

Assessing and Monitoring Critical Illness

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Initial assessment: The primary survey physical exam

When first encountering an obviously sick animal the aim of the initial examination is to rapidly identify any imminently life-threatening problems via a streamlined and efficient clinical examination. A very brief history should be obtained at presentation, focusing on the owner's chief complaint. Does the information suggest the patient is at high risk?

The cardiovascular, respiratory and central nervous systems should be evaluated first, followed by abdominal palpation and body temperature. The initial survey of each major body system is abbreviated such that the clinical signs that yield the most important information are evaluated first. Stabilization measures should be initiated for any major problems prior to the remainder of the full physical evaluation.

The initial physical exam focuses on basic information obtained by observing the animal as you approach it:

- What is the level of consciousness (LOC) - is the patient depressed or agitated?
- Can it walk?
- Can it draw a breath without difficulty?
- Does it look sick or dehydrated from a distance?

Next, a more focused exam concentrates attention on the organ system referred to in the owner complaint and other high-risk possibilities:

- Are there skin wounds or active bleeding?
- Is the abdomen distended or painful?
- Are the vital signs abnormal?

Specific components of the examination include vital signs (temperature, pulse, respiration, and pain, TPRP):

Temperature

Hypothermia may be due to environmental causes or severe illness such as heart failure or septic shock, particularly in cats.

Hyperthermia may be due to fever or nonfebrile conditions and the cause must be determined. If an elevated body temperature is due to environmental heat stress or seizures, the patient may need assisted cooling. If it is due to a fever the animal may need blankets and sometimes heat support to reach and maintain its desired temperature. No effort should be made to cool a febrile patient unless the temperature is $> 42.5^{\circ}\text{C}$ or if it is increasing toward that limit rapidly. When intervention is necessary it usually should be accomplished with an injectable nonsteroidal anti-inflammatory drug, NOT physical cooling.

Pulse (cardiovascular findings)

Heart rate is an extremely important measurement but must be interpreted in light of the animal's behavior. A sick, stressed, or anxious cat should always have a high (> 180 BPM) heart rate. Relative bradycardia is the most common serious rhythm disturbance in sick cats and when accompanied by hypothermia may be an ominous sign. Conversely, high heart rates in cats (220-280 BPM) is usually a physiologically appropriate response to anxiety, fear, excitement, heart disease, or significant noncardiac illness. A high heart rate in a quietly resting or obtunded dogs routinely indicates an appropriate response to underlying illness; in acute illness this is often driven by relative or absolute hypovolemia. A healthy, relaxed, quietly resting dog should have a heart rate of 35 – 80 BPM. This is rarely seen in the clinic, where the dog is anxious and alert in response to the physical examination. However, a dog that is depressed or obtunded by its illness and relatively unaware of its surroundings should have a heart rate approaching that range, and heart rates > 120 BPM (regardless of size) almost always indicate a compensatory response to illness. Heart rates > 140 BPM in this setting usually indicate severe trouble that will require intervention. Heart rates in excess of 220 BPM, or the presence of an irregular pulse, should prompt suspicion for the presence of an arrhythmia.

The femoral pulse should be carefully palpated to allow assessment of width (an indication of pulse pressure) and duration. Assessing the pulse width and duration allows rough estimation of pulse volume.



Figure 1 Figure 2 Figure 3 Figure 4

- Figure 1 illustrates the pulse profile of a normal dog with from a catheter placed in the dorsal metatarsal artery.
- Figure 2 is an example of a hyperkinetic pulse in an animal with anemia due to autoimmune destruction of red blood cells that has developed over several days. In this setting, blood volume is increased and cardiac contractility is more vigorous, resulting in an increased stroke volume. The pulse associated with each heart beat is longer in duration and the systolic-diastolic difference (pulse width) may be increased.
- Figure 3 is an example of a 'thready' pulse due to hypovolemia or mitral valve heart disease. Animals with these conditions respond by peripheral vasoconstriction and reduced compliance of the arterial tree, increased heart rate, and increased vigor of contraction of the left ventricle. The resulting pulse may have a reduced diastolic pressure (shifting the baseline pressure downward) but a pulse width (systolic-diastolic difference) that is normal or increased, and a pulse duration that is perceptibly reduced. This pulse is characteristic of animals compensating for reduced perfusion with appropriate peripheral vasoconstriction. The pulse is easy to find (because the pulse width is large) but is noticeable short.
- Figure 4 is an example of a 'weak' pulse characteristic of animals with hypotension from severe sepsis, septic shock, or anaphylaxis. These animals have inappropriate low peripheral vascular resistance and may have impaired heart function as well. The diastolic pressure (baseline) is shifted downward and the pulse width is noticeably reduced. This pulse may also be found in animals with hypovolemic shock when extreme hypovolemia overwhelms their compensatory response, and indicates that death is imminent if the hypovolemia is not immediately corrected. The pulse may be hard to find because of the small width, and the artery is easily collapsed with digital pressure because diastolic pressure is low.

Mucus membranes

In a normal animal should be pink with a capillary refill time (CRT) of around 1-2 seconds when the head is positioned above the level of the heart. After blanching the blood out of the oral mucosa over the maxilla, capillary refill is due to a combination of arterial flow and backwards flow from veins. The backwards flow partially explains why the CRT may be normal in a cadaver, and is the reason it is important to evaluate the CRT with the head positioned well above the heart in order to more accurately assess arterial flow. Pale mucus membranes may indicate anemia, hypoxemia from lung disease, or vasoconstriction due to hypovolemia or heart disease. Cyanotic mucus membranes most often suggest airway obstruction or loss of lung volume due to pleural space disease. A combination of pallor and cyanosis (grey color) suggests both poor perfusion and hypoxemia. Brown mucus membranes suggest the presence of methemoglobin.

Respiration

What is the respiratory pattern and rate? Tachypnea and hyperpnea often indicate a need to increase minute ventilation in response to cardiopulmonary or systemic disease. Fast shallow respirations are a common mechanism to increase minute ventilation in the face of lungs made stiff by edema or disease. Deep respirations often suggest that the patient needs to increase minute ventilation with normal lungs, for example as a method to compensate for metabolic acidosis. Abdominal breathing (active contraction of the abdominal muscles to increase the strength of exhalation) indicates a high need to force air out quickly though airways compromised by collapse or inflammation.

Pain

An assessment of patient pain should be considered part of every 'vital signs' assessment. Once the animal's condition is stable, this assessment should be performed in a standardized manner that everyone in the practice uses. See the end of this manuscript for an example of a pain scoring instrument in use at NCSU.

The secondary survey: A more comprehensive physical examination

Once life-threatening disorders have been ruled out or addressed a more comprehensive physical examination of organ systems is conducted; this includes careful auscultation of heart and lungs, more detailed inspection and palpation of the abdomen, and a

neurological evaluation. Abdominal palpation may reveal abnormalities that will lead you to imaging studies with radiographs and/or ultrasound examination. Nervous system dysfunction greater than expected from the degree of cardiovascular or respiratory compromise present should raise the suspicion of CNS disease and should prompt a more complete neurological examination. In general, gait abnormalities in single limbs are associated with less serious problems than when multiple limbs are affected.

Continued monitoring during hospitalization

Streamlining and standardizing the approach to major body system evaluation in the emergency patient allows the small animal emergency clinician to rapidly identify, assess and stabilize life-threatening abnormalities in an expedient fashion. Repeated examination of LOC, behavior, cardio-respiratory and nervous systems, and abdomen are essential for monitoring critically ill patients over time. Adjunctive monitoring techniques, using invasive or non-invasive technology, augment basic physical exam skills and provide an extra level of clinical information to drive decision making. The most important – or at least the most frequently performed - routine monitoring techniques at the NCSU companion animal intensive care unit are:

1. Repeated physical examinations
2. Basic labs: Packed cell volume/total solids (PCV/TS), glucose, BUN, urinalysis
3. Continuous ECG
4. Measures of water balance: weight, urine output, urine specific gravity, monitoring gastrointestinal and other losses

Then, depending on the particulars of the case, any of these may be the next most important for patient management:

1. Imaging studies: thoracic radiographs, ultrasound
2. Arterial blood pressure: non-invasive in most, invasive in some
3. Metabolic monitoring: arterial/venous blood gas (pH, pO₂, pCO₂) and K⁺, Na⁺, Cl⁻, Mg⁺⁺, Ca⁺⁺, lactate, and beta-hydroxybutyrate
4. Central venous pressure
5. Pulse oximetry
6. Coagulation monitoring: thromboelastography, aPTT, PT, platelet counts
7. Cytology/fluid analysis
8. Continuous glucose monitoring

Repeated physical examinations are the most important single patient monitoring tool in intensive care.

In our hospital, patients are examined at least once daily by an assigned student, by the admitting clinician, and by critical care faculty. A separate examination is performed by the overnight intern at the beginning of their evening shift. However, the most essential monitoring is performed by the nursing staff as they complete their hourly evaluations of patients. Physical parameters monitored by technicians include temperature, pulse, mucus membrane color, capillary refill time, respiration rate and pattern, attitude/orientation, appetite, pain assessment and mobility. Depending on patient need, these physical findings are repeated every 1-12 hours around the clock.

Basic labs: PCV/TS, glucose, BUN, urinalysis

The packed cell volume, total solids, glucose, and urea nitrogen are measured at least once daily and more often as circumstances require. The urea nitrogen is estimated with a dipstick test (AzostixTM), a test that is relatively insensitive but will alert us to large changes. The PCV/TS and glucose are simple tests of parameters that can change quickly. Changes in PCV and TS may indicate changes in hydration status, blood loss, or protein loss. The color of the serum in the hematocrit tube should be observed for signs of icterus or hemolysis. The buffy coat may be examined for crude appraisal of the WBC. If the blood is drawn directly from a vein instead of a catheter, a 25 gage needle should be used to minimize patient discomfort. Make sure that everyone who performs the PCV/TS and glucose tests is trained to do them in a standardized manner, and that someone is responsible for calibrating the refractometer on a regular basis. Animals that require frequent (hourly) glucose measurements may be instrumented with a subcutaneous glucose monitor. Urinalysis with a sediment examination for casts is performed daily in patients that are at risk for acute kidney injury.

Continuous ECG

The electrocardiograph (ECG) records the electrical activity of the heart and is the method by which cardiac arrhythmias are defined. Relatively inexpensive ECG monitors are now widely available to veterinarians, either as units designed for animals sold by companies specifically marketing to veterinarians or as reconditioned units sold by medical device distributors targeting the human medical market. Many of the “stand-alone” (bedside) ECG monitors have 2 electronic pressure ports and two electronic temperature ports. Newer models also have the capacity for respiratory monitoring (respiratory rate measurement, pulse oximetry, capnography) and other parameters.

In our unit the most frequent use for continuous ECG monitoring is as a surveillance tool to follow the resting heart rate in dogs. A sleeping or quietly resting dog should have a heart rate < 100 BPM, usually with some degree of respiratory sinus arrhythmia. A significant compensatory response to systemic illness will drive the heart rate higher. The heart rate may be as high as 120-140 BPM in animals with a substantial cardiovascular response to systemic illness. Higher heart rates almost always indicate inadequate compensation and require immediate attention.

The ECG is also used to monitor patients with arrhythmias and those at risk for developing arrhythmias. The ECG does not measure myocardial function or cardiac output and in fact may appear perfectly normal in the presence of marked abnormalities in heart function.

Prolonged ECG monitoring requires atraumatic electrodes; therefore, alligator clips are not used. Instead, disposable adhesive ECG patches are applied to clipped skin. Precise placement of electrodes and standard body positioning are not essential.

Measures of water balance: weight, urine output, urine specific gravity, monitoring gastrointestinal and other losses

Body weight is the single most important measurement of day-to-day changes in body water balance. It requires an accurate scale, and most inexpensive veterinary market scales in the US easily lose their calibration. A high-quality gram scale should be used for cats and small dogs, and a high quality walk-on scale should be used for larger dogs. Animals should always be positioned as close to the center of the scale platform as possible. Daily weights should be done after the animal urinates and defecates to limit the weight of changes in urine and fecal volume on the measurement. Have your scale serviced and calibrated on a regular basis!

Urine output is technically easy to measure and provides useful information about renal perfusion. When high accuracy is not essential, urine output may be estimated by allowing the animal to urinate on absorbent pads (dogs) or plastic litter (cats) and subtracting the dry weight of the collection device from the wet weight on the gram scale. If accurate measurement is required, an indwelling urinary catheter should be inserted and maintained with a closed collection system. The catheter is aseptically connected to a sterile closed collection system and the entire system is never elevated above the level of the patient, as this would allow retrograde flow of urine and contaminating bacteria into the bladder. 10-30 ml of hydrogen peroxide may be added to the collection bag to inhibit bacterial growth. The catheter is anchored to the vulva or sheath with a single suture. The collection tubing is anchored to the tail in females or to a rear limb or belly wrap in males to prevent traction on the catheter suture.

Urine production should be measured hourly in unstable patients. Urine production should be at least 1/2 - 1 ml/kg/hour, and is frequently much higher than this following adequate resuscitation of an animal with circulatory shock. The catheter should be removed as soon as possible to minimize the risk of bacterial infection.

Gastrointestinal losses may be estimated or more accurately measured by collection onto papers and absorbent pad with known dry weights. If estimated from puddles on the cage floor it is more accurate to estimate in terms of kitchen measurements and convert to ml: 1 teaspoon = 5 ml, 1 tablespoon = 15 ml, 1 cup = 240 ml.

Imaging studies

Thoracic radiographs are often indicated for sick animals at the time of admission for purposes of working up their presenting complaint or screening for occult neoplasia in animals with otherwise expensive treatment needs. They may be repeated for monitoring purposes for several reasons:

1. To confirm correct placement of central venous catheters and esophageal feeding tubes.
2. To identify or confirm the presence of aspiration injury, pneumonia, and other causes of acute lung injury
3. To confirm the presence of pulmonary edema or pleural effusion that may arise as a consequence of underlying disease or inappropriate fluid therapy.

Ultrasound examination within the emergency or intensive care unit are performed most often to

1. Screen for abdominal or pleural effusions (FAST and TFAST exams).
2. Look for evidence pneumothorax (disappearance of the pleural glide sign).
3. Assist in sample collection by cystocentesis.
4. Look for evidence of pericardial effusion and to estimate cardiac chamber size.

Arterial blood pressure: non-invasive vs. invasive

Hypotension is a common complication of serious illness, and blood pressure monitoring is critical to successful management of some patients. Normal blood pressure in dogs has been reported as:

Systolic: 148 +/- 16 mm Hg Diastolic: 87 +/- 8 mm Hg Mean: 102 +/- 9 mm Hg

Note that some stressed animals with acute illness often have systolic pressures > 200 mm Hg and need not be considered hypertensive. Arterial pressure may be conveniently measured by indirect (external) techniques including ultrasonic Doppler instrumentation (Ultrasonic Flow Detector, Parks Medical Electronics) and by oscillometric devices. Both techniques rely on the use of cuff occlusion of arterial blood flow in a limb or tail. The Doppler method requires use of an ultrasonic probe to detect blood flow distal to the cuff as pressure is gradually released from the cuff. The blood pressure is read off a manometer attached to the cuff, and systolic pressure is read when flow returns as the pressure is released. Oscillometric devices use a cuff in the same locations, but blood pressure is measured by machine detection of oscillations in cuff pressure as the pressure is slowly released. One advantage of the oscillometric monitors is that they will obtain readings without constant operator involvement, and may be programmed to repeat measurements at regular intervals. The Doppler technique requires active operator participation in each reading, and reliably measures only systolic blood pressure. Either method requires careful standardization of technique from measurement to measurement – same location, cuff size, and technical approach.

Both of these external techniques are technically difficult in animals with small limbs (cats and small dogs), hypovolemia, or hypotension. The Doppler technique is generally more reliable in small animals and at low pressures. The oscillometric method is

often inaccurate under those circumstances. Neither technique will reliably measure pressure in all critically ill animals. Consequently, many patients must be monitored by direct (invasive) techniques, utilizing an indwelling arterial catheter. The dorsal metatarsal artery is most often used for direct pressure monitoring. The vessel is catheterized with a 20 - 22 gauge polyurethane over-the-needle type catheter. Several products made specifically for peripheral arterial catheterization are available. Electronic arterial pressure monitors provide direct measurement of diastolic, systolic, and mean blood pressure.

Metabolic monitoring: arterial/venous blood gas (pH, pO₂, pCO₂) and K⁺, Na⁺, Cl⁻, Mg⁺⁺, Ca⁺⁺, lactate, and beta-hydroxybutyrate

Blood gas analysis is used to evaluate ventilation (pCO₂), lung ability to oxygenate the blood (pO₂), and hydrogen ion concentration (pH). Electrolytes are measured to determine the cause of any abnormalities in pH (when serum albumin or total protein is also known) and to screen for abnormally high or low concentrations of any that have immediate metabolic consequences. There are several examples of hand-held or bench-top blood gas analyzers that also measure electrolyte concentrations and lactate. Our ICU uses the Gem Premier™ system, a device that performs these assays in 90 seconds using as little as 0.2 ml of blood. If the blood gas analyzer does not measure chloride concentration, this should be assayed on the same sample of blood as the blood gases, sodium, and potassium to allow more accurate assessment of acid-base status. Ionized calcium concentration is frequently depressed in the critically ill, particularly animals with sepsis. Beta-hydroxybutyrate contributes to metabolic acidosis in sick diabetics and is a marker for more severe illness. It is not detected by ketone strips, which only react to acetoacetic acid, but can now be measured with a commercially available hand-held device.

Central venous pressure

Central venous pressure (CVP) measurement is a useful diagnostic procedure for the management of fluid therapy in general, and is sometimes nearly essential for effective management of refractory shock. The CVP is the blood pressure within the intrathoracic portions of the cranial or caudal vena cava. The CVP is only slightly higher than the right atrial pressure (RAP) and the two terms, CVP and RAP, are often used interchangeably. The CVP (or RAP) affects, and is affected by, cardiac output. Central venous pressure is measured clinically for two reasons, 1) to gain information about cardiac function, and 2) to gain information about venous return relative to cardiac performance. The technique for measurement has been described.

Electronic measurement of CVP is a more convenient (and potentially more accurate) method of measurement made feasible by the widespread availability of ECG monitors with dual electronic pressure ports. Materials needed in addition to the monitor itself include a pressure transducer (disposable or multiple-use), a sterile fluid path connected to the transducer ("pressure dome"), and a sterile tubing set to connect the pressure dome to the catheter. This may be an IV tubing extension set or an arterial pressure tube.

Measurement of CVP in animals during fluid challenge yields important information about cardiovascular status. As intravenous fluids are administered and the intravascular blood volume expands, venous return and CVP will begin to rise. A rapid (<5 minute) infusion of 20 ml/kg of crystalloid or 5 ml/kg of colloid into a euvoletic animal with normal cardiac function produces a modest increase in CVP (2 - 5 cm H₂O or 2-4 mm Hg) that returns to baseline within 15 minutes. A minimal increase or no increase in a patient's CVP implies that the vascular volume is markedly reduced. If the CVP rises and returns to baseline rapidly (< 5 minutes), this implies that there is reduced vascular volume and that the initial volume load has been accommodated by rapid changes in vasomotor tone. A large increase in CVP (>4 cm H₂O or > 3 mm Hg) implies reduced cardiac compliance or increased venous blood volume or both. A slow (15 minutes) return towards baseline indicates that blood volume is close to normal. A very prolonged return to baseline (>30 minutes) suggests that the intravascular blood volume is elevated relative to cardiac performance.

Pulse oximetry

Pulse oximetry may be used to estimate hemoglobin saturation in critically ill animals. The technique yields no direct information about tissue perfusion, cardiac output, or oxygen delivery. These devices use light emitting diodes to transmit 2 wavelengths of light – one in the red and another in the infrared band - through tissue. To use the device, a pulsating arterial bed must be positioned between the LED and the detector. A photodetector is placed on the opposite side of the tissue bed to measure the intensity of light that makes it through the tissue. Oxygenated hemoglobin absorbs less red light and more infrared light than desaturated hemoglobin, and this principle forms the basis of calculation of % saturation. As arterial blood pulses through the tissue bed separating the LED from the photodetector, the path length increases slightly and the tissue absorbs more light. By analyzing the ratio of absorption of red to infrared light and detecting the cyclic variations associated with pulsatile blood flow, pulse oximeters can accurately calculate the percent saturated hemoglobin. There are many different pulse oximeter models marketed for use in humans and animals. The tongue, lip, ear, tail, or foot (in small dogs and cats) may be suitable locations for probe placement.

There are at least 15 different models of pulse oximeters suitable for use in dogs and cats. In our ICU the device is most useful for continuous monitoring of dogs and cats on mechanical ventilation or immobile dogs on oxygen therapy for hypoxemia. If the percent saturation drifts downward but patient clinical status appears unchanged, the first thing response should be to reposition the sensor to see if this corrects the low reading.

Coagulation monitoring: Thromboelastography, aPTT, PT, platelet counts

Coagulopathies are common in critically ill animals and warrant aggressive monitoring. A falling platelet count is often seen in animals developing sepsis, pancreatitis, or other causes of a systemic inflammatory response. Thromboelastography is used primarily

to identify animals that are in a hypercoagulable state and those with excessive fibrinolysis. The aPTT test is used to identify animals with consumption of clotting factors and to monitor patient response to heparin therapy.

Cytology/fluid analysis

We perform in-unit cytology on fluid samples from any source to monitor cytological evidence of inflammation. Common indications for this include examination of fluid sediment from fluid accumulating in active closed drains (grenade systems) that are used as sentinels following abdominal surgery, sputum or tracheal wash sample, and urine sediment to look for evidence of kidney injury or infection.

Continuous glucose monitoring

Animals that require blood glucose monitoring 12-24 time a day benefit from continuous monitoring with a subcutaneous monitor that provides real-time output to a receiver (usually mounted on the cage door) every 5 minutes. The devices use a small subcutaneous probe fixed to a skin patch that is inserted into an area of the torso that does not move excessively. After a 30 minute “wetting” period, the probe is connected to the transmitter which is a small battery-powered analyzer that is fixed to the patient with a harness or stocking wrap of the torso. There is a bit of a learning curve to learn the optimal technique for placement, but once the device is properly set up and calibrated it provides around-the-clock monitoring for animals at risk of hypoglycemia (e.g., sepsis) or frequent adjustment of dextrose or insulin and dextrose. The unit generally functions well for up to 3 days, with calibration checks performed once or twice a day.

References are available upon request