Monitoring Vital Signs in Clinical and Research Animals

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The measurement of vital signs in mammals provides invaluable information concerning the health status of an animal in both clinical and research settings. Monitoring vital signs during anesthesia and postoperative recovery can minimize patient risk and reduce error in collection and interpretation of research data. A new device called the VitalScan Monitor® by Vetronics, Inc. has become available which can monitor all of the signs either individually or simultaneously.

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."

Attributed to Lord Kelvin

The word "*vital*" is an adjective defined as essential to life. Because the maintenance of arterial blood pressure, body temperature, respiratory rate, and heart rate within a normal range is necessary for survival in mammals, these physiologic parameters are known as vital signs. Not surprisingly, measurement of the vital signs provides invaluable information concerning the health status of an animal in both clinical and research settings. Moreover, monitoring vital signs during anesthesia and postoperative recovery is an important means of minimizing patient risk and reducing error in collection and interpretation of research data.

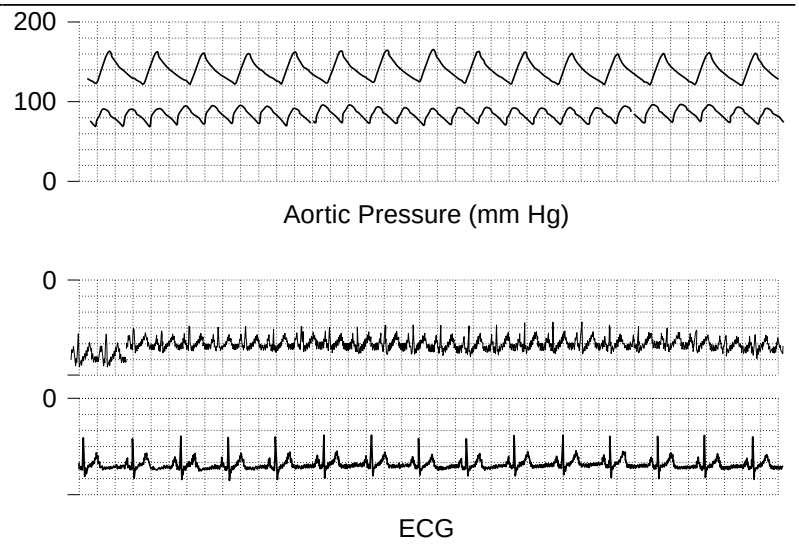
Blood Pressure Monitoring

Arterial blood pressure, which is also referred to as systemic arterial pressure or, simply, blood pressure, refers to the hydrostatic pressure exerted by the blood on the walls of the systemic arteries. Because it is a difference in pressure across the vascular system that drives the flow of blood, arterial blood pressure is an extremely important physiological parameter. Arterial blood pressure is generated during the repeated contractions of the left ventricular myocardium which force blood into the arterial system. Therefore, arterial blood pressure is pulsatile with its maximal value equivalent to systolic pressure and its minimal value the diastolic pressure. Mean arterial pressure is the time-weighted average of the instantaneous pressures during a single cardiac cycle. Mean arterial pressure represents the driving or perfusion pressure for most body tissues. Because of the dependence of blood flow on pressure, the body prioritizes the maintenance of arterial pressure within a normal or physiologic range in order to assure constant blood flow to the brain, heart, and kidneys. Animals are equipped with autonomic, humoral, and local mechanisms that operate to prevent a serious reduction of pressure, and these mechanisms frequently operate at the expense of optimal perfusion to various peripheral tissues and abdominal organs (1). The development of hypotension is usually ominous and often a terminal event. Monitoring of the arterial blood pressure is, therefore, important for early identification and successful therapeutic intervention.

Although reduced systemic blood pressure will impair tissue perfusion, the specific pressure at which blood flow to the vital organs is significantly decreased will vary depending on the rate of pressure reduction and the adequacy of compensatory mechanisms. In general, renal, cardiac, and cerebral perfusion are jeopardized when systolic pressure is less than 80 mmHg or when mean pressure is less than 60 mmHg (1).

Many anesthetic agents decrease blood pressure as a result of their effects on the heart or the peripheral vasculature. In addition, volume depletion, hypothermia, and arrhythmias frequently occur in anesthetized animals and tend to reduce arterial pressure. For these reasons it is prudent to continuously monitor blood pressure in heavily sedated or anesthetized animals as well as during the postoperative period. Blood pressure monitoring is especially critical when major surgery has been done or when complications have occurred.

Abnormally high blood pressure may also adversely affect patient survival and research results. Though less common than hypotension in the research setting, hypertension may result from administration of several anesthetic agents including ketamine, Telazol (a combination of tiletamine and zolazepam), xylazine, detomidine, and medetomidine (***F1***). Hyperten-



F1

Physiologic data obtained from a healthy research cat prior to (baseline) and following administration of the tranquilizing agent, medetomidine. Note the drug-induced increase in arterial blood pressure from the baseline value of 92/68 (systolic/diastolic) to 164/120 mmHg. Simultaneous recording of the electrocardiogram (ECG) demonstrates a reduction in heart rate from 187 to 107 beats/minute that is most likely a reflex mediated response to the increased blood pressure.

sion can produce life-threatening vital organ damage including cerebral hemorrhage and necrosis.

Several methods are available for monitoring arterial blood pressure. Blood pressure is determined by a complex interaction of physiologic variables including not only the contractile state of the left ventricle, the filling of the systemic vascular bed, and "run off" through peripheral resistance, but also reflections of the pressure and flow waves as well as resonance of the vasculature, external coupling equipment, and observation system (2). Therefore, any single method of measuring blood pressure is associated with a particular set of artifacts, and the measurements generated by different systems are not necessarily comparable. Furthermore, the relative utility or superiority of a given system may vary depending on purpose, convenience, clinical or research situation, and economic reality.

Direct blood pressure measurement involves placing an open-ended cannula into a peripheral artery and connecting the cannula via fluid-filled tubing to an external pressure transducer and amplifier. Direct blood pressure measurement is invasive and requires anesthesia in most animals. Measurements obtained by this method are affected by the anatomic site chosen; the cannula size, length and patency; the tubing stiffness, radius and length; the capacitance of the system (e.g. presence of air bubbles); and the frequency response of the transducer and amplifier (2).

Doppler techniques may be used to measure arterial pressure noninvasively. In animals, the Doppler technique is used to detect axial flow in a peripheral artery distal to an occlusive cuff (coupled to a manometer) as pressure in the cuff is gradually reduced. Although this would appear a simple, convenient, noninvasive, and relatively inexpensive method, the Doppler transducer is exquisitely position sensitive and is prone to dislodgment by surgical drapes and patient repositioning. When failure occurs, it is difficult to determine whether the blood pressure or the measurement system is at fault. Doppler systems only reliably provide systolic pressure data. These systems are not automated and become unusable in the presence of electrocautery.

Another noninvasive blood pressure monitoring device, the oscillotonometer, combines in a single mechanism a tonometer to indicate pressure relative to atmospheric and an oscillometer (sensitive plethysmograph) that detects the oscillating volume changes resulting from initiation of pulsatile blood flow in a peripheral artery as air is bled from an occlusive cuff. Oscillotonometric blood pressure measurement systems provide systolic, diastolic, and mean pressure data. Another advantage of this method is that readings can be obtained even when the pressure is low (2). Finally, oscillotonometric systems are automated and, hence, ideal for anesthetic and intraoperative monitoring in settings with limited personnel.

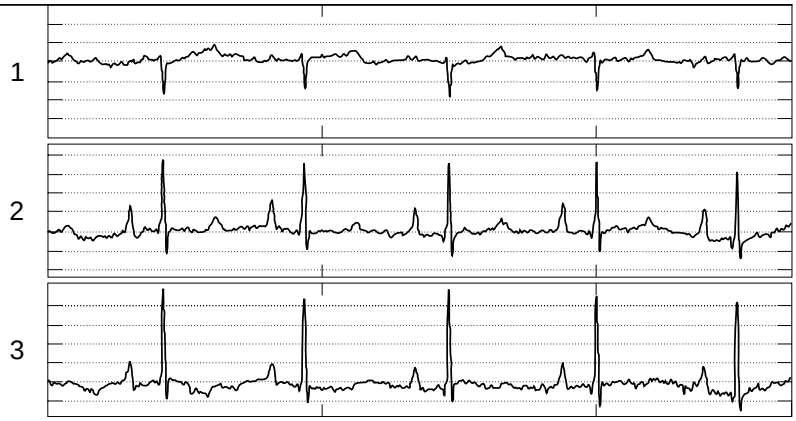
Heart Rate Monitoring

Adequate perfusion of tissues depends upon adequate cardiac output, and because cardiac output is the product of stroke volume and heart rate, an abnormally slow heart rate will significantly impair delivery of oxygen and nutrients. In conscious animals, a reduction in heart rate may arise from numerous disease processes including pathology of the cardiac pacemaking and/or conduction system, electrolyte imbalances, enhanced vagal tone, severe myocardial disease, and certain toxins. Various pharmacologic agents, such as the cardiac glycosides, beta-adrenergic antagonists, and calcium channel antagonists, can also produce life-threatening bradycardia. Sedatives and anesthetics often used in research animals may significantly diminish heart rate, either directly or as a reflex-induced response to altered blood pressure. Examples of such agents include the alpha$_2$-adrenergic agonists (xylazine, detomidine, and medetomidine), halothane, isoflurane, and narcotics (***F2***). Hypothermia is also a common cause of bradycardia in anesthetized animals.

Although heart rate and cardiac output are directly related over a physiologic range of heart rates, pathologically rapid heart rates result in attenuated ventricular filling and, therefore, reduced cardiac output. Tachycardias in both conscious and anesthetized animals frequently result from hypovolemia, pain, hypoxemia, acidosis, septicemia, fever, and toxemia. Drugs commonly used for sedation and anesthesia that may induce an excessively rapid heart rate include anticholin-

F2

Electrocardiogram recorded from a healthy cat sedated with detomidine, an alpha2-adrenergic agonist. The drug has produced an abnormally slow heart rate and first degree atrioventricular conduction block.



Vertical tick = 0.1 mv Horizontal tick = 1.0 second

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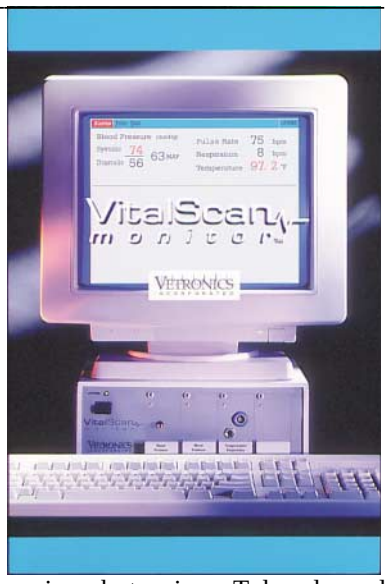
A computerized vital signs monitoring system for animal use available from Vetronics, Inc. (Lafayette, IN). The photo illustrates the system in use with a desk top computer, but it is also compatible with a notebook computer.



ergics, ketamine, Telazol, and propafol.

Early recognition and reversal of significant heart rate abnormalities are critical for the prevention of tissue ischemia that can threaten survival and adversely affect the quality of research data being collected. Therefore, heart rate monitoring is of paramount importance during the induction and maintenance of and recovery from anesthesia. Heart rate may be monitored manually by auscultation or palpation, or it may be measured and displayed continuously using several available automated systems. Additional information useful for appropriate therapeutic intervention is gained from monitoring the cardiac rhythm (by display of an electrocardiographic rhythm strip) in addition to monitoring the heart rate. Simultaneous monitoring of both the blood pressure and heart rate provides the clinician or researcher necessary information to predict the overall effect of a change in either of these vital parameters on delivery of blood to the tissues.

Monitoring of Body Temperature

In birds and mammals, maintenance of body temperature within a normal range is necessary to sustain the biochemical reactions that occur within the cells and, therefore, to sustain life. Hypothermia results when heat loss from the body exceeds heat production. Progressive hypothermia will produce progressive cerebral obtundation, a reduced anesthetic requirement, prolonged anesthetic recovery, bradycardia, impaired myocardial conductivity and automaticity, lactic acidosis, increased blood viscosity with microvascular stasis, apnea, and death (3). Hypothermia occurs commonly in anesthetized animals because of the absence of muscular activity, the vasodilating effects of many sedative and anesthetic agents, infusion of cold solutions, positioning of animals on noninsulated surfaces, cool environmental temperatures, wetting of the body surface with scrub solutions or urine, and the presence of open body cavities.

Mild to moderate intraoperative hypothermia is seldom detrimental to the patient unless the anesthetist fails to recognize its presence and continues to administer normothermic amounts of anesthesia, causing an anesthetic overdose. Since the development of hypothermia alters other important physiologic parameters such as metabolic rate, cardiac output, heart rate, blood pressure, hematocrit, and glomerular filtration, the development of hypothermia in an animal from which research data is being collected will have adverse effects on data collected and will obscure the interpretation of results. Therefore, monitoring of body temperature is important, not only for the well-being of the animal, but to prevent inaccuracy of research findings.

Hyperthermia is usually less problematic than hypothermia in research animals. However, intraoperative hyperthermia may occur with light anesthesia (high metabolic activity) and in large animals that are heavily draped and insulated (especially those breathing fully humidified gas). Malignant hyperthermia, triggered in susceptible animals by anesthetic agents or neuromuscular blocking agents, has been reported in dogs, cats, swine, and horses (3). Hyperthermia may have harmful effects which result primarily from an increased cellular oxygen consumption. Multiple organ dysfunction and failure may be the end result. In addition, failure to recognize a significant body temperature increase may obfuscate interpretation of research data.

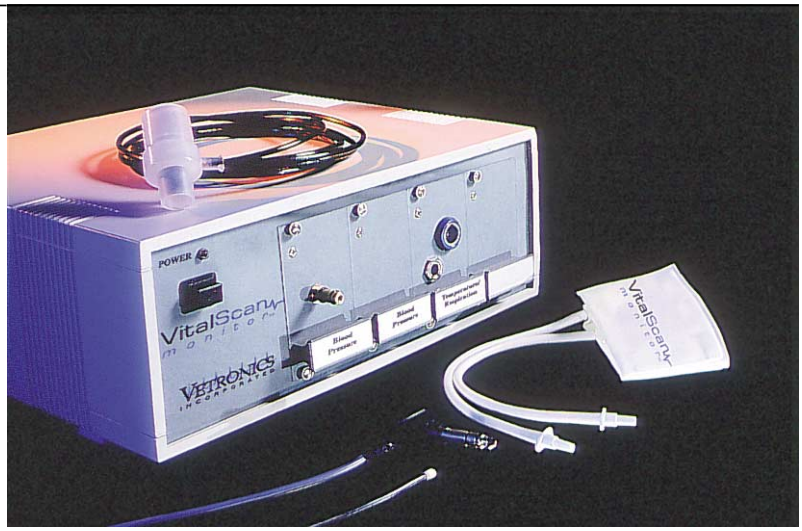
Automated monitoring of body temperature is usually accomplished by positioning a thermistor-tipped probe into the esophagus or rectum.

Monitoring of Respiratory Rate

Monitoring the rate of spontaneous respiration in a fully conscious animal is helpful for identifying the development of cardiac and respiratory diseases, metabolic disorders characterized by alteration of arterial pH, hemoglobin abnormalities, and neurologic disorders. In sedated or anesthetized ani-

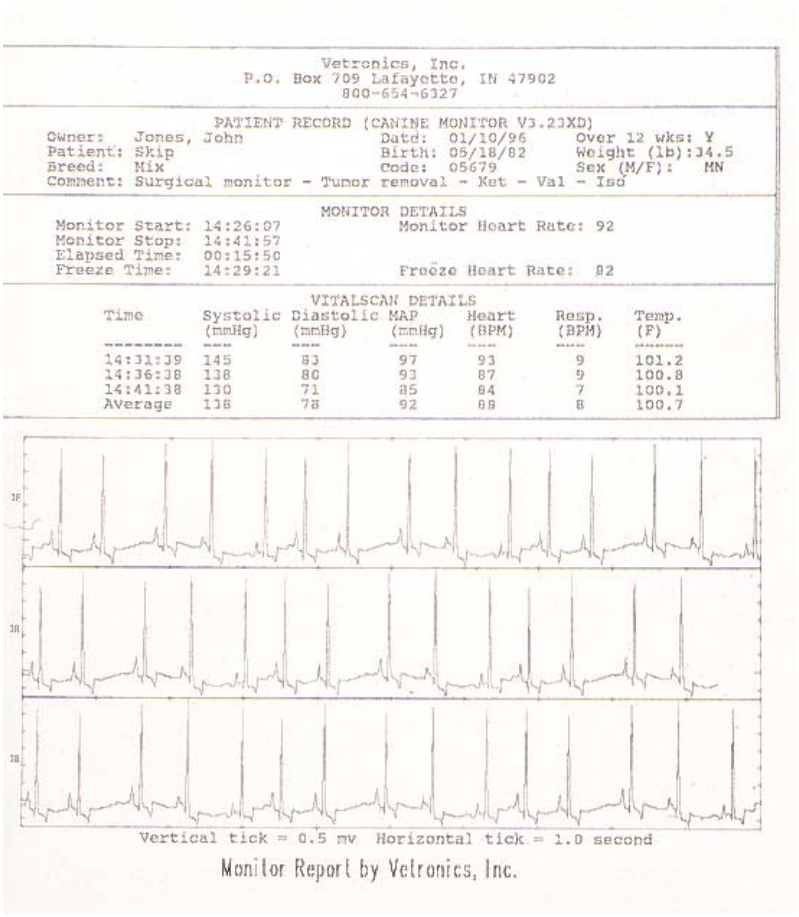
F4

Components of the VitalScan Monitor® for automated measurement and monitoring of vital signs in animals. The temperature probe appears in the foreground. This probe is inserted into the esophagus or rectum for monitoring body temperature. The air flow detector for monitoring of respiratory rate is shown on top of the analyzer. This sensor is placed at the end of the endotracheal tube. The inflatable cuff for measuring blood pressure is also shown. This cuff is placed around the forelimb, hindlimb, or tail for measurement of arterial blood pressure.



F5

Example of a vital signs monitoring report generated with a computerized system (VitalScan Monitor®, Vetronics, Inc., Lafayette, IN). Blood pressure, heart rate, respiratory rate, and body temperature data have been printed. An electrocardiographic recording for evaluation of the cardiac rhythm is also displayed.



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PATIENT RECORD (CANINE MONITOR V3.23XD)

Owner:	Jones, John	Date:	01/10/96	Over 12 wks:	Y
Patient:	Skip	Birth:	05/18/82	Weight (lb):	34.5
Breed:	Mix	Code:	05679	Sex (M/F):	MN
Comment:	Surgical monitor - Tumor removal - Ket - Val - Iso				

MONITOR DETAILS

Monitor Start:	14:26:07	Monitor Heart Rate:	92
Monitor Stop:	14:41:57		
Elapsed Time:	00:15:50		
Freeze Time:	14:29:21	Freeze Heart Rate:	92

VITALSCAN DETAILS

Time	Systolic (mmHg)	Diastolic (mmHg)	MAP (mmHg)	Heart (BPM)	Resp. (BPM)	Temp. (F)
14:31:39	145	83	97	93	9	101.2
14:36:38	138	80	93	87	9	100.8
14:41:38	130	71	85	84	7	100.1
Average	138	78	92	88	8	100.7

Vertical tick = 0.5 mv Horizontal tick = 1.0 second

Monitor Report by Vetronics, Inc.

mals, respiratory rate may be significantly altered because of direct effects of the pharmacologic agents used on the respiratory centers in the brain. In addition, anesthetics and neuromuscular blocking agents usually suppress the reflex alterations in respiratory rate that arise from metabolic and hematologic abnormalities. Continuous monitoring of the respiratory rate during anesthetic induction, maintenance, and recovery is an important means of assessing depth of anesthesia and adequacy of spontaneous or assisted ventilation.

Respiratory rate may be determined manually by counting chest wall excursions or breath sounds. Automated monitoring, commonly used in anesthetized or critically ill animals, is usually accomplished by means of placing a thermistor or air flow detector on the endotracheal tube. It may also be accomplished by means of impedence electrodes placed on the thoracic wall.

Monitoring Equipment

Various manufacturers market equipment for automated or manual measurement of vital signs. Most available systems monitor only heart rate and rhythm, blood pressure alone or in combination with heart rate, or body temperature. Recently, a computerized system for automated measurement and monitoring of all of the vital signs, either individually or simultaneously, has become available. This system, marketed by Vetronics, Inc. (Lafayette, IN) as the VitalScan Monitor®, is used with either a desk top or notebook computer (***F3*** and ***F4***). The VitalScan Monitor® has both audible and visual alarms with adjustable upper and lower limits for each physiological parameter. Monitor reports and trend reports can be displayed and printed (***F5***). This system uses an oscillotonometric method of blood pressure measurement, thus providing systolic, diastolic, and mean data. Components may be purchased individually or as a complete system.

References

1. *M.P. Littman and K.J. Drobatz in "Textbook of Veterinary Internal Medicine" 4th Edition (S.J. Ettinger and E.C. Feldman Eds.) W.B. Saunders Co, Philadelphia, 1995, 93 - 100.*
2. *J.M.R. Bruner in "Handbook of Blood Pressure Monitoring" PSG Publishing Company, Inc., Littleton, MA, 1978, pp. 63 - 99.*
3. *S.C. Haskins in "Textbook of Veterinary Internal Medicine" 4th Edition (S.J. Ettinger and E.C. Feldman Eds.) W.B. Saunders Co, Philadelphia, 1995, 26 - 30.*