Anesthesia and the neurosurgical patient:
Part I—Monitoring needs

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When administering anesthesia to the neurosurgical patient, utilization of monitoring techniques which provide the greatest margin of safety is one of the most critical factors to be considered in the total anesthesia care plan. The effects of anesthesia and surgery on the brain are usually deduced from arterial blood gas and blood pressure measurements.

It is essential, therefore, that the anesthetist recognize early any potential threats to central nervous system integrity in the anesthetized patient. Once alerted to potentially disastrous situations by careful attention to monitoring devices, changes in the anesthetic management or surgery can prevent permanent neurologic damage.

Some of the monitoring devices required for the neurosurgical patient are the same as those used during routine surgery. Many times, however, the variable and often physiologically threatening positions required for neurosurgical procedures (such as removal of vascular tumors and surgery near the vital centers of the brain) dictate special or more sophisticated monitoring needs. This article will explore monitoring devices for neurosurgery, including both invasive and noninvasive techniques.

Noninvasive techniques of monitoring

The routine noninvasive monitoring devices/methods include the indirect blood pressure measurement, precordial and esophageal stethoscopes, ECG and temperature probe.

Blood pressure monitoring. Blood pressure should be measured with a sphygmomanometer, Arterisonde, Dinamap, and more often in neurosurgical cases, an intra-arterial catheter. The arterial catheter method will be discussed later with other invasive methods of monitoring.

Auscultation is the most commonly used method of measuring blood pressure and consists of determining the onset (systolic pressure) and muffling (diastolic pressure) of Korotkoff sounds. The rate of decrease in pressure measured in the cuff is important. The American Heart Association recommends a pressure release of 2-3 torr per second. The stethoscope diaphragm should be under the distal portion of the cuff or slightly beyond for maximum efficiency in transducing the Korotkoff sounds because they originate from arterial oscillations distal to the occlusion point of the artery.

Even though the use of the Riva-Rocci air-filled occlusive cuff in conjunction with detecting the Korotkoff sounds to determine blood pressure...
dates back to before 1905, this 75-year-old method is still the most commonly used in anesthesia practice.

The other noninvasive methods for measuring blood pressure are the Arterisonde™ and the Dinamap™ which is a fully automatic oscillometric device.

_Arterisonde™:_ The Arterisonde™ is a semi-automatic ultrasonic device which detects the motion of the arterial wall during deflation of the cuff. The transducer portion of the Arterisonde™ must be applied over the brachial artery with a coupling gel to allow for the sending and receiving of the ultrasonic signal.

The accuracy of blood pressure determination with a cuff is dependent on the rate of deflation. The Arterisonde™ has mechanisms which allow for setting the rate of deflation. The instrument is designed so that the opening and closing of the artery under the cuff produces an electronically amplified, audible signal which the operator interprets much as he would the Korotkoff sounds when using a stethoscope.4

A disadvantage of the Arterisonde™ is that movement or bumping the cuff during the operative procedure causes the device to malfunction.

_Dinamap™:_ The Dinamap™ uses the small variations in cuff pressure with each heart beat as the signal to determine blood pressure. The signal is easy to obtain since it is present anytime the cuff is inflated on the arm and does not require any other sensor. Pressure oscillations, not sounds, are detected. The oscillometric method of determining the blood pressure allows for the determination of the mean arterial pressure as well as systolic and diastolic pressures.

The cuff application is straightforward with no accurate transducer position required. There is a marking on the inside of the cuff which indicates the proper cuff placement over the artery.

Since a sensor does not have to be placed over a specific artery, this method allows measurement of pressure at non-standard locations such as the ankle, thigh and wrist, etc.5

At the Presbyterian-University Hospital in Pittsburgh, we have found the Dinamap™ to be a very reliable method of monitoring the blood pressure in the neurosurgical patient regardless of the patient’s position or condition. Even though the determination of pressure takes longer than the other methods, it is probably the most accurate and reliable mode available since it includes the measurement of the mean pressure.

_Precordial/esophageal stethoscope monitoring._

In 1819, Laennec devised a rigid flanged tube for transthoracic listening. In 1901, Bowles manufactured a resonator with a diaphragm to enhance high-frequency sounds. It was not until the early 1960s, however, that this device became vitally important and came to be regarded as the most significant single monitoring device, probably because of its simplicity.2

The esophageal stethoscope came into common usage about 15 years ago and is very valuable during induction of anesthesia. The precordial or esophageal stethoscope provides us with beat-to-beat information so that respiratory inadequacy and dysrhythmias are very obvious to the ear. It also has the advantage of being close to the heart so that the sounds are intensified. Breath sounds are easily heard and cardiac irregularities can be easily detected.

In many neurosurgical cases the patient is fully draped and access to the facial area is limited. Even though all precautions are taken to secure endotracheal and breathing circuit tubes, the connections may be loosened by the weight of the surgical drape or necessary manipulation of the head. The esophageal stethoscope would convey the first signs of a decrease or loss of breath sounds from a partial or complete disconnection.

The esophageal stethoscope is also a method of identifying a venous air embolism. You would hear what is characteristically referred to as the “mill wheel murmur.” This is a late sign of air embolism. Air embolism detection will be discussed in more detail with the use of the Doppler monitoring device.

_ECG Monitoring._ The main value of the ECG as a continuously monitored variable during anesthesia is the availability of information on any deviation of heart rate and a baseline for the timing of mechanical cardiac events.6

Through numerous studies of lead configurations, Blackburn and colleagues found that bipolar leads with one exploring electrode overlying the left ventricle were superior to other leads in the detection of ST-segment and T-wave changes.7 The bipolar lead designated CM5 was the one found to be best in detecting ST-segment changes in a higher portion of patients.6 If a five lead ECG monitor is not available for use, a modified V5 is the best alternative for routine monitoring in anesthesia.

The ECG is useful for several reasons in the neurosurgical patient. Patients with central nervous system lesions or brain tumors exhibit various ECG abnormalities.1 It is possible that these are due to centrally mediated increases in sympathetic
tone, possibly due to the increased intracranial pressure (ICP).\textsuperscript{8} It has also been shown that in some cases of subarachnoid hemorrhage, patients have cardiac abnormalities.\textsuperscript{9} The patient undergoing a carotid endarterectomy is very susceptible to cerebral ischemia from possible cardiac arrhythmias, surgical intervention, and any reduction or rise in the blood pressure. This type of case is never attempted without an adequate ECG monitor.

In posterior fossa procedures, one often sees arrhythmias due to the surgical stimulation of the vital centers and/or cranial nerves. If a patient is in the sitting position, any alteration in rate or rhythm should alert the anesthetist to the possibility of air entrainment. In any of these instances it would be extremely difficult to diagnose or treat arrhythmias without an ECG monitor.

\textbf{Temperature monitoring.} Routine monitoring of the patient's temperature during surgery is now a common practice. This is primarily due to the cool, air conditioned operating rooms which may result in accidental hypothermia. Induced hypothermia is not commonly practiced anymore in neurosurgery. A decrease in body temperature during a craniotomy is common, however. Steps should be taken to prevent this from occurring.

A heated humidifier is standard equipment for all intracranial or long neurosurgical procedures at our institution. In cases where induced hypotension is used, a slightly lowered temperature at this time may be beneficial because of the decreased metabolism rate and therefore a reduction in oxygen consumption. It is essential, though, following this period of induced hypotension, that the temperature be brought back to a normal level to prevent untoward side effects.

The undesired side effects of accidental hypothermia include an increase in peripheral vascular resistance and increased myocardial work. Non-depolarizing muscle relaxants may be potentiated and postoperative shivering increases oxygen consumption.\textsuperscript{1} The patient's temperature should also be continuously monitored in the recovery room.

Though we most commonly see falls in temperature, the reverse situation may also occur with the temperature increasing. This may be due to the warm operating room lights or heavy surgical draping. If the surgical procedure is a craniotomy, we may also see a rise in temperature because of a disturbance to the temperature regulating mechanism in the anterior part of the hypothalamus. Surgery in this region may impair the ability to dissipate heat and result in a form of hyperthermia which is known as "neurogenic fever."

\textbf{EEG.} The electroencephalogram (EEG) is used to monitor neurosurgical as well as other patients. It can alert us to changes in anesthetic depth, ischemia, hypoxia or otherwise compromised central nervous system function. The ability of the EEG to provide us with a rapid method of determining inadequate perfusion of the brain has been well documented. With the technology currently available, automated EEG monitoring can alert us to irreparable damage before it occurs. Even though the EEG is a noninvasive device, it has not been generally applied in the operating room because of problems in acquiring and analyzing signals. Equipment is expensive, bulky and delicate. The data also needs expert interpretation and this can be a job in itself.

Scalp electrodes are used to record the EEG. The placement of the electrodes can be difficult at times, especially if the head is the area to be operated upon.

The cases for which we most commonly use EEG monitoring are carotid endarterectomies and superficial temporal artery to middle cerebral artery anastomosis.

\textbf{Doppler monitoring.} The most sensitive method for the detection of intracardiac gas is based upon the Doppler principle,\textsuperscript{10} which holds that a change in the frequency of waves (light, sound or radio) occurs when the source and the observer are in relative motion to each other. The frequency increases when they approach each other and decreases as they move apart.

It was not until the Doppler ultrasonic transducer was introduced into clinical practice by Maroon in 1968\textsuperscript{11} that small quantities, approximately 0.25 ml, of intracardiac air could be detected. The Doppler is mainly used in neurosurgery because air embolism is a common phenomenon in patients who are operated upon while in the sitting position. It is the only method at the present time which permits diagnosis before pathophysiologic changes occur in the heart rate, arterial or venous blood pressure, ECG or expired gases.\textsuperscript{12} The Doppler unit can be considered a prophylactic monitor because therapeutic measures are initiated immediately upon hearing air to prevent fulminating air embolism and cardiorespiratory collapse.

The precordial transducer generates a continuous 2.4 mHz Doppler ultrasonic signal which is reflected from moving red blood cells and cardiac structures. The signal is electronically converted to an audible sound. When air, an excellent acoustical reflector, passes through the ultrasonic field a high-pitched scratchy, roaring or "washing ma-
chine” type of noise is heard. This sound is characteristic of an air embolus. Its intensity is dependent upon its size and the time it remains in the ultrasonic field.

Proper placement of the transducer is critical if we want to prevent air from entering the pulmonary circulation. After initially placing a small amount of acoustical gel on the transducer, it is positioned just to the right of the sternum and a few inches above the xiphoid process. In most normal patients the right heart underlies the sternum between the 3rd and 6th interspaces. To check for proper positioning, a bolus of crystalloid solution injected rapidly into the right atrial catheter will produce a similar signal to that caused by air.

Capnograph. The capnograph is a monitoring device used for the neurosurgical patient undergoing surgery in an upright position. It provides continuous monitoring of end-tidal carbon dioxide (CO₂) and can warn of air embolism. As the volume of air entrained per unit time increases, the air traverses the heart and enters the pulmonary arterial system, where it ultimately lodges in the pulmonary microcirculation. This leads to a progressive reduction in lung perfusion relative to ventilation and the development of an increased physiologic dead space. The larger dead space has the effect of diluting the expired CO₂, thus decreasing the end-expiratory CO₂.

The capnograph connector should be placed directly onto the endotracheal tube to provide the most direct measurement of end-tidal CO₂. Placement in any other portion of the breathing circuit causes dilution of the expired gases and a less accurate reading.

The peripheral nerve stimulator. This method of monitoring neuromuscular relaxation is minimally invasive and is an important adjunct to the total monitoring of the neurosurgical patient. A patient known to have increases in intracranial pressure (ICP) requires a smooth induction of anesthesia. If intubation is attempted before the patient is completely relaxed, bucking, coughing or straining will produce a further increase in the ICP and this may be disastrous. A patient who is having a cerebral aneurysm clipped may rupture the aneurysm if induction or intubation is stormy and extreme elevation in blood pressure occurs. Another disastrous occurrence because of insufficient monitoring of neuromuscular relaxation would be any type of movement while the surgeon is working in the vital areas of the brain under the microscope.

Placement of the peripheral cutaneous nerve stimulator needles should be on the closest available arm over the ulnar nerve. The skin should be cleaned with an antiseptic solution before the insertion of the needles. After the administration of a sleep dose of a barbiturate, the stimulator should be checked for proper placement and function. Only then should the muscle relaxant be given for intubation. When all response to the peripheral nerve stimulator is gone, intubation may be performed safely.

Invasive monitoring techniques

Urinary catheter. In the neurosurgical patient undergoing induced hypotension or when extensive blood loss is a possibility, the urinary output is a good indicator of renal perfusion. A satisfactory urinary output of 50 ml/hr is adequate for most adults.

Patients undergoing craniotomies usually require some form of diuretic or osmotic agent or possibly both, depending on the presence of increased ICP. To avoid bladder distention, a Foley catheter is a must for all of these patients.

Arterial catheterization. Percutaneous arterial cannulation is the most frequently performed invasive monitoring procedure used in the neurosurgical patient. It provides beat-to-beat information of the blood pressure to facilitate rapid therapeutic intervention. It also allows frequent sampling for blood gas measurement.

Placement of the pressure transducer is very important in all neurosurgical patients, especially those who are in a sitting position. The transducer should be zeroed at the highest point on the skull and the distance from heart to head should be measured. For every inch of vertical height to the operating site above the heart level, there is a reduction in blood pressure of 2.0 mmHg. Accurate estimation of the cerebral perfusion pressure (CPP) in the sitting position cannot be taken lightly since a difference as little as 5-10 mmHg in the CPP below the cerebral blood flow autoregulatory threshold may cause brain ischemia.

An Allen's test should always be performed to determine if the ulnar flow is sufficient to provide blood supply to the hand if the radial artery becomes occluded. To perform an Allen’s test, both the radial and ulnar arteries should be occluded. The patient is then instructed to close his hand, making a fist and opening it several times. The hand will then appear blanched or white. With the hand in an open position the pressure on the ulnar artery should be released. If the ulnar collateral circulation is adequate, color will return to the
hand within a few seconds. If circulation is not restored in 10-15 seconds, that particular radial artery should not be cannulated.\textsuperscript{14} In preparation for radial artery cannulation, the hand should be supinated and the wrist dorsiflexed 50-60° over a rolled towel or bandage. The hand should be fixed to an arm board and the thumb taped to the side of the board to help stabilize the radial artery at the wrist. Over-extension of the wrist may obliterate the radial or ulnar pulse by stretching the vessels over bony structures.

After the skin is prepared with an antiseptic solution, the local anesthetic agent is infiltrated subcutaneously. An 18-gauge needle should be used to break the skin to facilitate entrance of the catheter and to minimize shearing of the catheter tip. While palpat ing the direction of the radial artery, the anesthetist then inserts the catheter at a 20° angle to the surface of the skin. Spurting of bright red blood indicates entry into the vessel. The needle should be held fixed and the cannula advanced into the lumen of the artery.\textsuperscript{14} After application of antibacterial ointment and the dressing, a blood sample should be drawn for measurement of blood gases on room air. Administration of a heparinized saline solution for flushing is extremely important to help minimize thrombosis and in keeping a good wave form.

The dorsalis pedis artery is a good alternative to the radial artery for monitoring. It is usually easy to cannulate and is readily accessible in most craniotomy patients.

Arterial blood pressure measurement is essential for posterior fossa surgery in view of the hemodynamic sequelae of positional changes and manipulation of the cranial nerves and brain stem. Blood pressure should also be continuously measured in those patients with severe cardiovascular disease and spinal cord tumors or injuries. A hypotensive episode can then be quickly recognized and corrected.

\textit{Central venous pressure.} Routine measurement of central venous pressure (CVP) has been advocated as a means of assessing cardiac filling pressure and thus, of assessing effective blood volume.

The central venous catheter is used for several reasons in the neurosurgical patient, depending on the procedure being performed. In those patients who require surgical correction of extracranial cerebral vascular disease, a CVP catheter is useful in determining the need for volume augmentation. These patients are usually on antihypertensive medications and frequently have intravascular volume depletion. The central intravenous route can also be used for administration of vasopressors and cardiotonic drugs.\textsuperscript{18} The patient having a cerebral aneurysm clipped should have a normal CVP measurement to minimize the possibility of arterial spasm following the clipping. With a fuller vascular tree, the incidence of spasm is thought to be less. Another use of the CVP is for the confirmation of an air embolus and the evacuation of air from the heart.

The insertion of the CVP catheter is usually through the median basilic, external or internal jugular vein. Although other sites for insertion are available, these are probably the most accepted for the neurosurgical patient. If at all possible, the arm should be used since it has the least complications and the technique there is very safe.

After the skin has been antiseptically prepared and a local anesthetic agent has been injected subcutaneously, the patient should be instructed to abduct the arm so that the ear touches the ipsilateral shoulder. This maneuver often prevents the catheter from entering the jugular vein.

Even though at times delays and difficulties are encountered with central venous line insertion, x-ray confirmation of placement is mandatory in all patients catheterized in the sitting position. It is not advisable to have the catheter inserted the night before surgery because of the possibility of fluid overload, arrhythmia, thromboembolism, infection, or occlusion of the catheter.\textsuperscript{18} X-ray confirmation of all CVP lines is not necessary. The patient undergoing a neurosurgical procedure who has a CVP line inserted for volume measurement need only to be instructed to take a deep breath, at which time the anesthetist can watch for the water column fluctuation.

A more accurate method of the CVP line placement without x-ray confirmation is the use of intravascular electrocardiography. The P wave configuration on the ECG with the saline-filled catheter functioning as a unipolar ECG lead displays large, upward deflecting waves as the tip approaches the right atrium. This deflection reverses upon entry into the ventricle and a high voltage QRS complex is observed.\textsuperscript{18} The biphasic P configuration indicates that the catheter is in the ideal position.

\textbf{Conclusion}

We must remember that clinical information provided by the unanesthetized patient is not available when the patient is under anesthesia. Therefore, we must rely on neurologic monitoring techniques to provide us with the needed information.
We must be able to interpret and assess this information in order to quickly recognize and correct threatening situations before they occur, thus providing the safest possible care for the neurosurgical patient.

REFERENCES


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