- Maggio F, DeFrancesco TF, Atkins CE, et al: Ocular lesions associated with systemic hypertension in cats: 69 cases (1985–1998). *JAVMA* 217(5):695–702, 2000.
- Acierio MJ, Labato MA: Hypertension in dogs and cats. *Compend Contin Educ Pract Vet* 26(5):336–346, 2004.
- Mishina M, Watanabe T, Fujii K, et al: A clinical evaluation of blood pressure through non-invasive measurement using the oscillometric procedure in conscious dogs. *J Vet Med Sci* 59(11):989–993, 1997.
- Cooke KC, Snyder PS: Treating hypertension in dogs and cats. *Vet Med* 96(2):151–158, 2001.

24. Finco DR: Association of systemic hypertension with renal injury in dogs with induced renal failure. *J Vet Intern Med* 18(3):289–294, 2004.
25. Sansom J, Rogers K, Wood JL: Blood pressure assessment in healthy cats and cats with hypertensive retinopathy. *Am J Vet Res* 65(2):245–252, 2004.
26. Cooke KC, Snyder PS: Diagnosing systemic hypertension in dogs and cats. *Vet Med* 96(2):145–149, 2001.
27. Grosenbaugh DA, Muir WW: Blood pressure monitoring. *Vet Med* 93(1):48–59, 1998.
28. Paddleford RR: *Manual of Small Animal Anesthesia*, ed 2. Philadelphia, WB Saunders, 1999.
29. Mazzaferro E, Wagner AE: Hypotension during anesthesia in dogs and cats: Recognition, causes, and treatment. *Compend Contin Educ Pract Vet* 23(8):728–735, 2001.
30. Carr AP: Measuring blood pressure in dogs and cats. *Vet Med* 96(2):135–144, 2001.
31. Mohrman DE, Heller LJ: *Cardiovascular Physiology*, ed 5. New York, McGraw-Hill, 2003.
32. Bodey AR, Mitchell AR, Bovee KC, et al: Comparison of direct and indirect (oscillometric) measurements of arterial blood pressure in conscious dogs. *Res Vet Sci* 61:17–21, 1996.
33. de Laforcade AM, Rozanski EA: Central venous pressure and arterial blood pressure measurements. *Vet Clin North Am Small Anim Pract* 31(6):1163–1174, 2001.
34. Waddell LS: Direct blood pressure monitoring. *Clin Tech Small Anim Pract* 15(3):111–115, 2000.
35. Stepien RL, Rapoport GS: Clinical comparison of three methods to measure blood pressure in nonsedated dogs. *JAVMA* 215(11):1623–1628, 1999.
36. Grandy JL, Dunlop CI, Hodgson DS, et al: Evaluation of the Doppler ultrasonic method of measuring systolic arterial blood pressure in cats. *Am J Vet Res* 53(7):1166–1169, 1992.
37. Berne RM, Levy MN: *Cardiovascular Physiology*, ed 8. St. Louis, Mosby, 2001, pp 135–150.
38. Burrows CF: Techniques and complications of intravenous and intraarterial catheterization in dogs and cats. *JAVMA* 163(12):1357–1363, 1973.
39. Geddes LA, Combs W, Denton W, et al: Indirect mean arterial pressure in the anesthetized dog. *Am J Physiology* 238:H664–H666, 1980.
40. Geddes LA, Whistler SJ: The error in indirect blood pressure measurement with the incorrect size of cuff. *Am Heart J* 96(1):4–6, 1978.
41. Valtonen MH, Eriksson LM: The effect of cuff width on accuracy of indirect measurement of blood pressure in dogs. *Res Vet Sci* 11:358–362, 1970.
42. Pedersen KM, Butler MA, Ersbøll AK, Pedersen HD: Evaluation of an oscillometric blood pressure monitor for use in anesthetized cats. *JAVMA* 221(5):646–650, 2002.
43. Sparkes AH, Caney SM, King MC, et al: Inter- and intraindividual variation in Doppler ultrasonic indirect blood pressure measurements in healthy cats. *J Vet Intern Med* 13:314–318, 1999.
44. McLeish I: Doppler ultrasonic arterial pressure measurement in the cat. *Vet Rec* 100:130–131, 1997.
45. Branson KR, Wagner-Mann CC, Mann FA: Evaluation of an oscillometric blood pressure monitor on anesthetized cats and the effect of cuff placement and fur on accuracy. *Vet Surg* 26:347–353, 1997.
46. Hunter JS, McGrath CJ, Thatcher CD, et al: Adaptation of human oscillometric blood pressure monitors for use in dogs. *Am J Vet Res* 51(9):1439–1442, 1990.
47. Meurs KM, Miller MW, Slater MR: Comparison of the indirect oscillometric and direct arterial methods for blood pressure measurements in anesthetized dogs. *JAAHA* 32:471–475, 1996.
48. Kallet AJ, Cowgill LD, Kass PH: Comparison of blood pressure measurements obtained in dogs by use of indirect oscillometry in a veterinary clinic versus at home. *JAVMA* 210(5):651–654, 1997.
49. Coulter DB, Keith JC: Blood pressures obtained by indirect measurement in conscious dogs. *JAVMA* 184(11):1375–1378, 1984.
50. Haberman CE, Morgan JD, Brown SA: Evaluation of Doppler ultrasonic and oscillometric methods of indirect blood pressure estimation in conscious and anesthetized cats, unpublished data, 1997.
51. Binns SH, Sisson DD, Buoscio DA, et al: Doppler ultrasonographic, oscillometric sphygmomanometric and photoplethysmographic techniques for non-invasive blood pressure measurement in anesthetized cats. *J Vet Intern Med* 9(6):405–414, 1995.
52. Haberman CE, Kang CW, Morgan JD, et al: Evaluation of Doppler ultrasonic and oscillometric methods of indirect blood pressure estimation in conscious beagles, unpublished data, 1997.
53. Caulkett NA, Cantwell SL, Houston DM: A comparison of indirect blood pressure monitoring techniques in the anesthetized cat. *Vet Surg* 27:370–377, 1998.
54. Jepson RE, Hartley V, Mendl M, et al: A comparison of CAT Doppler and oscillometric memoprint machines for non-invasive pressure measurement in conscious cats. *J Feline Med Surg* 7:147–152, 2004.
55. Chalifoux A, Dallaire A, Blais D, et al: Evaluation of the arterial blood pressure of dogs by two noninvasive methods. *Can J Comp Med* 49(4):419–423, 1985.
56. Bodey AR, Young LE, Bartam DH, et al: A comparison of direct and indirect (oscillometric) measurements of arterial blood pressure in anaesthetised dogs, using tail and limb cuffs. *Res Vet Sci* 57:265–269, 1994.
57. Hamlin RL, Kittleson MD, Rice D, et al: Noninvasive measurement of systemic arterial pressure in dogs by automatic sphygmomanometry. *Am J Vet Res* 43(7):1271–1273, 1982.
58. Sawyer DC, Brown M, Striker EL, et al: Comparison of direct and indirect blood pressure measurement in anesthetized dogs. *Lab Anim Sci* 41(2):134–138, 1991.
59. Vincent IC, Michell AR, Leahy RA: Non-invasive measurement of arterial blood pressure in dogs: A potential indicator for the identification of stress. *Res Vet Sci* 54:195–201, 1993.
60. Taburu H, Watanabe H, Tanaka M, et al: Non-invasive measurement of systemic arterial pressure by Finapres in anesthetized dogs. *Jpn J Vet Sci* 52(2):427–430, 1990.
61. Harvey J, Falsetti H, Cooper P, et al: Auscultatory indirect measurement of blood pressure in dogs. *Lab Anim Sci* 33(4):370–372, 1983.
62. Wessale JL, Smith LA, Reid M, et al: Indirect auscultatory systolic and diastolic pressures in the anesthetized dog. *Am J Vet Res* 46(10):2113–2132, 1985.
63. Weiser MG, Spangler WL, Gribble DH: Blood pressure measurement in the dog. *JAVMA* 171(4):364–368, 1977.
64. Freundlich JJ, Detweiler DK, Hance HE: Blood pressure determination by ultrasound Doppler. *Curr Ther Res* 14(2):73–80, 1972.
65. Mishina M, Watanabe T, Matsuoka S, et al: Diurnal variations of blood pressure in dogs. *J Vet Med Sci* 61(6):643–647, 1999.
66. Kirby R, Rudloff E: Fluid and electrolyte therapy, in Ettinger SJ, Feldman EC (eds): *Textbook of Veterinary Internal Medicine: Diseases of the Dog and Cat*, ed 5. Philadelphia, WB Saunders, 2000, pp 325–347.
67. Remillard RL, Ross JN, Eddy JB: Variance of indirect blood pressure measurements and prevalence of hypertension in clinically normal dogs. *Am J Vet Res* 52(4):561–565, 1991.
68. Stepien RL, Rapoport GS, Henik RA, et al: Comparative diagnostic test characteristics of oscillometric and Doppler ultrasonographic methods in the detection of systolic hypertension in dogs. *J Vet Intern Med* 17:65–72, 2003.
69. Bodey AR, Michell AR: Longitudinal studies of reproducibility and variability of indirect (oscillometric) blood pressure measurements in dogs: Evidence for tracking. *Res Vet Sci* 63(1):15–21, 1997.

ARTICLE #3 CE TEST



*This article qualifies for 2 contact hours of continuing education credit from the Auburn University College of Veterinary Medicine. **Paid subscribers may purchase individual CE tests or sign up for our annual CE program.** Those who wish to apply this credit to fulfill state relicensure requirements should consult their respective state authorities regarding the applicability of this program. To participate, fill out the test form inserted at the end of this issue or take CE tests online and get real-time scores at **CompendiumVet.com**. Test answers are available online free to paid subscribers as well.*

1. Which is not associated with secondary systemic hypertension?

- a. renal disease
- b. Cushing's disease
- c. hyperthyroidism
- d. cholangiohepatitis

2. Which statement is incorrect?

- a. Determinants of arterial BP include CO, systemic vascular resistance, and blood volume.
- b. SAP is the major determinant of organ perfusion pressure.
- c. Cardiac relaxation lasts longer than cardiac contraction.
- d. Pulse pressure is the difference between systolic and diastolic pressure.

3. Intervention treatment of hypotension is recommended at _____ mm Hg.

- a. an SAP of 60
- b. an MAP of 45
- c. an MAP of 60
- d. a DAP of 30

4. Which statement regarding direct arterial monitoring is correct?

- a. Artifactual changes in direct arterial readings are impossible.
- b. Healthy animals undergoing routine surgical procedures are commonly monitored with direct arterial catheterization.
- c. Waveform analysis is possible and can provide information about the patient as well as monitoring equipment.
- d. Direct arterial monitoring of BP is noninvasive.

5. The cuff width for oscillometric and Doppler monitors

- a. should be 30% to 40% of the width of the appendage.
- b. should be 20% to 30% of the circumference of the appendage.
- c. should be 30% to 40% of the circumference of the appendage.
- d. does not affect pressure readings.

6. In general, Doppler BP measurements tend to _____ direct arterial pressure measurements.

- a. underestimate
- b. overestimate
- c. agree with
- d. have no relation to

7. The advantages of oscillometric devices do not include

- a. alarm capabilities.
- b. efficiency for use in animals of any size.
- c. automation.
- d. the ability to obtain a reading in the presence of muscle movement.

8. Photoplethysmography

- a. has been widely studied in veterinary patients.
- b. is easily used in large dogs.
- c. detects arterial wall motion.
- d. allows waveform analysis.

9. When intervention is warranted for hypotension in an anesthetized patient, the first step is to

- a. increase the fluid rate.
- b. administer vasopressors.
- c. decrease the depth of anesthesia.
- d. increase the depth of anesthesia.

10. Hypertension can be suspected at

- a. SAPs of 100 mm Hg or higher.
- b. SAPs of 150 mm Hg or higher.
- c. DAPs of 80 mm Hg or higher.
- d. MAPs of 80 mm Hg or higher.