BLOOD PRESSURE MEASUREMENT

Part 1: Technology and Avoidance of Measurement Error

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There are many indications for blood pressure measurement and the valuable diagnostic information it provides. Consequently, many veterinarians would like to be able to make such measurements more frequently. On the other hand, they may be uncertain about technical issues, such as how to select the best type of system for their needs and how to avoid measurement error. There is a solution to both problems.

Many failed attempts to measure blood pressure can be ascribed to a lack of focus during the measurement process. An examiner who is distracted by the animal owner or staff members while taking the measurements, who is pressed for time, or who is irritated by the thought of having to take blood pressure (BP) measurements will hardly be able to obtain a valid reading.

Concrete Facts

In order to obtain rapid and valid blood pressure measurements, it is essential to have the necessary conviction and will to measure the blood pressure.

The accuracy and validity of the results and, thus, the success of BP measurement, is largely dependent on three types of factors:

- Equipment-related
- Operator-related (proper performance of measurement procedure)
- Animal-specific / stress-related

Which Technology Provides Which Advantages?

Today, there are basically three types of commercial blood pres-sure measurement systems with their own specific features and capabilities (Table 1). Studies conducted in the last 3 years have illustrated the various advantages and disadvantages of the available non-invasive blood pressure measurement systems. These differences can influence the accuracy measurements or the conditions for measurement performance.

Stepien et al. (2003) found that the accuracy of Doppler and oscillometric BP measurement systems becomes limited at pressures above 160 mmHg, which they defined as the **cutoff value**. Discrepancies of both systems in the high pressure range have been confirmed by many other investigators.

The five points listed below would appear to be key variables (Table 1):

- Gain and signal sampling
- Artifact recognition
- Valve characteristics
- Pulse-dependent linear deflation rate
- Processor speed and sampling rate

Glossary

Deflation rate: Speed of cuff deflation in mmHg per minute. In humans, 3 mmHg per minute is the rate at which one can measure one heartbeat per second, assuming the pulse is 60 beats per minute at the standard starting pressure (180 mmHg). If the pulse is faster, the deflation rate should be increased accordingly.

Sampling rate: Slice-by-slice signal resolution as in computed tomography.

Doppler: Doppler measurements are generated using two independent devices: the sphygmomanometer/cuff unit and an ultrasound sensor with amplifier and speaker. Since the cuff is inflated and deflated manually, a constant deflation rate cannot be achieved. Doppler systems measure the pressure in the cuff, not in the blood vessel, at the time of incidence of the acoustic signal, which can be heard on the speaker.

Fuzzy logic controller: Calculates the probable blood pressure of incoming signals, including artifacts.

Gain: Amplifies the pressure amplitude signal.

Feedback loop: Function by which a blood pressure measurement device can be set to perform automatically triggered measurements at set intervals. This function is mainly used in anesthesia monitoring, but also in the monitoring of intensive-care patients.

Oscillometry: Measurement of pulse wave-related oscillations in the wall of an artery. The signals are detected by a pressure transducer and converted to blood pressure values. The strongest oscillation or "maximum oscillation" is defined as the mean arterial pressure. An algorithm is used to convert these values to systolic and diastolic pressure readings.

HDO: High-definition oscillometry permits ultra-precise pulse recognition and thus makes it possible to recognize artifacts. HDO systems measure arterial wall oscillations (vibrations) produced by the incident pulse waves. A special algorithm is used for detection of presystolic amplitudes as well as of systolic (SAP), diastolic (DAP), and mean arterial pressures (MAP) (Fig. 1).

Glossary

High-definition oscillometry systems can differentiate between pulse waves and artifact signals. Their processors can analyze and measure individual pressure ranges separately and within microseconds. The processors used in classical oscillometry systems lack the speed and sensitivity to perform these functions.

Processor: The processor is entirely responsible for the calculation performance of an electronic device or computer. The higher the processor's capacity, the faster controls and adjustments can be carried out based on these computations. Conventional processors have a capacity of 8 or 16 bits. The latest generation of processors has 32-bit capacity. A 32-bit processor can perform calculations with a time lag of less than one microsecond. This permits real-time valve control and adjustment, which in turn allows for linear deflation of the valve across the entire pressure range. Slower processors do not have this capability. Since their regulatory and control circuits are too slow to allow programming of a valve across a defined linearity range, these systems develop measurement error in high and low pressure ranges.

Feedback loop: Instead of switching off, the device attempts to repeatedly analyze the range with the strongest signals (usually artifacts, sometimes the mean arterial pressure) by slightly re-inflating the cuff. The resulting mean value is used to calculate the systolic and diastolic blood pressure. Caution: Artifacts emit very strong signals that can be falsely identified as blood pressure signals.

Valve characteristics: Valves are used to regulate the cuff deflation rate. The factory preset linearity value is (70) 80–160. When used to measure high or low-pressure ranges, the valve must be programmable for real-time analysis. If not, it will be unable to perform linear deflation, which is needed to obtain accurate measurements. Mechanical valves are less sensitive than electronic valves. Furthermore, they cannot be programmed.

Importance of Real-time Analysis

Real-time analysis (Table 1) makes it possible to have signal amplification and resolution of individual amplitude signals several times above the capacity of the human ear. A system must be real-time capable in order to differentiate between presystolic amplitudes, increasing amplitudes (e.g., systolic pressure), maximum arterial pressure (MAP), decreasing amplitudes (i.e., diastolic pressure) and artifacts.

Costs and Cost Amortization

As with all technological systems, the cost of medical technology is decreasing over time. The acquisition prices of blood pressure systems are now in a range that ensures rapid amortization of costs. Typical prices are listed below:

- Doppler systems (including necessary accessories): approx. 800 to 1100 euros
- Oscillometric systems: approx.. 1200 to 3000 euros, depending on features
- HDO systems for veterinary practice: approx. 600 to 1400 euros

According to one survey, the actual fee charged for blood pressure measurement is 10 to 20 euros (listed as 7 euros in the German GOT fee schedule). Additional income for the veterinary practice is generated not only by the blood pressure measurement themselves, but also by the follow-up examinations and treatments frequently associated with them. The related increase in customer satisfaction is another important aspect. Assuming the fee is only 10 euros per measurement for only 2 patients per day, an amortization of costs for most blood pressure systems could be achieved within as little as 3 months.

Which System Is Best for You?

Both the ACVIM Hypertension Consensus Group and the Veterinary Blood Pressure Society (VBPS) formally recognize all three methods as non-invasive techniques for veterinary blood pressure measurement, provided no equipment intended for use in humans is used.

Humans and animals have very different types of pressure wave amplitudes. Blood pressure measurement systems intended for use in humans are therefore unsuitable for use in animals. Even if it were possible to detect measurement signals, it would not be possible to obtain reliable and correct measurement results.

Whenever possible, high-definition oscillometry should be used instead of conventional oscillometry. In addition to measuring the systolic and the diastolic pressure, HDO systems also determine the mean arterial pressure and the pulse rate. Doppler systems are associated with a risk of false interpretation of mean instead of systolic arterial pressure. Conventional and high-definition blood pressure measurements systems do not have this problem.)

Concrete Facts

Veterinarians who also treat a significant number of cats and small pets in addition to dogs will find High Definition Oscillometry to be not only the fastest and most precise BP measurement system, but also the simplest.

If an HDO system is used, it should be hooked up to a PC via a USB cable in order to observe the measurements on-screen. In many cases, the ability to visualize not only pressure amplitudes, but also arrhythmias and artifacts, greatly facilitates the interpretation of measurements.

Standard Procedure: The Key to Success

Everyone who has gone to their family doctor knows that blood pressure measurement is a quick and simple preliminary examination.

Table 1: Technical features of the different blood pressure measurement systems

	Doppler	Conventional Oscillometry	High-definition Oscillometry (HDO)
Gain	Acoustic detection of the return of blood flow (dependent on the examiner's individual hearing capacity and reaction speed at which the examiner can visually observe and mentally register the numbers on the sphygmomanometer gauge)	Fixed preset values for recognition of pulse waveforms and amplitudes	Allows manual adjustment of amplitude recognition settings (amplification) for each individual patient (range: 100 to 560 X)
Artifact recognition	Not possible	Two approximation strategies are used (depending on manufacturer) • Fuzzy logic • Feedback loop	Recognized artifacts are eliminated and do not interfere with measurements
Valve action	Mechanical valve; Linearity from ~160–80 mmHg	Mainly mechanical valves; Linearity from ~160–80 mmHg	Electronic valve Can detect and regulate pressure within microseconds; precise measurement is therefore possible, even outside the 160–80 mmHg range
Pulse-dependent linear deflation rate / cutoff value	Valve-determined cutoff value at approx. 160 mmHg; Since the mechanical valve is opened manually, linear deflation of cuff is not possible	Valve-determined cutoff value at approx. 160 mmHg; Valve is opened automatically (mechanical or electronic valves, the sensitivity of which can be adjusted more or less variably); Real-time analysis and, hence, real-time valve programming is not possible (8-bit processor);	Valve-determined cutoff value at approx. 160 mmHg; Real-time analysis and real-time valve programming is possible in the 5–300 mmHg pressure range (32-bit processor)
Processor speed and sampling rate	Real-time analysis not possible; Dependent on the examiner's hearing and reaction capacity; Detailed analysis not possible	Real-time analysis not possible; Permits pulse rate-dependent analysis (160–250 max., depending on the system), on average, of one entire amplitude in a maximum measurement range of 0–250 mmHg	Permits real-time analysis; Provides much higher resolution and permits analysis within micro-seconds; can therefore detect even the smallest signals and measure extremely high heart rates of 400 beats/min and higher

The entire BP measurement procedure rarely takes longer than 1-2 minutes. Then why is the procedure so much more complicated in veterinary medicine? Because, for example:

- Dogs and cats do not sit down and relax when you tell them to;
- The visit to the veterinarian causes excitement;
- Cats have their own concept of "short" and "long";
- Intensive purring, "pawing" and other feline relaxation activities produce massive artifacts.

So is frustration an inevitable part of small animal blood pressure measurement? NO! Not if the animal and the examiner follow certain rules. A **standard measurement procedure** is the first step towards obtaining rapid and valid BP measurements. Important factors to consider are described below.

Timing: Blood pressure measurements should always be taken after a short acclimation period and before the clinical examination.

Designated examiner: At least one person in each small animal practice or clinic should be designated and trained to perform blood pressure measurements. The designated examiner should preferably be a veterinary assistant, who should execute the measurements according to a standard procedure. This individual must a) be good with animals in general but with dogs and cats in particular and b) be patient and reliable.

Table 2: Implications of the different technologies for practical applications

	Doppler	Conventional oscillometry	High-definition oscillometry (HDO)
Specified measurement range	0–300 mmHg	0–300 mmHg	0–300 mmHg
Theoretical precision	~ 80–160 mmHg (valve) and user-dependent	~ 80–160 mmHg (valve) < 250 mmHg (processor)	0–450 mmHg (valve and processor)
Actual precision	? (User-dependent)	~ 80–160 mmHg	5–300 mmHg
Use of patient-specific measurement variables	Not possible	Manufacturer-dependent, maximum inflation pressure	Automatic calibration or manual adjustment of maximum inflation and deflation pressures, deflation rate and gain may be possible
Cuff volume recognition	NO	NO	YES
Time per measurement in cats	approx. 30 seconds to 2 minutes *	approx. 40 seconds to 2 min **	8–15 seconds ***
Measurement despite arrhythmia	Not possible	Limited (fuzzy logic) / Not possible	Possible
Sensitivity at low amplitudes °	Limited; There is no gain option since signal amplification is linked with noise amplification	Manufacturer-dependent limitations; Preset optimizer for cats (Memoprint)	Gain options: 50–1200 MD Science; 100–560 MDPro; 140–400 MD90; 280–560 MD15
Deflation rate °°	»Click« at 3 mmHg/min; otherwise not definable	Generally 3 mmHg/sec; Cardell: 3–7 mmHg/sec; Memoprint: 3–6 mmHg/sec	Individual and pulse-dependent adjustment from 3–21 mmHg/sec
High heart rate	Impedes measurement considerably	Manufacturer-dependent limitations occur at 160 bpm and higher	≤ 400 beats per minute (bpm) with MD15, MD90, MD Pro; > 400 bpm possible with MD Science
Provision of measurement results	Acoustic signal, cuff pressure read from sphygmomanometer dial	Digital display of SAP, DAP, MAP (depending on manufacturer), and pulse	Real-time display of results on screen of laptop or PC (Fig. 1) or digital display for users without PC connection; graphics display can be analyzed on PC at a later time
Telemedicine capabilities [1]	NO	NO	YES
Measurements during anesthesia	May be limited (depending on which anesthetic is used)	May be limited (depending on which anesthetic is used)	No limitations apply
Measurement at very low pressures (SAP < 60 mmHg)	Not possible	Not possible	Possible
Automated monitoring function	NO	Feedback loop function on some systems (manufacturer-dependent)	Feedback loop function, real-time measurement recording and on-screen presentation

* Dependent on factors like patient cooperation, signal strength, hearing capacity of user, and manual valve opening rate, etc.
** Mainly dependent on patient cooperativeness and therefore on (manufacturer-dependent) availability of fuzzy logic and feedback loop functions for artifact elimination.
*** Dependent on heart rate: the higher the heart rate, the faster the measurement.
° Small amplitudes are mainly attributable to small-diameter blood vessels (small animals, caudal artery, etc.) but also to impaired arterial elasticity (assess CNI as needed).
°° The higher the heart rate, the higher the deflation rate. Effects: a) To achieve as accurate a measurement as possible b) while simultaneously shorting the measurement time.
1 Transmission of measurements to an expert for assessment

Measurement procedure: Blood pressure measurements should be taken following a standard procedure (see box).

The measured BP is the average of all individual measurements--systolic and diastolic, respectively. Even if only one of the two pressures is elevated, the resulting hypertension can result in damage to organ systems, particularly the eye, heart, kidney and central nervous system.

If the blood pressure is high but it is not possible to identify any end organ damage or primary disease, the blood pressure should be reassessed on the following day (or within a short period). Background noise and distractions should be avoided during blood pressure measurement.

Since the blood pressure may also be elevated due to obesity or pain, these differentials must be considered and excluded.

If the examiner can create a relatively calm environment and does not send out any negative signals to the patient (agitation, time pressure, etc.), the patient will quickly become acclimated and the blood pressure can be measured without great fluctuations. The examiner's attention should always be focused on the patient. Furthermore, examiners should be mindful of the effects of the surroundings and of their own behavior on the blood pressure measurements while they follow the course of the measurements, for example, on a computer screen. This will make it considerably easier to interpret and discuss the measurement results after completion of measurements.

Procedure for blood pressure measurement (in accordance with the ACVIM Hypertension Consensus Group and Veterinary Blood Pressure Society guidelines)

Beginning: Let the patient get acquainted with the equipment and person taking the measurement.

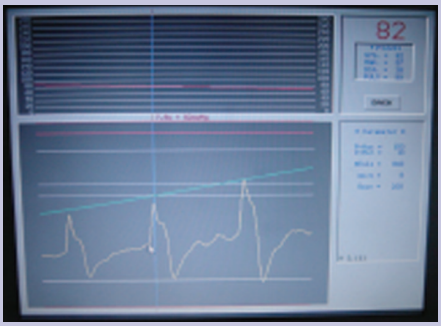
Positioning the patient: Place the animal in a relaxed position. Dogs: Preferentially place the animal in a down or laterally recumbent position; a standing position can be used if necessary. Next, apply the cuff to the tail. Cats and toy breed dogs: Measurements are generally taken with the animal lying on the owner's lap. Important: Take measurements at the level of the heart +/- 10 cm.

Applying the cuff: The cuff should ALWAYS be applied at the same site, e.g., below the elbow joint of a forelimb or on the root of the tail. The position should be specified as an internal practice standard or should be specified by the examiner. If it is necessary to take the measurements in another position (e.g., at the root of the tail of animals with acute congestive heart failure and dyspnea, who should never be placed in a recumbent position then this must be recorded in the patient file. The cuff should be applied snugly but not too tight (the little finger should fit underneath).

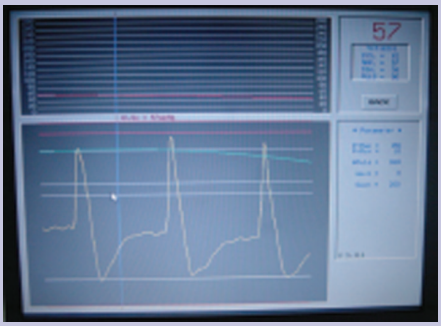
Owner conduct: Owners should be instructed to abstain from conversation during the BP measurement procedure (all 3-5 measurements).The owner may speak to and/or pet the animal gently (not too forcefully since this could produce artifacts) to calm the patient, but may not speak to the examiner.

Number of measurements: Depending on the degree of measurement variation that occurs due to white coat effect, excitation, etc., the measurement series should consist of 3 readings (fluctuations ≤ 20 mmHg) or 5 readings (fluctuations > 20 mmHg).

Fig. 1: Dog under anesthesia (isoflurane). Blood pressure: systolic 82, diastolic 38, mean arterial pressure (MAP) 57. No pathologic arrhythmias. Deflation rate 9 mmHg/sec, gain 200 (low pressure and weak amplitudes = high amplification required).



a: Representative systolic pressure curve (magnified)



b: Representative MAP pressure curve (magnified)

c: Representative diastolic pressure curve (magnified)

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Individual and Excitatory Effects

Excitatory stimuli lead to a sudden release of catecholamines, the concentration of which varies from one individual to another. This can produce considerable fluctuations in the blood pressure. Excitatory fluctuations are often triggered by staff members coming in and out of the examining room or by the ringing of a telephone, but may also be due to gestures made by the examiner that seem intimidating to the animal. The animals often sit quietly—but not relaxed—on the examination table and watch and change their ear position according to the vibrations they perceive. Examiners usually do not notice these changes unless they are focused on the animal while also being receptive for these stimuli. Therefore, it is extremely important to not let oneself be distracted while taking blood pressure measurements.

The "**white coat effect**" produces a longer-term excitatory change in the blood pressure. It generally results in a pronounced increase in the blood pressure, but there are known cases in which the blood pressure has decreased, presumably due to parasympathetic overactivation.

"White coat hypertension" is immediately recognizable and usually subsides within a few minutes. "White coat hypotension", on the other hand, sometimes occurs during the course of a measurement. In these cases, lower blood pressure readings may be observed.

In both cases, examiners should perform control measurements to rule out true anomalies. Frequently, the blood pressure must be measured at home in order to do so. The practice can lend the owner a BP measurement device for this purpose. An increasing number of owners are asking about the general possibility to monitor their pet's blood pressure at home. This is a very welcome trend for the future since it could permit the generation of multiple blood pressure curves, which are diagnostically much more sensitive than single measurements.

More frequent blood pressure measurement would be a particularly beneficial for patients with heart and kidney diseases. It would make it much easier to assess owner compliance in addition to monitoring the effects of the prescribed treatments (ACE inhibitors with or without calcium channel blockers, as needed, beta-blockers, calcium sensitizers, diuretics, infusion therapy, etc.).

Part 2 will describe in detail the interpretation of blood pressure measurements and the implications thereof, including the creation of an individually optimized treatment plan.

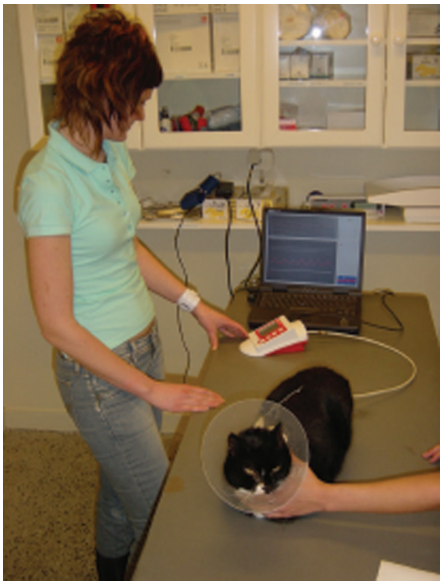

Fig. 2: Relaxed blood pressure measurement is also possible in cats. The cuff is placed on the tail or a forelimb. Tail measurements are much less susceptible to interference from animal movements.

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