# Indirect systolic blood pressure measurements in cats

– improved reliability with prolonged measurement time

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Swedish University of Agricultural Sciences, SLU
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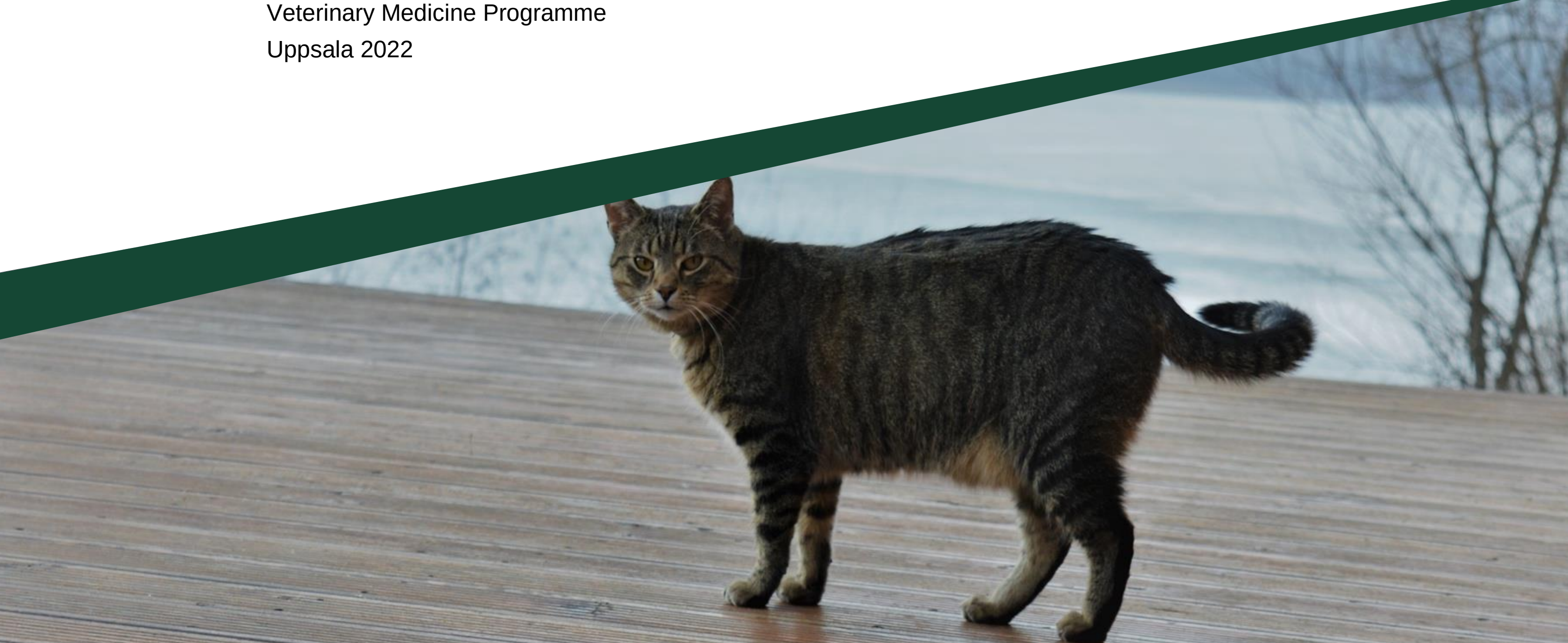

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# Abstract

Blood pressure (BP) measurements in cats are performed regularly in the clinical setting. As cats are easily stressed by their surroundings, the so-called white coat effect can easily influence the measurements obtained in the clinical environment. For some animals this could lead to a false diagnosis of hypertension. On the other hand, true hypertension that is not diagnosed (and therefore not treated) might eventually lead to damage of target organs. Therefore, reliable BP measurements are a very important part of the clinical handling of feline patients.

In order to minimize anxiety-induced rises in blood pressure, it is essential to perform blood pressure measurements in cats using a stress-reduced measurement process. This includes, amongst others, having the owner present, using a quiet location with dimmed lights as well as allowing the cat to acclimatize to its surroundings before beginning the measurements. Following a stress-reduced blood pressure protocol might enable the cat to relax and eventually reach a lower plateau in its blood pressure measurement results. The primary purpose of this study was to examine whether a prolonged measurement time can allow the cat to acclimatize to a clinical environment to such an extent that it lowers the cat's stress level and, in turn, generates a more distinct plateau of lower BP measurement results. Another purpose was to examine the owner's perception of performing a BP measurement on their cat themselves when using an automated indirect BP measuring device.

A total of 37 cats were included in the study. Twenty-six cats were subject to a prolonged measurement procedure. A clear downward trend was seen in recorded BP for most of the cats during the prolonged measurement time. During the prolonged measurement time, a median number of five additional BP measurements were performed. Most owners in this study reported it to be easy to perform BP measurements on their cats.

The study concludes that a prolonged BP measurement time will in general result in lower BP values. By prolonging the BP measurement time, the white coat effect can be reduced in some cats. According to this study, a prolonged BP measurement time should be recommended for cats with initially high BP measurement results. The study also concludes that it is beneficial to allow the cat owner to perform BP measurements on their animal themselves, if and when possible.


*Keywords*: feline, situational hypertension, high definition oscillometry

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# Abbreviations

| | |
|---|---|
| ACVIM | American College of Veterinary Internal Medicine |
| BP | Blood pressure |
| BV | Blood volume |
| CKD | Chronic kidney disease |
| CO | Cardiac output |
| DBP | Diastolic blood pressure |
| HDO | High definition oscillometry |
| MAP | Mean arterial pressure |
| mSBP | Mean systolic blood pressure |
| PR | Pulse rate |
| RAAS | Renin angiotensin aldosterone system |
| SVR | Systemic vascular resistance |
| TOD | Target organ damage |
| UDS | Universitetsdjursjukhuset (University Animal Hospital) |
| WCE | White Coat Effect |

# 1. Introduction

Blood pressure (BP) measurement in cats is performed regularly in the clinical setting. Evaluation of BP is used as a diagnostic and monitoring tool for a range of diseases in feline medicine. Cats are easily influenced by external factors in their environment, which makes it more difficult to obtain reliable BP measurements in the clinical environment for this species. The so-called white coat effect (WCE), which is well known in humans, has also been reported in cats (Belew *et al*. 1999). Awake cats tend to experience high levels of stress in new environments. This might lead to an elevation in BP, which in the clinical setting may complicate the evaluation of a potentially hypertensive patient. It could also result in a false diagnosis of hypertension.

To increase the reliability of BP measurements performed in cats, it is of interest to evaluate various factors that can influence BP measurement results. An updated consensus statement from the American College of Veterinary Internal Medicine (ACVIM) was made available in 2018 to clinicians handling hypertensive patients (Acierno *et al.* 2018). The guidelines, applicable to BP measurements in both dogs and cats, recommend that a series of measurements should be recorded for every patient. Furthermore, they suggest that with a prolonged measurement process, a plateau might eventually be reached in some individuals.

## 1.1. Purpose of the study

The primary purpose of this study was to examine whether a prolonged measurement time can allow the cat to acclimatize to a clinical environment to such an extent that it lowers the cat's stress level and, in turn, generates a plateau of lower BP measurement results.

Another purpose was to examine the owner's perception of performing a BP measurement on their cat themselves when using an automated indirect BP measuring device.

# 2. Literature review

## 2.1. Regulation of blood pressure

Blood pressure regulation is a complex physiological process involving several organs, as well as both neural and hormonal systems. Homeostatic mechanisms of the heart, kidneys and vasculature interact with the central nervous system and endocrine/paracrine mediators to regulate the BP (Taylor *et al.* 2017; Elliott 2020).

The BP will vary during a cardiac cycle; the systolic blood pressure (SBP) will be the highest pressure, and the diastolic blood pressure (DBP) will be the lowest (Sjaastad *et al.* 2010). The mean arterial pressure (MAP) is approximately the mean pressure in the arterial system during one cycle (Durham 2017). Normally MAP will be closer to the DBP as the diastolic phase lasts longer, but it will go up with an increasing pulse rate (PR) as the diastolic phase then shortens (Sjaastad *et al.* 2010). Every heartbeat will produce a slightly different BP, but when the BP is measured, it is the mean BP of a series of heartbeats that is examined (Durham 2017).

The mean BP is the result of cardiac output (CO), which in turn results from stroke volume, heart rate and systemic vascular resistance (SVR) (Taylor *et al. 2017)*. Systemic vascular resistance is mainly controlled by the size and tonus of the arterioles. This is in turn influenced by numerous endothelial, systemically circulating and local tissue factors. The elasticity of the arteries regulates how easily the walls of the arteries expand because of increased internal pressure (Sjaastad *et al.* 2010). If the arterioles have low elasticity, the rapid ejection phase of the heart (systole) will create a high arterial pressure and the refill phase (diastole) will create a low arterial pressure. Low arterial elasticity is therefore connected to a higher pulse pressure as the difference between SBP and DBP increases. Arterial elasticity is known to decrease with rising age, which is one of the factors contributing to both animals and humans tending to have an increasing blood pressure with age. Changes in physical and digestive activity as well as emotional status also affect CO and SVR. Blood volume (BV) is relatively constant as it is well regulated. The kidneys regulate BV through the renin-angiotensin-aldosterone system (RAAS) and through pressure natriuresis. The RAAS affects SVR directly through vasoconstriction (by angiotensin II) and through renal reabsorption of water and sodium (by aldosterone). Simultaneously, changes in BV and cardiac output are balanced with the excretion of water and sodium in the pressure natriuresis.

All these factors are coordinated through sensory systems that detect alterations in BP or BV and initiate feedback control mechanisms (Elliott 2020). These include baroreceptors in the arteries together with stretch receptors located in the atria and in the renal afferent arterioles. This process enables the BP to be continuously maintained at an average level close to 100 mm Hg in all mammals (excluding the giraffe).

## 2.2. Feline blood pressure

### 2.2.1. Normal blood pressure in cats

The available research presents a rather large variation in results regarding the average normal SBP in cats (Table 1). This is in part due to differences in the populations studied as well as variances in the type of device used (Taylor *et al.* 2017).

*Table 1: Systolic blood pressure (mean and SD) in apparently healthy, conscious cats in a selection of studies.*

| Study | Year | Method | No. of animals | Systolic blood pressure (mm Hg) |
|---|---|---|---|---|
| Bodey and Sansom | 1998 | Traditional Oscillometry | 203 | **139 ± 27** |
| Mishina *et al* | 1998 | Traditional Oscillometry | 60 | **115 ± 10** |
| Hanås *et al* | 2021 | High Definition Oscillometry | 94 | **136 ± 17** |
| Kobayashi *et al* | 1990 | Doppler Ultrasonography | 33 | **118 ± 11** |
| Sparkes *et al* | 1999 | Doppler Ultrasonography | 50 | **162 ± 19** |
| Payne *et al* | 2017 | Doppler Ultrasonography | 780 | **121 ± 16** |
| Mishina *et al* | 2006 | Intra arterial (Telemetry) | 20 | **118 ± 11** |
| **Mean (of these six studies)** | | | | **130** |

Several studies have concluded that an increasing age is associated with a higher blood pressure in cats (Bodey & Sansom 1998; Mishina *et al.* 1998; Sansom *et al.* 2004; Bijsmans *et al.* 2015; Payne *et al.* 2017; Hanås *et al.* 2021). Contrarily, two studies have shown no connection between age and an increase in blood pressure in cats (Kobayashi *et al.* 1990; Sparkes *et al.* 1999).

Two of the previously mentioned studies observed no correlation between body weight and blood pressure (Bodey & Sansom 1998; Sparkes *et al.* 1999) but Payne *et al.* (2017) determined that underweight cats had a slightly lower blood pressure than cats of normal weight, or obese cats. Furthermore, Payne *et al.* observed that increased nervousness, neutering, history of being a stray and male sex were all factors correlated to a higher blood pressure. On the other side, Bodey and Sansom (1998) as well as Mishina *et al.* (1998), found that sex had no effect on the blood pressure. These studies also failed to document any effects of breed on blood pressure. In contrast, Hanås *et al.* (2021) showed in their study that Birman cats had lower blood pressure when compared to two other breeds (Norwegian forest and Domestic shorthair breed).

### 2.2.2. Hypertension in cats

Hypertension is a widely recognized condition in cats, but most likely continues to be underdiagnosed. (Taylor *et al.* 2017). Hypertension in cats has been reported as being most commonly systolic alone (or systolic and diastolic) but is rarely only diastolic. It is therefore acceptable to use only SBP to evaluate hypertension in cats (Kobayashi *et al.* 1990). Brown *et al.* (2007) proposed the following classification of hypertension in dogs and cats:

1. Idiopathic hypertension
2. Secondary hypertension
3. White Coat (situational) hypertension

*Idiopathic (primary) hypertension*

Idiopathic hypertension is defined as a persistently elevated level of blood pressure that has no identifiable underlying condition or disease (Brown *et al.* 2007). In humans, more than 90% of cases of hypertension do not have a recognizable cause (Oparil *et al.* 2003). Research has shown that idiopathic hypertension could account for between 13 and 20 percent of hypertensive cats (Maggio *et al.* 2000; Elliott *et al.* 2001; Jepson *et al.* 2007). For example, Jepson *et al.* (2007) demonstrated in their study that 12% of non-azotemic and non-hyperthyroid cats presented with hypertension at study inclusion. Persistently elevated levels of BP indicate that the neurohumoral and/or renal systems in charge of BP regulation are in some way abnormal (Brown *et al.* 2007). Subclinical disease of these organ systems should thus be ruled out in order to be able to classify the hypertension in a patient as idiopathic. It has therefore been proposed by Brown *et al.* (2007) that a diagnosis of idiopathic hypertension can be established when consistent BP measurements show a persistent increase in BP, along with normal levels of blood biochemistry and a normal urinalysis. Additional diagnostics, such as screening for hyperthyroidism in cats, should also be considered in affected patients. The stress effect on blood pressure measurements should also be ruled out.

*Secondary hypertension*

Hypertension is considered secondary when the patient has a concurrent condition causing the persistently elevated BP (Acierno *et al*. 2018). Most commonly, it is due to an illness or disease known to cause hypertension. It can also be the side effect of an administrated medication or caused by the consumption of a toxic substance. Secondary hypertension is reported as the most common type of hypertension in cats (Acierno *et al.* 2018; Stepien 2011, Taylor *et al.* 2017).

Data from several studies has determined that renal disease is associated with hypertension in cats (Kobayashi *et al*. 1990; Bodey & Sansom 1998; Mishina *et al*. 1998; Sander *et al*. 1998; Bijsmans *et al*. 2015). Kobayashi *et al.* (1990) also saw a significant increase in BP in cats with hyperthyroidism. Similarly, both Morrow *et al.* (2009) as well as Syme and Elliott (2003) found an association between hyperthyroidism and hypertension. Moreover, both of these studies showed that many cats diagnosed and treated for hyperthyroidism will develop hypertension within the first six months of treatment. Maggio *et al.* (2000) showed a correlation between hypertension and conditions such as diabetes mellitus and primary hyperaldosteronism. Hypertension as a side effect of medical treatment was demonstrated by Chalhoub *et al*. (2012) in their study on treatment of chronic kidney disease (CKD) related anemia with Darbepoetin alfa. In the study, 37 % of cats that were previously normotensive, developed hypertension during the course of treatment with Darbepoetin. Hypertension has been reported as a sign of toxicity in cats exposed to human ADHD medication (Stern & Schell 2018), as well as Mirtazapine (Ferguson *et al*. 2016). One study concluded that exposure to cadmium might result in the development of hypertension in cats (Finch *et al*. 2012).

*White Coat or Situational hypertension*

Situational hypertension is an anxiety- or excitement-induced increase in BP (Acierno *et al.* 2018). This can occur when a BP measurement in a clinical environment leads to such stress and/or excitement, that a substantial physiological increase in BP is seen in an otherwise normotensive patient. The phenomenon is well documented in human medicine (Clark *et al.* 2014), and has been established in cats as well (Belew *et al.* 1999; Sparkes *et al.* 1999). One of the cats in the study by Belew *et al.* (1999) showed an 80 mm Hg difference in SBP when exposed to a simulated clinical appointment. Mishina *et al.* (1997) determined that the BP of canines would decrease when measurements were repeated, pointing towards a reduction in stress as the animal gets used to the measurement procedure itself. Based on research from human medicine, it has been proposed that a potential training-effect, resulting from repeated veterinary visits, could reduce situational hypertension (Fogari *et al.* 1996). Belew *et al.* (1999) however showed that no such habituation effect occurred in the cats of their studied population. Likewise, Sparkes *et al.* (1999) found in their study that the BP of the studied cats did not vary substantially, when measurements were repeated for several days.

### 2.2.3. Target organ damage

A persistently sustained high BP will eventually result in hypoxia of the capillaries, tissue damage, hemorrhaging and infarction (Nelson & Couto 2014). So-called target organs that are especially vulnerable to this damage are the kidneys, eyes, heart and brain (Brown *et al.* 2007; Nelson & Couto 2014). This target organ damage (TOD), resulting from chronic hypertension, can have severe clinical consequences (Acierno *et al.* 2018). Clinical signs of TOD may be marked, and can actually be the reason why a cat is brought to the veterinarian (Maggio *et al.* 2000). An example of this is acute blindness. On the other hand, TOD could be absent in some hypertensive cats, and instead the clinical signs of the underlying disease can dominate (Kobayashi *et al.* 1990; Bodey & Sansom 1998; Elliott *et al.* 2001).

*Heart*

Hypertension will cause an increased afterload of the heart, which will stimulate hypertrophy of the left ventricle wall (Chetboul *et al.* 2003; Nelson & Couto 2014). Nelson *et al.* (2002) found that the hypertensive cats in their study showed a dilation of the proximal ascending aorta compared to the healthy cats in the study.

*Eyes*

Target organ damage of the eye, resulting from hypertension, includes retinopathy and choroidopathy. This has been established in many studies (Bodey & Sansom 1998; Maggio *et al.* 2000; Chetboul *et al.* 2003; Sansom *et al.* 2004; Conroy *et al.* 2018). Bodey and Sansom (1998) found a higher BP in cats with ocular change consistent with hypertensive retinopathy. Likewise, Chetboul *et al.* (2003) demonstrated that cats with retinopathies had significantly higher BP than other hypertensive cats, and Sansom *et al.* (2004) determined that hypertensive retinopathy was common in cats with a SBP above 168 mm Hg. Further, Maggio *et al.* (2000) found that retinal lesions, predominantly related to choroidal damage, were common in cats with hypertension.

*Kidneys*

Renal injury and proteinuria related to hypertension have been demonstrated in several studies of cats with chronic kidney disease (CKD) (Syme *et al.* 2006; Chakrabarti *et al.* 2013; Reynolds & Lefebvre 2013). Further, proteinuria has been connected to the progression of CKD in cats (King *et al.* 2006; Syme *et al.* 2006). This is of importance, as CKD is one of the most common diseases affecting cats (Reynolds & Lefebvre 2013).

*Brain*

Encephalopathy caused by hypertension has been reported in cats (Littman 1994; Maggio *et al.* 2000). Neurological abnormalities were reported in 46% of hypertensive cats in one study (Littman 1994), and in 29% of the hypertensive cats in another study (Maggio *et al.* 2000).

### 2.2.4. Classifying Hypertension

It is recommended that older cats and those with coexisting diseases that are associated with secondary hypertension should have regular BP measurements taken. (Brown *et al.* 2007; Acierno *et al.* 2018). Cats with, or at risk of, TOD should also have their BP assessed regularly. The International Renal Interest Society (2021) proposes a classification of blood pressure in cats and dogs (table 2) based on the potential risk of future TOD.

*Table 2: Substaging of systolic blood pressure in dogs and cats based on risk for future target-organ damage (International Renal Interest Society 2021).*

| Systolic Blood Pressure mm Hg | Blood Pressure Substage | Risk of Future Target Organ Damage |
|---|---|---|
| <140 | Normotensive | Minimal |
| 140 – 159 | Prehypertensive | Low |
| 160 – 179 | Hypertensive | Moderate |
| ≥ 180 | Severely hypertensive | High |

This classification can work as an aid in the handling of clinical patients. The ACVIM consensus statement recommends that measurements should be repeated on at least two occasions to confirm the results (Acierno *et al.* 2018). In the case of prehypertensive patients (140 – 159 mm Hg) the measurements can be repeated over the course of one or two months. The same is recommended for hypertensive patients (160 – 179 mm Hg) with a moderate risk of developing TOD. However, patients with graver hypertension (above 180 mm Hg) are considered to be at high risk of developing TOD and should thus have their BP measurements completed within 1-2 weeks. When situational hypertension as well as measurement errors have been rejected, conditions related to secondary hypertension should be examined. The BP measurements should be integrated with the patients history and a thorough physical examination, in which special attention should be focused on identifying factors reflecting TOD (Stepien 2011). When hypertension is found along with signs of TOD, the probability of the elevated BP representing true hypertension is increased.

Taylor *et al.* (2017) proposed that a more extensive routine monitoring of the BP in cats would possibly allow for an earlier identification of hypertension. This would in turn enable a more rapid provision of effective treatment to prevent TOD, hopefully reducing the morbidity related to hypertension. Eventhough no specific data on hypertension-associated morbidity for cats is available, this proposal is supported by the findings of a retrospective cohort study by Conroy *et al.* (2018) on 282 hypertensive cats. They found improved survival in cats that were diagnosed as hypertensive when monitored for pre-existing disease, compared to cats that were not diagnosed as hypertensive until after clinical signs were recognized. It should however be noted that routing monitoring of BP in all cats would require a sufficiently specific screening method. As the currently available screening methods (indirect BP measurement devices) are not very specific, screening on a large scale would most likely produce a large number of falsely positive results (patients with falsely diagnosed hypertension).

## 2.3. Measuring blood pressure

### 2.3.1. Direct blood pressure measurement

A direct blood pressure measurement is performed by placing a catheter inside an artery (Sjaastad *et al.* 2010). The catheter is filled with fluid and connected to a transducer which converts the oscillations in pressure of the fluid into electrical signals that can be recorded. This method can be used in fully anesthetized animals, or with a telemetric signal transfer, in awake, freely moving animals. This method is considered to be the golden standard, however, it is rarely used, as it is invasive, painful and impractical in the standard clinical setting (Acierno *et al.* 2018).

### 2.3.2. Indirect blood pressure measurement

As the feasibility of direct blood pressure measurement techniques is low, indirect methods are currently used in standard clinical screenings (Brown *et al.* 2007). The devices available are non-invasive and fairly simple in their use. However, the equipment used for these measurements should be chosen with care in order to achieve reliable results (Taylor *et al.* 2017).

*Oscillometry*

Indirect blood pressure measurement using oscillometry is performed using an inflatable cuff that can be placed on either one of the extremities or on the tail of the animal (Sjaastad *et al.* 2010). The cuff inflates to a pressure exceeding the SBP and then gradually deflates, registering the oscillations in air pressure in the cuff. Traditional oscillometry has been shown in many studies to be less accurate for BP assessment than doppler in conscious cats (Sander *et al.* 1998; Pedersen *et al.* 2002; Haberman *et al.* 2004; Jepson *et al.* 2005). Additionally, these studies had trouble, or in many cases even failed, in obtaining a BP measurement value using an oscillometric device.

Traditional oscillometry was further developed and resulted in the high definition oscillometry (HDO) available today. The HDO performs the measurements at much higher speeds, which enables it to measure SBP, DBP and MAP directly, while traditional oscillometry only measures MAP and calculates the rest through an algorithm (Egner 2015). HDO was validated for the use in conscious cats in a study by Martel *et al.* (2013). The study, performed on six cats, showed that the HDO, when compared to direct BP measurements, provides accurate results in conscious cats. It was also easier to obtain values with the HDO compared to traditional oscillometry. On the other hand, Petric *et al.* (2010) and Sander *et al.* (1998) established that the HDO, when compared to the doppler technique, overestimated low pressure and underestimated high values of BP in cats. Lyberg *et al.* (2021) further demonstrated that differences between different types of oscillometric devices occur as well. In their study on dogs, they found that one oscillometric device (HDO; S+B medVet Babenhausen, Germany) showed consistently lower levels of SBP than another one (petMAP; Ramsey Medical Inc, Tampa, Florida) and this difference increased with higher SBP. A positive aspect that was lifted about the HDO in the study is the fact that the measurements can be performed by the owner themselves, possibly reducing the WCE in some cases.

*Doppler Ultrasonography*

This technique uses the change in frequency that can be registered when an ultrasound is emitted towards a blood vessel (Nelson & Couto 2014). The emitted wave is compared to the echoes that return as the ultrasound wave bounces off the moving blood cells in the artery. The change in frequency that occurs, the Doppler shift, can be converted to an audible sound. A cuff is used to constrict the blood flow and the ultrasound probe is placed below the level of the cuff. The cuff is then inflated until no flow sound is heard. The SBP is established as the pressure when the flow sound reappears, and the DBP as the pressure when the flow sound changes its character. Haberman *et al.* (2004) demonstrated a good correlation between the BP measurements performed using this method, when compared to direct BP measurements of the cats in the study. To be noted, the device did underestimate the BP in several cases, and the level of inaccuracy increased with higher BP. Gouni *et al.* (2015) concluded from their study on healthy conscious cats, that measurement of DBP is more difficult than measurement of SBP with a Doppler ultrasonography device, and thus requires a more trained observer. In another study on conscious cats, in 49% of readings, the doppler device failed to obtain a DBP reading (Jepson *et al.* 2005).

### 2.3.3. The measurement procedure

Incorrect BP measurement techniques might lead to an under- or overdiagnosis of systemic hypertension in otherwise normotensive cats (Stepien 2011). To assure the reliability of the results, all care should be taken to follow a standard procedure when measuring BP. An adapted version of the ACVIM consensus statement protocol for BP measurement in dogs and cats can be seen below (Acierno *et al.* 2018).

- The device should be calibrated to the relevant species.
- A standardized procedure should be used for all measurements.
- The room in which measurements are taken should be calm, isolated and away from other animals. In general, the animal owner should be present. The patient should be conscious and should be allowed an acclimatization period of 5–10 minutes in the room before the measurements begin.
- The animal should be placed in a comfortable position, on either side or sternally, in order to minimize the vertical distance from the placement of the cuff to the heart (should be less than 10 cm).
- An appropriately sized cuff should be used. The cuff should be placed on the tail or on any of the extremities.
- Measurements should begin once the patient is calm and without movement.
- The first measurement should not be used. A minimum of five to seven consecutive measurements, consistent with each other, should be recorded. The blood pressure in some patients will continually drop. The measurements should continue until the pressure reaches a plateau, and five to seven consecutive values should then be recorded.
- Measurements should be repeated, adjusting the cuff placement as needed, in order to obtain consistent values.
- An average of all values (minus those excluded) should be used to obtain the final BP value.
- A standardized protocol should be used to record the measurements and should include the size, placement and any adjustments done to the cuff, person performing the measurements and the final result.

*Environment*

It can be technically difficult to obtain a reproducible blood pressure measurement when the cats are difficult in handling or anxious (Stepien 2011). According to recommendations, anxiety and stress in the handled animals can be reduced by carrying out the measurements in a quiet, isolated area, away from other animals (Stepien 2011; Acierno *et al.* 2018). Hanås *et al.* (2021) showed in their study on 94 cats that the clinical setting did not have an effect on the SBP. They did, however, see higher levels, and larger variation, in measured MAP, DBP and PR when the cat was placed on the table instead of being in its own carrier.

According to the ACVIM consensus statement, the animal should be allowed time to acclimatize to its surroundings (Acierno *et al.* 2018). This is supported by a study in which a period of acclimatization to the room showed a significant decrease in SBP in the cats studied compared to the SBP measured before the period of acclimatization (Sparkes *et al.* 1999).

Pereira *et al.* (2016) studied if pheromones could be useful in reducing stress for cats in a clinical setting. The study concluded that Feliway®, when sprayed on the examination table, decreases stress among cats during veterinary visits (Pereira *et al.* 2016). Bedding from home or a blanket previously sprayed with Feliway® could thus be used during the measurements to further reduce the animals' level of stress.

*Person performing the measurements*

Studies show that the choice of person who performs the measurements is of importance; when a more trained and experienced individual measures SBP, an improvement in reproducibility of results will be seen (Gouni *et al.* 2015). With regards to the WCE, a systematic review in human medicine showed that the effect is minimized when a nurse performs the measurements, instead of a physician (Clark *et al.* 2014). No equivalent study was found in cats. However, Lyberg *et al.* (2021) concluded from their study in dogs that suspected situational hypertension might be reduced if the owners themselves are instructed to perform the BP measurements. The study found that the SBP measured by a trained veterinary student was higher than the values recorded by the dog owner. This could be compared to a fully automated reading of BP, which has been shown in a meta-analysis to be a reliable method for minimizing the WCE in human patients (Roerecke *et al.* 2019). In such a reading, no medical staff is involved in the measurements; the patient simply inserts their arm into the BP measuring device which performs the measurements independently. In a veterinary clinical setting, the recommendation is that a nurse or a trained veterinary technician is preferred to a veterinarian for taking the measurements (Taylor *et al.* 2017; Acierno *et al.* 2018). This recommendation is however not evidence-based but is based on the collective expertise of the authors. The ACVIM guidelines recommend that the animal owner should be present for the measurements (Acierno *et al.* 2018). However, emotional contagion is a phenomenon that has been observed between dogs and their owners (Sümegi *et al.* 2014; Yong & Ruffman 2014). No equivalent study has been conducted in cats, but an animal owner that is highly stressed during a visit to the veterinary clinic may affect the emotional state of its cat in a similar way.

*Cuff size*

Selecting a correct cuff size and the location where the cuff is positioned are of importance for a correct BP measurement. The recommendation is that the width of the cuff used, should be about 30 - 40% of the circumference of the extremity/tail (Acierno *et al.* 2018). Sparkes *et al.* (1999) concluded from their study, by means of Doppler ultrasonography, that by using a larger cuff, the SBP was considerably lower than when a smaller cuff was used for the measurement. As to the placement of the cuff, Petric *et al.* (2010), found more discrepancies in values when the cuff was placed on the tail, compared to the leg. Cannon & Brett, (2012) on the other hand, concluded that by placing the cuff on the tail there was a decrease in the number of failed measurement attempts. The studied cats also seemed to tolerate the measurements better when the cuff was placed on the tail than when the cuff was placed on the extremity (Cannon & Brett 2012). Both of the later studies used an HDO device to perform the measurements.

# 3. Material and methods

## 3.1. Cats in the study

The cats recruited for the study were privately owned cats of varying breeds and ages. These cats were recruited by word of mouth (during September 2021) as part of a healthy control group of a larger study on chronic kidney disease (Urinpeptidomik för detektion av tidig njursjukdom hos katt, ethical review number: 5.8.18-14326/2020). These cats were, to the best of their owners´ knowledge, clinically healthy. Furthermore, a number of cats that were visiting the policlinic at the University Animal Hospital (UDS) at the Swedish University of Agriculture (from September to November 2021) were also included if a blood pressure measurement was part of their clinical workup.

## 3.2. Blood pressure measurements

The study was conducted at UDS in the fall of 2021. Blood pressure measurements were performed according to the ACVIM blood pressure consensus statement (Acierno *et al.* 2018). The owners arrived at the small animal clinic and the cats registered as per a regular visit to the animal hospital. The owner and the cat were then allowed into an examination room where the lights had previously been dimmed and the cat was subsequently allowed an acclimatization period of ten to fifteen minutes. The carrier was open, and the cat was allowed to move freely around the room at this time. Following the acclimatization period, it was decided in consultation with the owner, whether the cat would be least stressed on a blanket on the examination table or within its carrier. Each cat was provided a blanket sprayed with pheromones (Feliway®), to sit on or to be covered with.

The equipment used for BP measurements was MemoDiagnostic Vet HDO (S+B medVet Babenhausen, Germany). The inflatable cuff used on all cats in the study was of standard size for cats (C1) which is provided with the HDO equipment. The inflatable cuff was placed on the tail, as closely to the tail base as possible. The hair was not clipped in any of the cats, and no gel or alcohol was used. The cats were then placed or allowed to lie on their left or right side, or in sternal recumbency.

The cat owner was standing or sitting closely to the cat in order to pet and gently restrain the cat, if needed, during the measurements. The measurements started with five to ten BP readings performed by the student [JW] straight after one another and the results were noted in the protocol (see Appendix 1). If the cat was considered to be normotensive at this point (mean SBP (mSBP) < 140 mm Hg) the examination was concluded. If there was any uncertainty whether the patient was normotensive after the initial five to ten measurements, the student [JW] left the room and the cat owner continued to perform the measurements, alone in the room with the cat. All values were noted in the protocol, as well as any obvious disturbances which occurred during the measurements. If the cat moved around, the cuff slid off the tail or the cat sat up during the time of a measurement - the measurement was repeated. Once five values in a row with a value <150 mm Hg of SBP had been noted in the protocol, or if the cat was simply non-cooperative after a repeated number of measurements, the owner was instructed to conclude the measurements.

Finally, the cat owner was interviewed about the difficulty of performing the measurements. This was answered using a three-point scale of "easy", "moderately difficult" and "difficult". The cat owners could also list any disturbances they had perceived during the time of the measurement.

The initial mSBP for all cats in the study was calculated as a mean value of all recorded SBP values performed by JW that were not obviously erroneous. For the prolonged measurements, the first five consecutive readings that resulted in a mSBP < 140 mmHg were identified. The number of measurements needed (during the prolonged measurement) to produce a mSBP < 140 mmHg were counted. The final mSBP was calculated as a mean value of the five lowest consecutive SBP readings obtained for each cat.

# 4. Results

## 4.1. Cats in the study

A total of 37 cats were included in the study, 31 healthy controls (group 1) and six cats that were visiting UDS at the time of this study (group 2). The cats in group 2 were visiting UDS for suspected hyperthyroidism (n=3), admission for iodine treatment (n=2) and a follow-up visit for a suspected intoxication (n=1). The cat owners were veterinary students (n=19), veterinary technician students (n=6) or private individuals (n=12). Seventeen cats were female and 20 were males. Twenty-eight Domestic shorthair, four Siberian, two Birman, one Devon Rex, one Ocicat and one Ragdoll cat were recruited to the study. The median (range) age of all cats was 46 months (10 months – 220 months). The median age of the cats in group 1 was 37 months (10 months – 220 months) and in group 2 it was 158 months (96 months – 185 months). The median (range) weight of all cats in the study was 4,4 kg (3,1 kg – 6,7 kg).

## 4.2. Blood pressure measurements

The results for all cats in the study are presented in table 3 (for detailed results see Appendix 2). The first measurement as well as any obviously erroneous values (physiologically impossible or anxiety-induced) have been excluded for all cats. All initial SBP measurements were performed by JW, except for one (cat number (no.) 16) where it was performed by the cat owner. Likewise, all prolonged measurements were performed by the cat owner, except for one (cat no. 36) where it was performed by JW, because of owner preferences.

Of all 37 cats in the study, 26 had an initial mSBP >140 mm Hg, and therefore according to the study protocol, were subject to a prolonged BP measurement (see figure 1). Additionally, as the initial mSBP was not calculated directly but was merely estimated by JW at the time of measurement (due to lack of time), cats no. 19 and 20 were subject to a prolonged measurement, despite having an initial mSBP <140 mm Hg. The BP values have still been reported in Table 3 for these cats as it is interesting to see that a further decrease in BP can be seen with a prolonged measurement time.

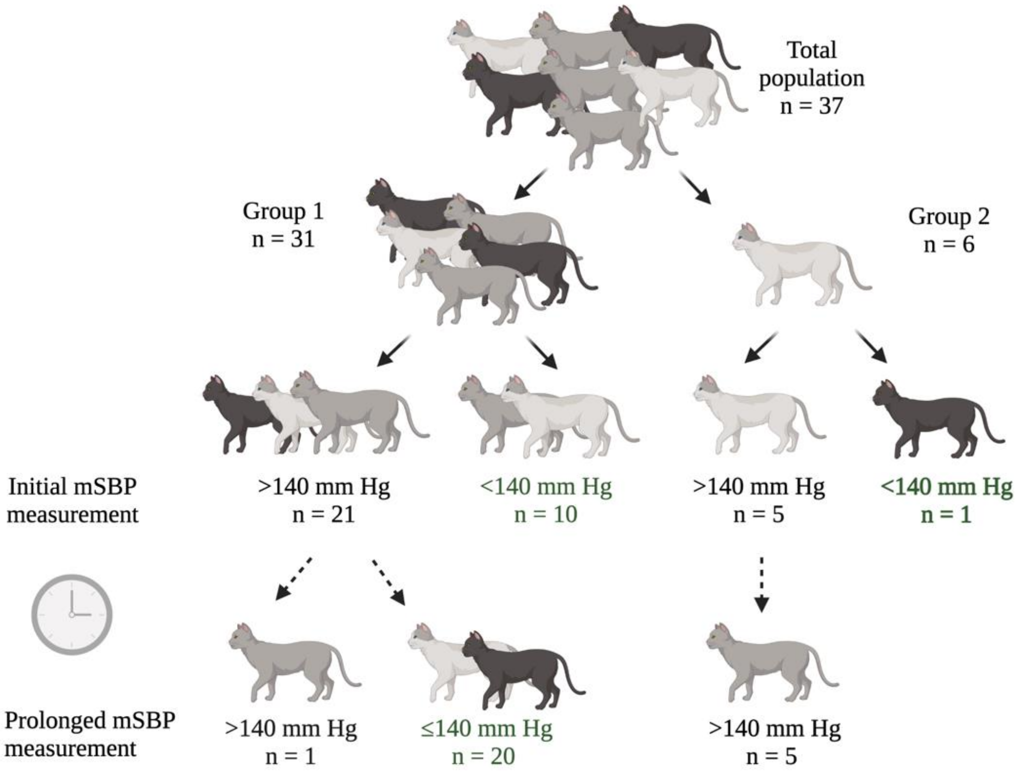


*Figure 1: Flowchart presenting the distribution of the cats in the study. Created with Biorender.com.*

A clear downward trend in SBP could be seen for most cats during the prolonged measurement time (as an example see cat no. 5 in Figure 2). The median (range) mSBP for the nine cats that were not subject to prolonged measurements was 135 mm Hg (122 mm Hg – 139 mm Hg).

Cat no. 12 showed increasing levels of SBP during the prolonged measurements (see figure 2). The remaining cats from group 1 that were subject to a prolonged measurement time (n=20), showed a median (range) of 25 (3 – 36) mm Hg lower mSBPs in the final reading, compared to their initial reading.

Of the cats in group 2 (n=6), one cat (cat no. 37) was initially normotensive and the remaining five cats were subject to a prolonged SBP reading. For one cat, the owner only managed to record one BP measurement before concluding the measurements because the cat was uncooperative. Two cats (cats no. 33 and 35) showed a lower mSBP after a prolonged measurement procedure. Another two cats (cat no. 34 and 36) showed a slight downward trend as prolonged measurements were performed, but measurements were concluded before reaching mSBP<140 mm Hg because of high levels of stress in both the cats and the owners (see figure 2). The cats in group 2 that were subject to a prolonged measurement time (n=4), showed a median (range) of 7 mm (5 – 29) Hg lower mSBP in the final reading, compared to their initial reading.

*Table 3: The results of SBP measurements for all cats. * =the mSBP calculated using less than 5 consecutive readings, †=owner performed all measurements, ‡=JW performed all measurements.*

| Cat no. | JW Initial measurement | Prolonged measurement | Additional measurements | | |
|---|---|---|---|---|---|
| | **mSBP (mm Hg)** | **No. of BP measurements until mSBP <140 mm Hg** | No. of BP measurements until Final mSBP | Final mSBP (mm Hg) | Change in mSBP (mm Hg), ± % change |
| 1 | 138 | **-** | - | - | - |
| 2 | 125 | **-** | - | - | - |
| 3 | 142 | **7** | 9 | 124 | 18, -12% |
| 4 | 145 | **5** | 21 | 115 | 30, -21% |
| 5 | 169 | **8** | 8 | 140 | 29, -17% |
| 6 | 143 | **5** | 5 | 140 | 3, -2% |
| 7 | 153 | **5** | 6 | 125 | 28, -18% |
| 8 | 136 | **-** | - | - | - |
| 9 | 125 | **-** | - | - | - |
| 10 | 161 | **11** | 12 | 130 | 31, 19% |
| 11 | 139 | **-** | - | - | - |
| 12 | 143 | **-** | 4 | 162 | 21, +15% |
| 13 | 135 | **-** | - | - | - |
| 14 | 168 | **9** | 9 | 136 | 32, -19% |
| 15 | 153 | **5** | 7 | 120 | 33, -22% |
| 16 | 135† | **-** | - | - | - |
| 17 | 153 | **7** | 8 | 136 | 17, -11% |
| 18 | 149 | **15** | 28 | 127 | 22, -15% |
| 19 | 132 | - | 9 | 110 | 22, -17% |
| 20 | 137 | - | 10 | 129 | 8, -6% |
| 21 | 167 | **14** | 14 | 134* | 33, -20% |
| 22 | 171 | **4** | 4 | 137* | 34, -20% |
| 23 | 158 | **5** | 6 | 130 | 28, -18% |
| 24 | 150 | **5** | 7 | 137 | 13, -9% |
| 25 | 133 | **-** | - | - | - |
| 26 | 156 | **5** | 5 | 136 | 20, -13% |
| 27 | 150 | **35** | 35 | 138* | 12, -8% |
| 28 | 143 | **5** | 13 | 122 | 21, -15% |
| 29 | 144 | **5** | 6 | 130 | 14, -10% |
| 30 | 147 | **5** | 7 | 111* | 36, -25% |
| 31 | 144 | **5** | 6 | 132 | 12, -8% |
| 32 | 199 | - | - | - | - |
| 33 | 171 | **-** | 23 | 142 | 29, -17% |
| 34 | 162 | **-** | 7 | 157 | 5, -3% |
| 35 | 152 | **-** | 14 | 145* | 13, -9% |
| 36 | 191 | **-** | 18 | 185‡ | 6, -3% |
| 37 | 122 | **-** | - | - | - |

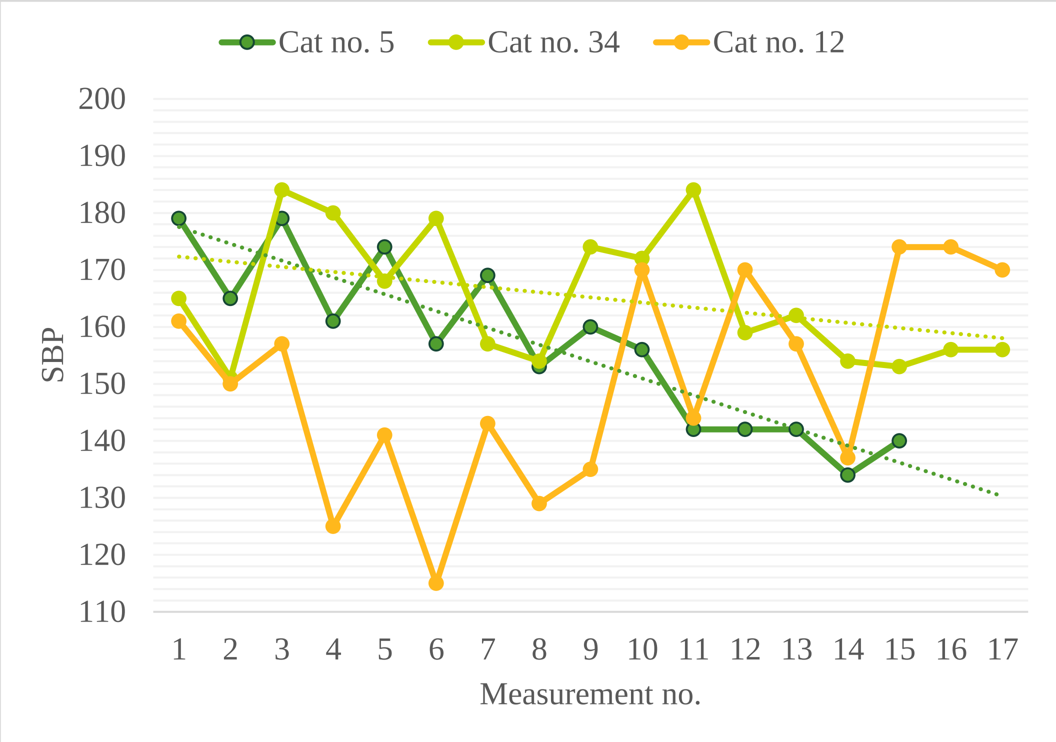


*Figure 2: Graphic illustration of distribution of SBP readings for three of the cats in the study. Cat no. 5 showed a strong downward trend as the measurements were prolonged. Cat no. 34 showed a mild downward trend. Cat no. 12 initially fell in SBP but then rose again.*

The largest total difference between initial mSBP and final mSBP was noted in cat no. 30, which had an initial mSBP of 147 mm Hg and a final mSBP of 111 mm Hg.

A total number of 615 BP measurements were recorded in this study. Of all cats in the study that were subject to a prolonged measurement, a median (range) of 5 (4 – 35) measurements were recorded, before the cat reached a mSBP <140 mm Hg. For 13 cats the cat owner continued to perform BP measurements, even though they had already recorded five BP values <150 mm Hg in the protocol. For seven of these (cat no. 4, 15, 18, 19, 20, 24, 28), the SBP continued to drop further during the additionally prolonged BP measurements (as an example see figure 3). For three cats (no. 7, 26, 31), the mSBP rose with the additionally prolonged measurements (figure 3). For three cats (no. 10, 17, 23), the mSBP stayed at the same level with additionally prolonged measurements (figure 3).

For eight cats in the study, four from group 1 (cat no. 21, 22, 27, 30) and four from group 2 (cat no. 32, 34, 35, 36), the owner/JW did not record five consecutive readings below 150 mm Hg before the measurements were concluded. For one of these cats, cat no. 32, the owner was not able to record any SBP value below 150 mm Hg, before concluding the measurements.

One cat was included two times in the study, on two separate occasions (cat no. 32 and 36).

| Cat no. 4 | Initial measurement no. | | | | | | | Prolonged measurement no. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **25** | **26** | **27** | **28** | **29** | **30** |
| **SBP** | ~~127~~ | 121 | 133 | 170 | 147 | 140 | 160 | 112 | 143 | 115 | 124 | 122 | 128 | 157 | 124 | 123 | 122 | 119 | 122 | 119 | 123 | 119 | 122 | 111 | 117 | 113 | 119 | 117 | 118 | 121 |
| **mSBP** | **145** | | | | | | | **123** | | | | | | | | | | | | | | | | **115** | | | | | | |

| Cat no. 31 | Initial measurement no. | | | | | Prolonged measurement no. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** |
| **SBP** | ~~184~~ | 146 | 158 | 133 | 139 | 158 | 134 | 126 | 134 | 124 | 142 | 169 | 162 | 154 | 174 | 163 |
| **mSBP** | **144** | | | | | | **132** | | | | | **164** | | | | |

| Cat no. 17 | Initial measurement no. | | | | Prolonged measurement no. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
| **SBP** | ~~187~~ | 125 | 191 | 144 | 150 | 143 | 151 | 137 | 140 | 133 | 128 | 141 | 136 | 144 |
| **mSBP** | **153** | | | | | | **136** | | | | | | | |

*Figure 3: SBP measurements of cat no. 4, 31 and 17. Cat no. 4 showed lower mSBP levels with additionally prolonged measurements. Cat no. 31 showed rising mSBP levels with additionally prolonged measurements. Cat no. 17 showed no change in mSBP with additionally prolonged measurements.*

Blood pressure measurements were performed on the blanket on the table (n=14), in the lower half of the carrier placed on the table (n=13), with entire carrier on the table (n=5) or on the floor (n=5) (see figure 4). Of the 37 cats, n=32 (86,5%) made use of the pheromone blanket during the measurement procedure.

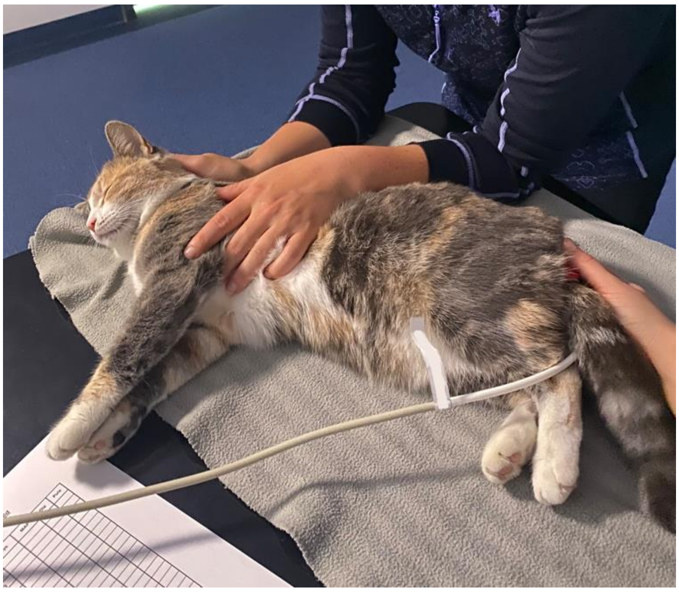

*Figure 4: Blood pressure measurement performed with the cat on a blanket on the table, placed on its right side, with owner gently restraining the cat. Author: Julia Wlosinska*

Of the 27 owners that performed a BP measurement on their cat, n=15 (56%) answered that it was "easy" to perform the measurements, n=8 (30%) answered that it was "moderately difficult", and n=4 (15%) said it was "difficult" to measure the BP on their cat. The following reasons were listed as disturbances during the measurement procedure by the cat owners: the cat was stressed by noises outside the room (n=16), the cat moved (n=9), noise from the laundry room (n=6), the cuff slid off (n=6), the cat tried to leave the table (n=5), or the BP machine showed an "error" message (n=4). One cat owner listed their own stress as the reason for measurement being difficult. Seven cat owners answered that no disturbances were observed during the BP measurement procedure.

Cat no. 27 was recruited towards the end of the study and the cat owner had a work-related commitment taking place simultaneously as the BP measurement was scheduled. The owner was quite stressed during the measurement procedure. This cat required 35 BP measurements before reaching mSBP <140 mm Hg, the highest number of prolonged measurements of all cats in the study.

# 5. Discussion

Of 37 cats in the study, 26 were subject to a prolonged measurement. After the prolonged measurement time, an additional 20 cats reached a mSBP <140 mm Hg. A median of 5 prolonged measurements were performed before mSBP <140 mm Hg. 23 of 27 cat owners that performed a prolonged BP measurement thought it was "easy" or "moderately difficult" to perform a BP measurement on their cat, while four cat owners said it was "difficult". Thirteen cat owners continued to measure the BP of their cat even after reaching the criterion to conclude the measurements. One of these cats dropped by 25% in BP from its initial mSBP to its final mSBP.

In general, for those cats that were subject to a prolonged measurement time, a clear downward trend could be seen in the recorded SBP values. In many instances (n=18), there was a drop in measured SBP directly after the author (JW) left the room. This would support the findings of the Lyberg *et al.* (2021) study where the dog owner was able to record lower BP values as the student left the room. This could indicate that a WCE was experienced by the cats in this study as has been reported in earlier studies (Belew *et al*. 1999). For the cats that were excluded from a prolonged measurement, the mean initial mSBP was established as 135 mm Hg. This is comparable to the mean SBP of 130 mmHg recorded in earlier studies in healthy cats (table 1).

Many of the cats in group 1 showed a rapid drop in BP towards the final mSBP of 140 mm Hg or below after JW left the room. This would suggest low levels of stress among these cats. The most reasonable explanation for low levels of stress in group 1 is the fact that these cats were clinically healthy, unlike most cats in group 2. Secondly, many of the cats in group 1 were owned by veterinary- or veterinary nurse students. These cats can be presumed to be quite used to being handled. As was noted in this study, once the cuff has been attached, inflated and deflated a few times, many cats were able to relax, especially after the staff leaves the room. Having this in mind, it could be beneficial for owners of cats that need regular BP measurements, to use a cuff or something similar to a cuff and "practice" BP measurements with the cat at home.

Another reason that could explain lower levels of stress among group 1 is that many of the cats were quite young and many had not been to the veterinary office before. A few cat owners described how their cat was historically significantly less stressed the first time the cat visited the veterinarian, compared to how they reacted during subsequent visits. This would support the finding by Belew *et al.* (1999) that no habituation effect was observed in the cats in their study. Indeed, it could be presumed that an animal that has experienced pain or sickness (most likely a negative event) and visited a veterinary clinic at the same time, would correlate the two events and thus experience high levels of fear and anxiety with subsequent visits to the veterinarian. This in turn, could be reflected in higher levels of BP. This reasoning could be applied when examining the difference in SBP among the two groups; the majority of cats in group 2 had a higher mSBP (both initial and final) than the healthy cats (group 1) included in the study. The cats in group 2 were older than the cats in group 1 and had been to the veterinary office on several occasions prior to the visit when this study was performed. Further, many cats in group 2 possibly had an underlying condition related to secondary hypertension.

Another factor that seems to influence the results is the perceived stress level of the cat owner themselves. The cats in Group 1 were recruited specifically for the study and came to the visit at the clinic knowing that it would take one to two hours. The cat owners were prepared in advance for the fact that they would be taking the blood pressure on their cats and were looking forward to the experience. The cat owners of group 2 were visiting the clinic with their cat and did not know beforehand that they would be a part of a study. These cat owners were concerned for the health of their cat and a few of them (as perceived in the interview by JW following the BP measurement procedure) were a bit frustrated with the prolonged measurement procedure. This was supported by one of the cat owners who listed in the protocol that their own stress level made measurements difficult. The same applied to one of the owners of a cat in group 1. Because studies of emotional contagion have only been performed on canines, it can only be theorized whether the stress level of the owner would influence the BP results in cats. However, emotional contagion could have impacted the BP results obtained for cats like no. 27 (Sümegi *et al.* 2014; Yong & Ruffman 2014). In the future, the protocol used for the BP measurement procedure could include a box where the owner states if they are stressed or not during the measurement procedure. This could perhaps give the clinician an indication of the general stress level in the examination room where the BP measurements are taking place.

Some of the owners of the cats in group 1 were eager to produce a large number of measurements as they knew they were part of a study on prolonged measurement time. These cat owners (n=13) continued to measure the BP of their cat even after they had reached a level below 150 mm Hg for five consecutive measurements. For about half of these cats (7 of 13), the BP continued to drop further as the measurements continued. It is relevant to see that the cat is able to drop even further in mSBP as the measurements are additionally prolonged.

A prolonged BP measurement procedure will not lead to lower levels of anxiety in all cats. This was demonstrated in cat no. 12 (see figure 2). This cat had an initial mSBP of 143 mm Hg. To be noted, out of the initial ten BP readings conducted by JW, five consecutive ones were at a level below 150 mm Hg (mSBP 131 mm Hg). As JW left the room and the owner continued to perform the measurements, the cat became more and more anxious. The final mSBP for this cat, 162 mm Hg, is an average of the last five measurements recorded by the owner. After this point the owner “was not able to keep the cat on the table any longer” and had to conclude the measurements. This cat is an example of when a prolonged measurement time does not lead to a decrease in stress levels for the animal but actually has the opposite effect. From a clinical perspective, cat no. 12 would be classified as normotensive already based on its initial mSBP measurements, and therefore would not benefit from a prolonged measurement procedure. Cat no. 31 quickly dropped to its final mSBP as JW left the room. The owner however performed an additional five measurements after this, and the owner reported the cat as being “annoyed” by the procedure at that point. This is an example of when a normotensive animal shows increasing levels of stress related to a prolonged measurement procedure. In terms of developing the prolonged measurement procedure in the future, it is a straightforward instruction for the owner to continue the measurements until “five consecutive measurements below 150 mm Hg” have been registered, however, it could also lead to an unnecessary number of measurements due to the above-mentioned reasons. A way to avoid this would be to instruct the owners that if a majority of SBP values in close proximity (for example seven out of ten) are below 150 mm Hg, the measurements can be concluded.

Most cat owners (23 of 27) experience it to be ”easy” or “moderately difficult” to complete the measurements. Seven cat owners said that performing the measurements was both ”easy” and also reported no disturbances at all related to the measurement process. These owners said that their cat was relaxed during the whole procedure, meaning there was no need to restrain the cat or readjusting the cuff and therefore it was uncomplicated for them to simply note the results in the protocol. Four of these cat owners were veterinary students, who felt comfortable handling the cat as well as the equipment.

Four owners said that it was “difficult” to perform the measurements, as their cat was very anxious and either wanted to sit up instead of laying down or tried to leave the table all together. Two of these owners were those who decided their cat would be more comfortable on the floor. This made the measurement process more difficult as the cat naturally had more freedom to walk around as it was placed on the floor for the measurements. Many owners explained that they would need ”a third hand” to be able to restrain the cat, make sure the cuff was correctly placed and pet the cat – all while recording the measurements in the protocol. Based on this, it would perhaps be beneficial if two cat owners (if possible) could be present for their cats’ BP measurements – one to gently restrain and pet, and one to perform the measurements, without involvement of the staff. Another possibility would be to place the cat in its carrier for the measurements, however, in this study only five cat owners decided that the carrier is where their cat would be more comfortable.

The second question in the protocol concerned any disturbance perceived by the owner during the measurement. As stated previously, the room mainly used for this study was an examination room separate from the other examination rooms in the clinic. This room was chosen in order to minimize the number of staff and animals moving outside the door, as instructed in the ACVIM guidelines (Acierno *et al.* 2018). Nevertheless, “disturbing sounds” was the most commonly reported disturbance and was reported by 16 cat owners. Unfortunately, the room was located next to the laundry room, which meant that on many occasions either a washing machine or a tumble drier was in use, making a substantial amount of noise as the measurements were being taken. This was a marked stress factor for some of the cats, as reported by six cat owners afterwards. This factor shows the difficulty in reproducing an optimal setting in the clinical environment. Even if a best practice is developed it can be hard to accommodate for all recommendations on a daily basis in the veterinary clinic.

The measurement procedure was standardized as much as possible. For most measurements the same room (separate from the busy policlinic) was used, however, for a few number of measurements as well as for all cats in group 2, the "cat friendly" examination rooms of the policlinic at UDS were used for the measurements (rooms where only cats can be seen, and where pheromone dispensers are placed in the room). As these rooms were not "separate" and quiet in the same way as the room used for most patients of group 1, this could have affected the stress levels of the cats. Interestingly, none of the cat owners in group 2 reported "noise outside the examination room" to be a disturbing factor.

The HDO equipment used in this study has previously been validated in a study on cats by Martel *et al.* (2013) according to the guidelines available at the time (Brown *et al.* 2007). However, Martel *et al.* conducted their study on only six animals, which is not enough, as the number of animals should be at least eight (Brown *et al.* 2007). In this study we have not compared our BP results to a gold standard and therefore we cannot evaluate the precision of the HDO instrument. However, the design of the study required the cat owner to perform BP measurements on their cat themselves. Thanks to the user-friendliness of the HDO equipment, this was possible. The HDO is fairly simple in its operation and all owners were able to register at least one value for their cat. Most owners (97%) were able to register at least five measurements for their cat. Optimally, the owner should have a short introduction to why the animal needs to stay still during the measurement. In order for the owner to be able to obtain reliable measurements for their cat, they should be comfortable in "handling" the animal. This includes being able to gently restrain the cat while for example placing or adjusting the cuff on the tail. Another possibility would be to place the cat in a restraining bag or in its carrier, which would limit the animal's mobility and perhaps make the results more consistent, however, this could probably be very stressful for some cats, leading to falsely high BP results.

It has been argued that appropriately trained personnel are more suitable for performing BP measurements (Gouni *et al.* 2015). As staff are not present in the room, the animal owner cannot always be expected to directly evaluate whether an individual BP reading is obviously erroneous or not, adjust the cuff when needed, note movements of the animal and so forth. However, when prolonged measurements are performed, as in this study, the HDO software makes less of a difference as the large number of values recorded in the prolonged measurement procedure makes any erroneous outliers of lesser importance. Nevertheless, it could be of benefit to use the accompanying HDO software for BP measurements recorded alone by an animal owner, in order to enable subsequent exclusion of obviously erroneous measurements due to for example movement artifacts. This would most likely be even more beneficial in animals which show a large variety in their initial SBP measurements.

Each cat was provided with a blanket sprayed with Pheromones. All cats except five made use of the blanket. These blankets are prepared in advance as the scent should be allowed to "rest" on the textile for at least one hour before it is used for the cat. However, on many days the animal hospital had a shortage of pre-sprayed blankets. In those cases, a blanket was sprayed with pheromones only minutes before being used for the cats, which could have affected the efficiency of the product. Unlike what was reported by Pereira *et al.* (2016), no obvious differences in stress level were observed between cats that did or did not make use of the blanket.

One of the cats in group 2, cat no. 33, was initially markedly hypertensive (initial mSBP of 171 mm Hg). The cat did not try to escape the examination table but was evidently stressed and had tachypnea. As JW left the examination room and the owner proceeded with performing the measurements, the SBP of the cat was steady at a value close to the initial mSBP. The owner performed 14 prolonged BP measurements. The cat then lied on the floor of the examination room and rested for about 10 minutes. JW reentered the room. The HDO machine was moved to the floor and the cuff was reattached to the tail while the cat was on the floor, noticeably more relaxed than previously (Figure 5). The prolonged measurements continued and a final mSBP of 142 mm Hg was then recorded. The patient, who would initially be classified as hypertensive, could instead be classified as normotensive after a prolonged BP measurement time of about 40 minutes. It is difficult to determine whether the prolonged measurement time or the change in setting from table to floor had a stronger influence on the experienced stress of this cat. According to Hanås *et al.* (2021) no significant difference was seen in measured SBP between different clinical settings in the studied population of (relatively) young, healthy cats. As cat no. 33 was neither young nor clinically healthy, its results cannot fully be compared to the study population of Hanås *et al*. Nevertheless, as it never tried to leave the examination table during the measurement process, it can be assumed that for this individual cat the prolonged measurement time most likely contributed significantly to its reduction in stress.

*Figure 5: Initially hypertensive patient, with normotensive measurements after 40 minutes. Author: Julia Wlosinska*

One owner brought two cats with them to the appointment. One of the cats seemed to be very stressed by the situation which was reflected in its BP value. When JW left the examination room, the SBP of the cat was maintained at a level close to its initial mSBP. After five readings had been performed by the owner, the other cat, which was allowed to roam freely around the room, jumped onto the examination table, lied down next to the first cat and started purring. The cat that was having its BP measured, instantly dropped in BP and stayed at this level throughout the rest of the measurement procedure. This observation could be of value in situations where an animal that has a companion or a flock at home, requires a BP measurement. In said case it could be beneficial to bring both or all animals to the clinic, for the sake of companionship, and perhaps, contribute to lower stress levels in the animal being examined. It would be interesting to study this observation at a larger scale in the future.

One cat was seen twice, on two separate occasions (cat no. 32 and 36). The initial mSBP for the first visit was 199 mm Hg, but the owner was not able to record more than one measurement on the cat as JW left the room. The explanation was that the cat was highly stressed and left the table. The cat owner did not wish to perform any further attempts in obtaining a SBP measurement for the cat at that point in time. During the next visit one month later, the initial mSBP of the cat was at 191 mm Hg. This time, the owner also declared that they would not be able to measure the BP on the cat alone, and asked JW to stay in the room. JW conducted a prolonged measurement on the cat, which dropped to a mSBP of 185 mm Hg over 18 measurements. No distinct downward trend in BP was seen in this cat. The consistently elevated BP values for the cat might be explained by the WCE, emotional contagion from the owner, or the cat being truly hypertensive. The result is similar to that reported by Sparkes *et al.* (1999), where cats showed little variation in SBP results when measured over several days. Still, the population studied by

Sparkes *et al.* consisted of healthy cats, which the abovementioned cat, most probably, was not.

A thing to be noted about the feasibility of reproducing these results in a clinical environment is the time-consuming nature of a prolonged BP measurement. It can take about 40 minutes to produce results such as those seen in this study. It would be favorable to inform the animal owner beforehand that they need to be prepared to spend one, sometimes two hours in the clinic in order to achieve the stress-free conditions required for a reliable BP measurement. In terms of value for the patient, a reliable BP measurement is highly desirable, as any BP measurement in a cat poses a risk for false diagnosis of hypertension. However, the procedure must also be feasible in the daily workings of a veterinary practice, and of course, for the animal owner.

*Limitations*

The cats were recruited for the study by word of mouth, which resulted in the inclusion of a large number of cats being owned by veterinary or veterinary nurse students. These cats in general showed low levels of BP in the clinical environment, which perhaps is not representative for the cat population as a whole. It would be favorable to include a larger number of cats that were visiting the animal hospital. This was not made due to time limitations in data collection for this thesis.

The HDO software was not used in this study, as recommended by the manufacturer and this may have influenced the results. However, as noted earlier usage of the HDO software is of lesser significance when a large number of recordings are made, as in this study. Further, an earlier study has concluded that usage of the HDO without the software is reasonable (Lyberg *et al.* 2021).

*Conclusion*

This study shows that for many cats a downward trend in SBP can be seen when measurements are prolonged. A probable WCE was observed in some of the cats of the study, and therefore letting the owner perform prolonged BP measurements, with an adequate introduction, may reduce overdiagnosis of hypertension. Most cat owners in the study thought it was easy to perform BP measurements on their cat using the HDO. Even though the procedure might not be easy to perform for some owners and cats, it is still beneficial for those cats that can be classified as normotensive and thus avoid unnecessary hypertensive treatment. The study shows that prolonged BP measurements can be recommended for cats with initially high SBP values.

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# Popular science summary

Measuring the blood pressure of cats is frequently performed by animal healthcare staff. The “white coat effect” is when a blood pressure measurement in a clinical environment makes the patients’ blood pressure temporarily higher (because of stress) which gives a falsely high blood pressure result. This phenomenon is well known in humans and has also been established in cats. Because cats are easily stressed by their surroundings, it is very important to reduce all stress when taking blood pressure measurements in cats.

A stress-free blood pressure measurement procedure in the clinic includes things such as: having the owner of the cat present, performing the measurement in a room that is quiet and has dimmed lights, letting the cat get used to its surroundings before starting the measurements, and so on. Another recommendation is to continue the measurements until the cat reaches a lower plateau in its blood pressure measurement results.

In this study, we wanted to examine if it is possible to reach lower blood pressure measurement results in cats, if the blood pressure is measured for a longer time. Therefore, in addition to the routine blood pressure measurements, additional measurements were performed by the cat owner. We also wanted to see how the cat owner would experience measuring the blood pressure of their cat on their own.

Thirty-seven cats were in the study. Eleven cats had a normal blood pressure measurement at the start, but twenty-six cats did not and were part of the prolonged measurement procedure. Almost all cats had a falling blood pressure in the prolonged measurements. Most commonly the owner did 5 prolonged measurements, before the cat reached a normal blood pressure.

As the staff left the room and the owner measured the blood pressure on their cat alone, many of the cats had a lower blood pressure measurement result very quickly. This could mean that the cats experienced the “white coat effect” in the beginning of the measurements but were able to relax during the prolonged measurements when the staff left the room. Most cat owners said that it was easy to measure the blood pressure on their cat.

According to the study, measuring the blood pressure for a longer time on cats, means that lower blood pressure values will be recorded. A suspected “white coat effect” can be reduced by measuring the blood pressure for a longer time. According to this study, it is valuable if the owner can measure the blood pressure on their cat on their own.

# Appendix 1

**Protokoll**

**Blodtrycksstudie 2021 - Förlängd mättid**

Datum: _____________

Fäst patient etikett

**Information till djurägare**

*Dokumentera alla mätningar du gör i protokollet på baksidan. Om fem mätningar i nära anslutning till varandra alla visar ett systoliskt blodtryck under 150 mmHg, AVBRYT MÄTNINGARNA och sätt ut den gröna skylten utanför dörren. Om problem uppstår, sätt i stället ut den röda skylten. Personal kommer snart.*

**För vårdpersonal**

Antal djurägare närvarande vid mätningen: ………………

Ange om optimerad miljö har erbjudits (kryssa i relevant):

Dämpad belysning i rummet | Hund/katt i ägarens knä

Feliway-filt (katt) | Katt placerad i bur

_____________________

**Frågor till djurägare efter att mätningarna har avslutats:**

Hur upplevdes det att utföra mätningarna (kryssa)

Enkelt | Medelsvårt | Svårt

Upplevde du några störningsmoment under tiden för mätningarna?

JA, vilka? …………………………… | NEJ

| Mätning nr | Sys | MAP | Dia | Puls | Mätning nr | Sys | MAP | Dia | Puls |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | 31 | | | | |
| 2 | | | | | 32 | | | | |
| 3 | | | | | 33 | | | | |
| 4 | | | | | 34 | | | | |
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| 29 | | | | | 59 | | | | |
| 30 | | | | | 60 | | | | |

# Appendix 2

| Demographics | | | | | Initial measurement no. (SBP) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feline nr | Breed | Sex (M/F) | Age (months) | Weight (kg) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | DSB | M | 19 | 4,8 | 166 | 153 | 137 | 143 | 149 | 146 | 109 | 137 | 136 | 130 | | |
| 2 | DSB | F | 16 | 3,7 | 192 | 128 | 126 | 143 | 127 | 101 | 136 | 132 | 116 | 105 | 157 | 101 |
| 3 | DSB | F | 54 | 5,2 | 166 | 128 | 150 | 124 | 156 | 135 | 142 | 156 | | | | |
| 4 | Ocicat | M | 13 | 6,2 | 127 | 121 | 133 | 170 | 147 | 140 | 160 | | | | | |
| 5 | DSB | F | 27 | 3,7 | 163 | 179 | 165 | 179 | 161 | 174 | 157 | 169 | | | | |
| 6 | DSB | F | 37 | 3,1 | 166 | 148 | 146 | 134 | 137 | 143 | 150 | | | | | |
| 7 | DSB | M | 10 | 5,5 | 156 | 110 | 175 | 164 | 161 | 170 | | | | | | |
| 8 | Ragdoll | F | 16 | 4,3 | 157 | 114 | 151 | 102 | 154 | 140 | 135 | 125 | 165 | 89 | | |
| 9 | DSB | M | 63 | 3,7 | 120 | 82 | 114 | 99 | 151 | 144 | 127 | 116 | 119 | 131 | | |
| 10 | DSB | M | 36 | 3,8 | 173 | 177 | 155 | 159 | 151 | | | | | | | |
| 11 | DSB | F | 161 | 4,4 | 64 | 70 | 141 | 141 | 152 | 102 | 143 | 143 | 148 | 174 | | |
| 12 | DSB | F | 220 | 3,9 | 161 | 150 | 157 | 125 | 141 | 115 | 143 | 129 | 135 | 170 | | |
| 13 | DSB | M | 45 | 3,8 | 138 | 130 | 145 | 100 | 78 | 145 | 164 | 123 | | | | |
| 14 | DSB | M | 46 | 5,4 | 141 | 184 | 168 | 167 | 153 | | | | | | | |
| 15 | DSB | M | 15 | 3,0 | 85 | 150 | 155 | | | | | | | | | |
| 16 | DSB | F | 15 | 3,6 | 128 | 130 | 117 | 127 | 116 | 167 | 164 | 162 | 121 | 134 | 107 | |
| 17 | DSB | F | 57 | 4,3 | 187 | 125 | 191 | 144 | | | | | | | | |
| 18 | Siberian | F | 22 | 4,4 | 87 | 127 | 163 | 145 | 171 | 140 | | | | | | |
| 19 | Devon Rex | M | 11 | 4,4 | 109 | 146 | 126 | 100 | 128 | 158 | | | | | | |
| 20 | DSB | M | 10 | 4,6 | 194 | 124 | 187 | 100 | 83 | 72 | | | | | | |
| 21 | DSB | F | 26 | 4,6 | 152 | 161 | 167 | 173 | 167 | | | | | | | |
| 22 | Siberian | F | 100 | 3,5 | 183 | 166 | 180 | 171 | 167 | | | | | | | |
| 23 | DSB | M | 208 | 5,1 | 113 | 163 | 171 | 163 | 133 | | | | | | | |
| 24 | DSB | M | 16 | 3,7 | 188 | 154 | 99 | 165 | 179 | 153 | | | | | | |
| 25 | DSB | F | 12 | 3,5 | 140 | 140 | 102 | 132 | 106 | 152 | 157 | 92 | 174 | | | |
| 26 | DSB | F | 85 | 5,2 | 136 | 148 | 138 | 150 | 148 | 165 | 166 | 174 | | | | |
| 27 | Siberian | F | 63 | 5,1 | 168 | 133 | 165 | 146 | 150 | 156 | | | | | | |
| 28 | Birma | M | 42 | 4,8 | 115 | 124 | 152 | 130 | 164 | 108 | | | | | | |
| 29 | DSB | M | 99 | 5,3 | 153 | 159 | 139 | 141 | 140 | 140 | | | | | | |
| 30 | DSB | M | 66 | 4,0 | 149 | 225 | 153 | 124 | 125 | 117 | 133 | 165 | | | | |
| 31 | Siberian | F | 79 | 3,3 | 184 | 146 | 158 | 133 | 139 | | | | | | | |
| 32 | DSB | M | 185 | 6,5 | 186 | 188 | 170 | 227 | 209 | 223 | 177 | | | | | |
| 33 | DSB | M | 167 | 4,6 | 150 | 193 | 152 | 175 | 150 | 185 | | | | | | |
| 34 | DSB | F | 149 | 4,5 | 165 | 151 | 184 | 180 | 168 | 121 | 179 | 157 | 154 | | | |
| 35 | DSB | M | 141 | 6,7 | 156 | 140 | 145 | 149 | 148 | 179 | 166 | | | | | |
| 36 | DSB | M | 185 | 6,5 | 191 | 197 | 191 | 200 | 185 | 180 | | | | | | |
| 37 | Birma | M | 96 | 3,9 | 164 | 119 | 133 | 91 | 125 | 124 | 127 | 130 | 121 | 125 | | |

| | Prolonged measurement no. (SBP) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feline nr | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | 140 | 149 | 174 | 131 | 137 | 124 | 120 | 109 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | 112 | 143 | 115 | 124 | 122 | 128 | 157 | 124 | 123 | 122 | 119 | 122 | 119 | 123 | 119 | 122 | 111 | 117 | 113 | 119 | 117 | 118 | 121 | | | | | | | | | | | | | |
| 5 | 153 | 160 | 156 | 142 | 142 | 142 | 134 | 140 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | 148 | 134 | 135 | 141 | 143 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | 155 | 135 | 132 | 109 | 145 | 106 | 159 | 160 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 150 | 148 | 123 | 157 | 139 | 154 | 151 | 127 | 132 | 137 | 128 | 125 | 130 | 146 | | | | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | 144 | 170 | 157 | 137 | 174 | 174 | 170 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | 164 | 163 | 163 | 173 | 145 | 145 | 144 | 145 | 99 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 89 | 119 | 104 | 126 | 116 | 148 | 111 | 100 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | 150 | 143 | 151 | 137 | 140 | 133 | 128 | 141 | 136 | 144 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | 170 | 166 | 159 | 149 | 165 | 133 | 146 | 129 | 177 | 158 | 144 | 134 | 135 | 137 | 145 | 145 | 136 | 134 | 130 | 137 | 128 | 125 | 138 | 131 | 126 | 129 | 124 | 126 | 131 | 128 | 127 | 128 | | | | |
| 19 | 132 | 145 | 141 | 112 | 108 | 128 | 103 | 103 | 110 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | 193 | 86 | 110 | 146 | 139 | 125 | 133 | 147 | 116 | 127 | 124 | 155 | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | 150 | 172 | 168 | 160 | 135 | 145 | 149 | 151 | 178 | 145 | 144 | 129 | 152 | 98 | 144 | 193 | 187 | 172 | 150 | 135 | 99 | 140 | 146 | 86 | 138 | | | | | | | | | | | |
| 22 | 153 | 148 | 139 | 124 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 23 | 130 | 128 | 128 | 133 | 134 | 127 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | 134 | 142 | 140 | 138 | 137 | 136 | 136 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 26 | 142 | 127 | 147 | 129 | 135 | 154 | 160 | 138 | 138 | 74 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 27 | 141 | 149 | 148 | 157 | 167 | 138 | 159 | 148 | 161 | 173 | 168 | 161 | 181 | 164 | 157 | 160 | 152 | 156 | 164 | 150 | 153 | 151 | 142 | 147 | 155 | 154 | 150 | 135 | 140 | 149 | 153 | 81 | 147 | 126 | 138 | 124 |
| 28 | 129 | 122 | 126 | 122 | 138 | 139 | 133 | 119 | 124 | 126 | 124 | 122 | 113 | | | | | | | | | | | | | | | | | | | | | | | |
| 29 | 151 | 125 | 124 | 138 | 130 | 134 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 30 | 132 | 188 | 107 | 112 | 119 | 107 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 31 | 158 | 134 | 126 | 134 | 124 | 142 | 169 | 162 | 154 | 174 | 163 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 32 | 206 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 33 | 173 | 185 | 189 | 179 | 194 | 181 | 189 | 182 | 182 | 178 | 164 | 179 | 130 | 181 | 160 | 152 | 159 | 146 | 146 | 143 | 143 | 141 | 136 | | | | | | | | | | | | | |
| 34 | 174 | 172 | 184 | 159 | 162 | 154 | 153 | 156 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 35 | 163 | 157 | 174 | 181 | 173 | 172 | 161 | 160 | 152 | 156 | 150 | 144 | 132 | 141 | | | | | | | | | | | | | | | | | | | | | | |
| 36 | 192 | 194 | 188 | 190 | 162 | 155 | 194 | 194 | 147 | 151 | 186 | 171 | 192 | 187 | 183 | 180 | 186 | 187 | | | | | | | | | | | | | | | | | | |
| 37 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |