The understanding of blood pressure and its disorders in companion animals as well the technology for blood pressure measurement have evolved dramatically over the last 15 years. Much more as in human medicine, monitoring this very important parameter plays a key role in diagnosing disease and the initiation and fine-tuning of therapy. This parameter also offers valuable insight into the likelihood of hypertensive target organ damage or the risk of hypoperfusion and organ compromise in association with hypotension. As a consequence, blood pressure monitoring has become a more routine procedure in many veterinary clinics worldwide.

### SUMMARY

The understanding of blood pressure and its disorders in companion animals as well the technology for blood pressure measurement have evolved dramatically over the last 15 years. Much more as in human medicine, monitoring this very important parameter plays a key role in diagnosing disease and the initiation and fine-tuning of therapy. This parameter also offers valuable insight into the likelihood of hypertensive target organ damage or the risk of hypoperfusion and organ compromise in association with hypotension. As a consequence, blood pressure monitoring has become a more routine procedure in many veterinary clinics worldwide.

### The role of blood pressure (BP) in overall patient evaluation

Kidney disease, diabetes mellitus, hyperthyroidism and hyperadrenocorticism are the main causes of a pathologic rise in blood pressure in small animal patients [1]. Pain (especially acute pain), obesity and other uncommon diseases like a pheochromocytoma can cause elevated blood pressures as well. Hypotension is most commonly encountered during anesthesia and in critically ill patients suffering from trauma, poisoning, shock or severe heart failure. Both hypertension and hypotension can be caused by drugs as well. Given the varied causes of low and high blood pressure it is clear that there are a multitude of indications to measure blood pressure. Routine annual evaluation in healthy animals and frequent monitoring in at-risk patients would be medically sound practice.

### Abnormalities in Blood Pressure

Blood pressure is - physiologically - one of the most tightly controlled parameters in humans and animals, since maintaining blood pressure is vital for guaranteeing normal organ function. Both hypertension and hypotension can limit life expectancy and quality of life, especially if the abnormality persists for long time periods or if the changes are dramatic. Baroreceptors, chemoreceptors, and the central pressure control in the medulla oblongata are the main components of the control system that aims to secure adequate perfusion by maintaining normal blood pressures. The main effector system is the Renin-Angiotensin-Aldosterone system. Additionally catecholamines, ANP, Prostaglandins etc. play a vital role.

Short term and long term compensatory mechanisms can be activated to keep blood pressure within a physiological range. However with certain diseases, these mechanisms don’t work adequately any more and thus hypertension or hypotension develop.

### Hypertension

Most commonly companion animals suffer from secondary hypertension, that is there is an underlying disease causing blood pressure to rise (see table 2). In humans the term
primary or essential hypertension is commonly used when an underlying reason is not found for elevated blood pressure. This term is not appropriate in veterinary medicine. In those cases, where an underlying causative disease cannot be identified, the term idiopathic hypertension should be used. [1] Another common cause for high blood pressure readings is white-coat-hypertension, which is not a true hypertensive state, rather a short term response to a stressful situation. [10].

According to the Guidelines of the ACVIM Hypertension consensus panel [2] and the Veterinary Blood Pressure Society (www.vbps-online.org) hypertension is defined according to its risk for target organ damage (TOD) (Table 3).

Isolated diastolic hypertension can cause TOD as can isolated systolic hypertension. Because of this it is always strongly recommended to measure both systolic and diastolic pressure and to evaluate the patient for hypertension based on both values.

Deciding when to initiate therapy for hypertension can be a challenge since white coat hypertension can lead to inappropriate therapy. Of course if target organ damage is present, especially ocular or CNS signs, treatment should be initiated. In those cases where TOD is not apparent and pressures are not dangerously elevated, repeated measurements over the following days are recommended to verify hypertension, preferably at least on 3 occasions. If the results are still unclear or the patient is uncooperative in the clinic setting, consideration should be given to having the pet owner measure blood pressure at home. Ideally blood pressure monitoring systems should offer memory and download functions (HDO) so that the results can be critically reviewed afterwards by the veterinarian.

If repeated measurements or the presence of target organ damage confirm pathologic hypertension, the next steps depend on the severity and presence of TOD:

**Minimal Risk of TOD: <150/95** but above the species specific normal value; no treatment is recommended. In the presence of other symptoms which might indicate an underlying disease, efforts should be made to diagnose this disease and treat it if possible.

Blood Pressure should be re-evaluated at least once a year.

**Mild Risk of TOD: <160/100**

The main focus should be put on diagnosing any underlying disease and treatment of those diseases. The patient’s blood pressure should be frequently re-evaluated. If TOD is present additional medications may be needed. Treatment of hypertension, potentially treating the underlying disease may be adequate to treat this degree of hypertension. Target value: <150/95. ACE-I are often used as they are beneficial in heart and renal disease but also lower blood pressure up to 20 mmHg.

**Moderate Risk of TOD: <180/120**

TOD and the benefits of hypertensive therapy have been established for BP in this range [4,5,6,7,8,9]. Particular efforts should be put into diagnosing not only potential underlying diseases but also TOD. Again, treatment should be directed towards the causative diseases and secondarily - if necessary, additional drugs (e.g. Amlodipine for hypertension).
### Table 2: Haemodynamic mechanisms of disease associated with hypertension

<table>
<thead>
<tr>
<th>Disease</th>
<th>Haemodynamic Mechanism</th>
<th>Cardiovascular Effects</th>
<th>Periphery</th>
<th>Initial BP changes</th>
<th>Later BP changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart disease</td>
<td>Catecholamine release, RAAS activation</td>
<td>Heart rate ↑, SV ↑ (DCM in early stages only) → CO ↑; myocardial tone decreases as heart failure progresses → CO ↓</td>
<td>Vasoconstriction, volume retention increased preload and afterload</td>
<td>↑ May temporarily appear normal</td>
<td>↓ to ↓↓</td>
</tr>
<tr>
<td>Kidney disease</td>
<td>RAAS activation, growth factors</td>
<td>LV hypertrophy → heart rate ↑, SV ↑ → CO ↑</td>
<td>Vasoconstriction (kidney: → increased filtration pressure → ... → glomerulosclerosis), volume retention &gt;&gt; increased preload/afterload</td>
<td>↑</td>
<td>↑↑ (↑)</td>
</tr>
<tr>
<td>Hyperthyroidism</td>
<td>Increased beta-adrenergic activity, RAAS activation, eventually secondary nephropathy</td>
<td>Heart rate ↑, SV ↑, ventricular hypertrophy → CO ↑</td>
<td>Vasoconstriction, volume retention increased preload/afterload</td>
<td>↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Hyperadrenocorticism</td>
<td>Catecholamine synthesis, α and β receptor stimulation, RAAS activation, vasopressor effects ?</td>
<td>Heart rate ↑, SV ↑, CO ↑, LV hypertrophy</td>
<td>Vasoconstriction, volume retention increased preload/afterload</td>
<td>↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>Diabetic nephropathy, lipid metabolism disturbance → vasculopathy</td>
<td>Heart rate ↑, CO ↑, LV hypertrophy</td>
<td>Vessel changes, vasoconstriction, later volume retention</td>
<td>↑</td>
<td>↑↑</td>
</tr>
<tr>
<td>Acromegaly</td>
<td>Increased aldosterone secretion, increased sodium and water retention</td>
<td>Unknown (somatotropin-induced hypertrophy?)</td>
<td>Volume retention increased preload</td>
<td>(↑)</td>
<td>(↑)</td>
</tr>
<tr>
<td>Hyperestrogenism</td>
<td>Vasoconstriction, volume retention increased preload/afterload</td>
<td></td>
<td></td>
<td>(↑)</td>
<td>(↑)</td>
</tr>
<tr>
<td>Pheochromocytoma</td>
<td>Catecholamine secretion (massive, often episodic), stimulation of renin release</td>
<td>Heart rate ↑, SV ↑, CO ↑</td>
<td>Vasoconstriction ↑</td>
<td>↑↑↑</td>
<td>↑↑↑</td>
</tr>
<tr>
<td>Primary hyperaldosteronism</td>
<td>Increased secretion of mineralocorticoids, especially aldosterone</td>
<td>Unknown</td>
<td>Volume retention</td>
<td>(↑)</td>
<td>↑</td>
</tr>
<tr>
<td>Neurological changes</td>
<td>Lesions of diencephalon, pain → sympathetic nervous activity → catecholamine secretion ↑</td>
<td>Heart rate ↑, SV ↑, CO ↑</td>
<td>Vasoconstriction</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Anemia</td>
<td>Chemoreceptors sense oxygen deficit</td>
<td>Heart rate ↑, SV ↑, CO ↑</td>
<td>Vasoconstriction</td>
<td>↑</td>
<td>↑</td>
</tr>
</tbody>
</table>

**Severe Risk of TOD: >180/120**

It is unlikely that white-coat hypertension would cause such high values [2]. If no TOD is present, repeating blood pressure readings several times over the next few hours can help to eliminate white-coat hypertension as a differential. TOD is very likely to develop with sustained blood pressures in this range. Therefore - if the underlying disease can not be identified and treated promptly or in a case where blood pressure is above 200/130 antihypertensive medication should be initiated immediately and diagnosis of the disease should be the next goal. Treatment can than be adjusted according to the individual patient presentation. With TOD present, a more rapid reduction of blood pressure is warranted. Amlodipine is a commonly used Ca-Channel blocker for that purpose. It acts mainly on the arterial walls and has almost no effects on the heart (16.1).

In this stage very often combinations of drugs are necessary. Especially proteinuria at present, ACE-I play an important role to stabilise the patient both with regard to blood pressure and with regard to kidney status.

**Hypotension**

Hypotension is quite common in daily veterinary practice. Hypotension in awake animals can be found with advanced stages of heart disease, with arrhythmias (bradycardia and tachycardia), with cardiac tamponade, hypoxia, sepsis, shock etc. Hypotension is extremely common in anaesthetised patients and is the main adverse side effect of anaesthesia. (like a cute renal failure).
Severity of hypotension is linked to the risk of malperfusion, mainly of the kidney, the heart and the brain.

Severe and long-lasting depression of blood pressure can result in inadequate perfusion of vital organs. The heart and the brain are very susceptible and thus can suffer easily from severe hypotension. The kidneys are also very susceptible to damage, especially if renal autoregulation is impaired/lost. Acute renal failure is a potential consequence of hypotension.

What factors can lead to hypotension?
Generally decreases in heart rate, cardiac output, stroke volume or total peripheral resistance can cause hypotension.

Patients that are hypotensive prior to anaesthesia induction are at much greater risk of developing severe hypotension in comparison to normotensive or hypertensive patients. Chronically hypertensive people are very prone to swings in BP and can get quite hypotensive under GA. Also their equilibrium is set at a higher BP so under anesthesia we need to have a higher cut-off before we give BP support.
Because of this, blood pressure should be measured prior to anaesthesia in patients with heart disease, symptoms of hypotension (weakness, lethargy, cool extremities, poor capillary refill time, syncope) or those animals which might not be adequately hydrated.
In many cases fluid therapy can help to minimize hypotension from various causes, especially if related to low circulating volume.

Treatment of hypotension has to be directed towards:
- Normalisation of venous return (e.g. re-positioning of the animal).
- Addressing causative factors (arrhythmias, hypercapnia, hypoxia).
- Fluids.
- Pressor and inotropic agents (sympathomimetics, non-adrenergic inotropes and vasopressors).

Table 5 shows some of the key factors contributing to hypotension [11]

<table>
<thead>
<tr>
<th>Severity</th>
<th>Awake animals</th>
<th>Inhalation anesthesia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild hypotension</td>
<td>&lt;100/60</td>
<td>&lt;90/50</td>
</tr>
<tr>
<td>Moderate hypotension</td>
<td>&lt;90/50</td>
<td>&lt;80/40</td>
</tr>
<tr>
<td>Severe hypotension</td>
<td>&lt;70/50</td>
<td>&lt;60/30</td>
</tr>
</tbody>
</table>

Table 4: Division of hypotension

How to get reliable blood pressure readings
Although it is not a difficult task per se, there are some guidelines which need to be followed to allow fast and reliable readings. However the most important prerequisite is:

The willingness to measure blood pressure
The influence of environmental stress but also the influence of an impatient examiner on blood pressure is described in literature[10]. Thus certain guidelines should be followed to allow a relaxed and fast reading as well as reliable accurate results:
- Blood pressure measurements should be taken in a quiet room.
- Visitors or employees should not walk in and out of the room while a patient is being measured.
- The animal should have a few minutes to get used to the environment prior to measurement.
- The animal should be handled in a calm and patient manner.
- In each clinic, only a few individuals should be selected to obtain blood pressure measurements to minimize operator based variability.
- Measurements should be taken in a relaxed and comfortable position for the pet.
- The appropriate equipment should be used and limitations (Doppler, conventional oscillometry, Plethysmography) should be well known to allow correct interpretation of the results.
- With HDO technology, measurements using the base of the tail are easiest and fastest, though limbs can also be used.
- During the course of the 3-5 readings, ideally no conversation should be carried out with the pet owner or other persons. This allows the examiner to concentrate on the measurement.

Short term variations in blood pressure
Physiological variation of blood pressure is always present and depends on the basal sympathetic tone of the individual (up to 10 - 20 mmHg in between the single readings)
White coat effect/hypertension
This variation is a stress related elevation of blood pressure at the beginning of the readings. Over time it generally disappears. Therefore, additional readings are needed or allow the animal additional time to relax. It may be a consideration to wait 5 minutes and then start the measurement series again.

Stress related variation
This is a very common situation in the average practice. It is hard to keep the clinic environment completely quiet, so these variations are very likely to occur. In general, initial readings with just minor physiologic variations are generated, then a stress situation occurs (somebody coming into the room, a phone rings, etc.). The next reading will be much higher, followed, if no further stress occurs, by normal readings.

Thus it is vital to allow the animal to adjust to the environment: Cats: take the cat out of its kennel. Let the cat decide which is the preferred position (sitting or lying on the examination table, being held by the pet owner).

Small dogs: The patient can be placed on the examination table or held by the owner.

Large dogs: If possible, take the measurements with the patient positioned on the floor.

Positioning of the patient:
- “down” position at the base of the tail or on the front limb below the elbow.
- lateral recumbency, with the cuff being placed on the base of the tail or on the forelimb on the ground.
- standing position, measuring on the base of the tail.

Technology
Blood pressure measurement is a simple procedure but requires the use of technical equipment. The operator must therefore
- know the instrument.
- know how to operate the instrument and how to detect sources of error.
- know how to correctly and carefully apply the cuff.
- minimize stress factors.

In general, since it is important to evaluate both the systolic and diastolic blood pressure, preference should be given to technology which determines both values. It is absolutely vital that the operator be skilled with the equipment being used to maximise the chances that reproducible results are obtained. A variety of factors will influence which unit is best suited for an individual clinic including ease of use, cost, number of units needed, etc. Of course once a unit has been obtained it is vital that it be used frequently to become well versed in its use.
### Table 6 Technical features of the different technologies

<table>
<thead>
<tr>
<th>Feature</th>
<th>Doppler</th>
<th>Conventional Oscillometry</th>
<th>High-definition Oscillometry (HDO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>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)</td>
<td>Fixed preset values for recognition of pulse waveforms and amplitudes</td>
<td>Allows manual adjustment of amplitude recognition settings (amplification) for each individual patient (range: 100 to 560–640)</td>
</tr>
</tbody>
</table>
| 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 cut off value at ca. 160 mmHg; Since the mechanical valve is opened manually, linear deflation of cuff is not possible | Valve-determined cut off value at ca. 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 cut off value at ca. 160 mmHg; Real-time analysis and real-time valve programming (securing accuracy) is possible in the 0–300 mmHg (-450 mmHg - MD science) 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 microseconds; can therefore detect even the smallest signals and measure extremely high heart rates of 400 beats/min and higher |
Table 7: Implications of the different technologies for practical applications

<table>
<thead>
<tr>
<th>Specified measurement range</th>
<th>Doppler</th>
<th>Conventional oscillometry</th>
<th>High-definition oscillometry (HDO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–300 mmHg</td>
<td>0–300 mmHg</td>
<td>0–300 mmHg</td>
<td></td>
</tr>
<tr>
<td>Theoretical precision</td>
<td>~ 80–160 mmHg (valve) and user-dependent</td>
<td>~ 80–160 mmHg (valve) &lt; 250 mmHg (processor)</td>
<td>0–450 mmHg (valve and processor)</td>
</tr>
<tr>
<td>Actual precision</td>
<td>? (User-dependent)</td>
<td>~ 80–160 mmHg</td>
<td>5–300 mmHg (5–450 mmHg MD Science)</td>
</tr>
<tr>
<td>Use of patient-specific measurement variables</td>
<td>Not possible</td>
<td>Manufacturer-dependent, maximum inflation pressure</td>
<td>Automatic or manual adjustment of maximum inflation and deflation pressures, deflation rate and gain</td>
</tr>
<tr>
<td>Cuff volume recognition</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Time per measurement in cats</td>
<td>ca. 30 seconds to 2 minutes *</td>
<td>ca. 40 seconds to 2 min **</td>
<td>8–15 seconds ***</td>
</tr>
<tr>
<td>Measurement despite arrhythmia</td>
<td>Not possible</td>
<td>Limited (fuzzy logic)/ Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Sensitivity at low amplitudes °</td>
<td>Limited; There is no gain option since signal amplification is linked with noise amplification</td>
<td>Manufacturer-dependent limitations; Preset optimizer for cat (Memoprint)</td>
<td>Gain options depending on the unit 100 - 640 (50 - 1200 MD science)</td>
</tr>
<tr>
<td>Deflation rate °°</td>
<td>»Click« at 3 mmHg/min; otherwise not definable</td>
<td>Generally 3 mmHg/sec; Cardell: 3–7 mmHg/sec; Memoprint: 3–6 mmHg/sec</td>
<td>Individual and pulse-dependent adjustment from 3–18 mmHg/sec</td>
</tr>
<tr>
<td>High heart rate</td>
<td>Impedes measurement considerably</td>
<td>Manufacturer-dependent limitations occur at 160 bpm and higher</td>
<td>&lt; 400 beats per minute &gt; 400 bpm possible with MD Science</td>
</tr>
<tr>
<td>Provision of measurement results</td>
<td>Acoustic signal, cuff pressure read from sphygmomanometer dial indicating either systolic on mean arterial pressure - can not be differentiated</td>
<td>Digital display of SAP, DAP, MAP (depending on manufacturer), and pulse</td>
<td>Real-time display of results on screen of laptop or PC and/or digital display on the unit for users without PC connection; graphics display can be analyzed on PC at a later time</td>
</tr>
<tr>
<td>Telemedicine capabilities ¹</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Measurements during anesthesia</td>
<td>May be limited (depending on which anaesthetic is used)</td>
<td>May be limited (depending on which anaesthetic is used)</td>
<td>No limitations apply</td>
</tr>
<tr>
<td>Measurement at very low pressures (SAP &lt; 60 mmHg)</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Automated monitoring function</td>
<td>NO</td>
<td>Feedback loop function on some systems (manufacturer-dependent)</td>
<td>Feedback loop function, real-time measurement recording and on-screen presentation</td>
</tr>
</tbody>
</table>

* 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 shortening the measurement time.
¹ Transmission of measurements to an expert for assessment.
Blood Pressure in Small Animals - Part 1: Hypertension and hypotension and an update on technology - A.P. Carr

Acknowledgements
Permission to reprint Tables 2, 4 and 5 has been kindly given by Erhardt W, Henke J, Carr A, Egner B: Importance of Blood Pressure Measurement. In: Essential Facts of Blood Pressure in Dogs and Cats. P 46-48, VBS GmbH 2007

Literature


Editor’s Note
The ‘Blood Pressure in Small Animals’ paper in this issue, is the first of two commissioned by FECAVA to bring readers up to date with all aspects of the subject. It is inevitable therefore that the section on Technology gives extensive information regarding the recent advances in oscillometric blood pressure monitoring technology. It should however be borne in mind that many Veterinary surgeons, including some who specialise in cardiology, prefer to continue to use the oscillometric and Doppler units to which they are accustomed, and which they find work very well. EJCAP would welcome any comments or experience with the different systems available. If these are forthcoming we intend to publish letters or a summary of points made in our next issue. The authors of the paper have been involved with the development of HDO technology, but have declared no financial interest in the S+B Med VET monitor.