New Concepts in Perioperative Normothermia:

From Monitoring to Management

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All general anesthetics impair thermoregulation and hamper the ability of generating or retaining heat. In addition, the cold environment of the operating room (OR), causes body heat to flow from the core to the periphery, further placing patients at risk for hypothermia. Spinal or epidural anesthesia produces sympathetic blockade and also may lead to a hypothermic state. Hypothermia in turn causes a decrease in metabolic rate, leading to further reduction in heat production.

Morbidity as a result of hypothermia includes cardiac events, coagulopathy, infection, delayed wound healing, delayed postanesthetic recovery, and prolonged hospitalization.[1] Moreover, cerebral metabolism decreases linearly by about 8% for each decrease of 1°C in temperature, from 35°C to 25°C.[2] These risks have prompted recommendations from several authorities and bodies, including the Surgical Care Improvement Project (SCIP) and the Centers for Medicare & Medicaid Services (CMS), for temperature monitoring and the implementation of warming strategies to maintain intra- and postoperative temperature of at least 36°C.

However, a lack of consistency among temperature measurement techniques in the pre-, intra-, and postoperative phases hinders the ability to adequately determine the presence of or the degree of hypothermia (or hyperthermia) perioperatively. Ideally, the same temperature measurement method should be used in all 3 phases.

In order to achieve perioperative normothermia, it is necessary first to address challenges that have long frustrated investigators and clinicians. As those obstacles are addressed, and clinicians properly monitor temperature at the main site of anesthetic action, achieve consistency of temperature measurement, understand thermal effects from a macro to molecular dimension, and properly use prewarming and warming, they maximize their ability to prevent complications while optimizing patient outcomes.

Defining Normothermia

The first point to consider in addressing perioperative normothermia and achieving optimal perioperative temperature management is the definition of normothermia. Surprisingly, the establishment of 37°C (98.6°F) as the normal temperature of the human body was based on a single work conducted by Carl Wunderlich in Germany more than 140 years ago.[3] Uncertainty still exists as to what constitutes normal body temperature—ambiguity highlighted by several studies, some recent, that have called into question Wunderlich's 37°C standard.[4-7] A report by Mackowiak et al in the *Journal of the American Medical Association* (*JAMA*) found that a lower level of temperature, between 98.06°F and 98.24°F (36.7°C and 36.8°C), is the true normal average core body temperature for adults.[4] In this large population study, 37°C had no special significance and was not "the overall mean temperature, the mean temperature of any of the time period studied, the median temperature, or the single most frequently recorded temperature," according to the authors. Nor did it fall within the 99.9% confidence limits (98.06°F to 98.24°F [36.7°C to 36.8°C]). This lower level for normothermia is more in line with Fahrenheit's studies indicating normal body core temperature to be around 98°F (36.6°C), which also is consistent with previous investigations.[6-7] Recent research also supports lower normal temperatures in adults, as well as higher temperatures in animals (bovine models suggest 38.3°C).[5,8]

The critical factor preventing clinical use of average body temperature is individual variability, which as noted in the *JAMA* report, "limits the application of mean values derived from population studies to individual subjects."[4]

Compounding the problem of the definition of normothermia is another major issue: the technical deficiencies in methodologies for measuring body temperature. These deficiencies are long-standing, and methods for measuring core temperature today are similar to those used since the middle of the 18th century.[9] Now as then, no gold standard exists for measuring body temperature.

Such limitations prevent straightforward answers to simple questions, such as whether a given patient is hypothermic or febrile. Measurement at one body site may indicate normothermia, whereas simultaneous measurement at another site suggests hypothermia. Moreover, identifying fever, which is of clinical importance during the preanesthetic assessment, also is challenging. Different thermometry methodology—oral versus forehead—may produce different temperature readings. Low-grade fever of approximately 100.4°F, may lead to canceling surgery. Such fever events therefore should be carefully evaluated to assure that there is no overestimation[5] (due to compensation factors) by the thermometer used nor ingestion of warm fluid or food prior to the preoperative evaluation.

How to properly care for patients and achieve good outcomes without a solid standard is a challenge faced not only by anesthesiologists but by any clinician or investigator trying to measure body temperature. However, in anesthesiology the proper assessment of body temperature may be critical as the drugs, actions, and environment in perioperative settings can undermine the ability of the brain to regulate body temperature and prevent behavioral corrective action. In this scenario, hypothermia may result, leading to costly and potentially fatal complications including myocardial infarction, arrhythmias, bleeding, infections, and increased cost of care.[1]

The risk for malignant hyperthermia (MH) further supports the need for accurate and continuous temperature measurement. Indeed, routine monitoring of body temperature during anesthesia was implemented after the description of MH in the 1960s, when it became clear that mortality from the condition was greatly reduced by early detection of thermal changes.[10] A recent report showed that the likelihood of any complication in MH increased 2.9 times per 2°C increase in maximum temperature.[11] Accurate temperature monitoring during general anesthetics and early dantrolene administration decreased the 35% MH morbidity rate.[11] Moreover, trauma and stroke patients and the associated increased risk for cerebral hyperthermia also calls for careful brain temperature monitoring.

How To Measure Temperature

Global authorities in anesthesiology and medicine have cited inadequacies with virtually all thermometry.[12-23] Results of various studies do not support the use of temporal artery/forehead thermometers and ear canal infrared thermometry for perioperative temperature measurement.[12-14] Other common complaints include the lack of precision of oral and tympanic thermometers, which can delay treatment or prompt unnecessary interventions; rectal thermometry leading to perforations, spread of enteric infection, and arrhythmia; and many other problems.[15-21]

In 2003, the British government issued a Medical Alert warning against ear thermometers,[22] and indicated that artificially low readings by ear thermometers were delaying medical care and causing complications; despite this, in 2006 investigators in England showed that the problem remains and patients were continuing to suffer as a result.[23]

Temperature monitoring traditionally has relied on sites not biologically configured for temperature measurement. Accessed skin sites (such as the axilla or forehead) are structured for thermal insulation, not the transmission of heat. Skin is comprised of fat and insulating layers of variable thickness that do not conduct heat well. The body is covered by a thermal insulatory wall that includes a thick fat layer and prevents skin measurement of temperature.[24] Correction factors are not feasible due to variations in insulatory layers among individuals, sites on same individuals, and over time on the same location.[24]

In fact, fat has the same thermoconductivity as oak. Therefore, measuring temperature from any surface skin area can be compared with taking measurements on the outside surface of an oak cask to determine the temperature of its contents. Moreover, the thickness varies not only at any given point across the surface of an individual cask but also between each separate cask.

Whereas the skin is designed for thermal insulation, internal sites such as the mouth, ear, esophagus, nasopharynx, rectum, and bladder are structured for ingestion, air exchange, excretion, and auditory sensation. Their contents—food, feces, liquid, air—may hamper accurate thermometry readings. In addition, invading the body comes at a great cost, including risk for injury and malpositioning because the location of the probe cannot be viewed during measurement. This presents another problem that may affect measurement: hidden inflammation. Cystitis, esophagitis, gastric reflux, otitis, and any inflammatory condition can lead to errors and falsely elevated temperature. Even if esophageal lesions are identified, they tend to be located at the optimal position for the thermal sensor in the distal esophagus, further hampering the ability to use the technique. Measurement in nonthermally configured sites (eg, tympanic membrane) also may conflict with natural body protection; cerumen, which has antifungal and antibacterial function, may impede access and must be removed for proper measurement of temperature in the ear.[25]

Main Site of Anesthetic Action

The main site of anesthetic action is the brain. Cerebral homeostasis demands an internal thermal milieu that must be maintained within strict parameters for optimal kinetics of biochemical reactions and synaptic transmission. The brain regulates a narrow thermodynamic range of normality and is the organ most sensitive to temperature change. Therefore, from the perspective of an anesthesiologist in the OR, the brain is the site most clinically relevant for normothermia.

Unlike the rectum, bladder, or esophagus, if the brain is hot or cold, thermal injury and disruption of neuronal function are likely. Thus, measurement in peripheral sites may hinder proper management of the main organ at risk.[12-23,26,27]

During periods of normothermia, brain and core temperature tend to agree.[8,28-31] However, during anesthesia and when thermal levels begin to shift toward extremes, brain and core temperature often decouple.[8,28-33] Hence, at the time clinicians most need to identify the brain thermal status, core may be unable to provide this critical information.

The brain contains a thermally undisturbed path, the brain temperature tunnel (BTT), that permits direct and continuous noninvasive measurement of the brain's internal temperature.[28-30] The BTT is thermodynamically structured to transmit an undisturbed thermal signal that serves as a natural temperature indicator. The skin surface over the BTT is uniquely thin and fat-free, and due to this lack of insulation produces the highest surface temperature on the body surface, and by overlying a thermal tunnel to the brain allows assessing brain temperature.

Temperature at the BTT and esophagus have been found to be similar at onset of monitoring after induction of general anesthesia, averaging 36.37°C and 36.58°C, respectively.[29] However, at the time of direct intraparenchymal probe placement, brain temperature averaged 36.44°C. The adherence of BTT to brain was indicated by the simultaneous BTT reading of 36.45°C. In contrast, esophageal temperature was 36.90°C. The 0.50°C difference between intra-brain and esophageal and the 0.49°C difference between BTT and esophageal are virtually identical to the reported difference of 0.50°C between invasive brain temperatures and core during craniotomy.[31]

Studies using infrared emission have demonstrated that measurements at the BTT are more accurate than those of the forehead or other sites, likely a result of optimal thermal transmission and emission of the site (Figure 1).[34] Recent research found a 1.7°C mean difference between the BTT and the highest forehead temperature, which was consistent with a report by Sessler and colleagues that found a 1.3°C underestimation of core temperature by forehead scanning.[20]

Direct monitoring of brain temperature has not been feasible; intracranial catheters rarely are used and are particularly hazardous in the context of the systemic anticoagulation required for procedures such as coronary artery bypass. The BTT provides a location for noninvasive method of continosly monitoring brain temperature using an adhesive sensor positioned between the eye and the eyebrow and adjacent to the bridge of the nose (BTT, Brain Tunnelgenix Technologies Corp.).

Monitoring nasopharyngeal temperature is possible. However, it may increase the risk for bleeding in the presence of anticoagulation and is prone to displacement and distortion by movement of air and anesthetic gas.[35] Moreover, it underestimates jugular temperature,[36-37] leading to the conclusion that reliance on nasopharyngeal temperature may expose the brain to periods of hyperthermia.[37] Core temperature tends not to reflect brain hyperthermia,[28] and studies have shown that the brain may be subject to overheating during cardiopulmonary bypass (CPB), leading to postoperative cognitive dysfunction.[38] Evidence suggests that reliance on the bladder as a site of measurement during CPB can lead to excessive brain rewarming and potential brain injury.[28] Moreover, core temperature monitoring was unable to detect brain cooling, including during deliberate hypothermia.[29-32]

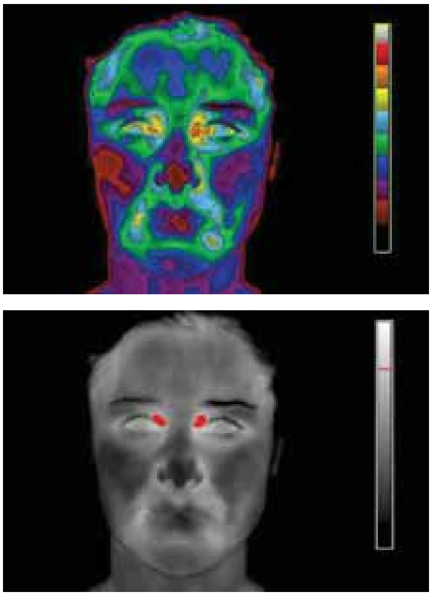

Figure 1. Thermal mapping of the face shows highest emission (red) at the fat-free skin site of the brain temperature tunnel.

Table 1. Practical Steps To Preserve Perioperative Normothermia

1. Identify normothermia level for each patient.
2. Determine presence or absence of hypothermia and risk for hypothermia. If the patient has clinical and thermal evidence of hypothermia, the clinician may consider:
• Prewarming
• Intraoperative warming with conventional methods and/or warm fluids
• Possible warming and humidification of inspired gases
• Increasing OR ambient temperature (up to 20°C), until patient is draped
3. Monitor temperature continuously and use the same methodology during all phases (pre, intra-, and postoperative) to allow appropriate comparison.
4. Use active intraoperative warming, and monitor internal body temperature (core or brain) to maintain normothermia while avoiding overheating.
5. Aim to maintain core or brain temperature 36°C postoperatively, and ideally, avoid, throughout the perioperative period, a body temperature change >1°C from the normothermia level.

Achieving and Maintaining Normothermia

Establishment of the normothermia level for each patient may be a key factor in improving outcomes and avoiding complications as well as optimizing prewarming and warming procedures (Table 1).

Normothermia from the vantage of thermal physiology can be characterized as the range of temperature that constitutes the optimal thermal zone for brain function. In practical terms, the range of normalcy is narrow. In addition, the central nervous system is constantly fine-tuning to maintain cerebral thermal homeostasis. However, as the body deviates from its optimal thermal status, mechanisms for heat loss or heat gain are activated, reflecting the brain trying to correct a status of hyperthermia or hypothermia, respectively.

Determining Normothermia

A major challenge is to determine the level of temperature considered normal because there is a large variation of normal core temperature (eg, 34.4°C to 37.8°C for rectal).[39] Thus, a rectal reading of 35°C may indicate normothermia for a patient with low metabolic rate. Ideally, the objective should consist of identifying the temperature that clinically corresponds to normothermia for an individual patient.

Normothermia constitutes the optimal thermal status for brain function, which may be reflected by the brain being quiescent in relation to activation of effectors to an increase or decrease in body temperature. In practical terms, as the body moves significantly away from this optimal status, mechanisms for heat loss or heat gain are activated. These are characterized by vasodilation/sweating and vasoconstriction/shivering and other systemic responses.

A clinical way to gauge if a patient is within normothermia levels is to observe the presence of autonomic responses that occur as a result of the brain activating effectors to prevent cerebral hypothermia or hyperthermia. Vascular changes, such as those that produce vasoconstriction or dilation are more difficult to ascertain, as many factors can contribute to such changes. However, some physiologic responses are more specific to thermoregulation, such as sweating and shivering, which can be more easily observed.

Sweating or shivering may indicate that the patient is experiencing hyperthermia or hypothermia even if the temperature reading appears to be normal. It is important to ask the patient if he or she feels cold, hot, or neither, and note the response in the chart. Similarly, a note also should be made about any evident autonomic response at the time of temperature measurement, including sweating, shivering, and cold hands or feet. Optimally, to identify normothermia one should rely on a numerical readout of core or brain temperature (but not skin) and the presence or absence of autonomic responses.

To read true temperature with a spot-check thermometer, a 3-minute reading thermometer without predictive or correction factors should be used to set a baseline core temperature preoperatively.[40] For oral measurement to be valid, the patient should not have ingested food or liquids for about 40 minutes prior to reading.[40] Attention also should be paid to respiratory rate; oral measurements are reduced by a striking 1°C with a rate of at least 20 respirations per minute,[16] while bradypnea can cause falsely elevated temperature.

Because current SCIP rules evaluate primarily the temperature level at 30 minutes before the end of anesthesia or the first 15 minutes postanesthesia, patients may be exposed to harmful hypothermia intraoperatively. Continuous temperature monitoring allows evaluating the whole perioperative temperature scenario. Moreover, anticoagulated and hypothermic patients are at increased risk for bleeding, thus hampering the safe use of tympanic and nasopharyngeal temperature probes. In addition, lack of consistent measuring sites and techniques throughout the 3 perioperative phases void the ability to compare temperature levels perioperatively and ultimately preclude detecting changes of temperature from baseline.

Intraoperative and early postoperative are critical periods for developing infection, and cardiac events tend to occur at the early postoperative phase. Hence, continuous monitoring of temperature and maintaining normothermia during these periods may reduce infection rate while preventing cardiovascular injury. Continuous temperature monitoring intraoperatively also can be used to gauge the need to adjust drug doses to avoid unexpected overdosing because hypothermia reduces drug metabolism and prolong their action.

The determination of hypothermia or hyperthermia, should be based on deviation from the individual baseline normothermia. In order to achieve and/or maintain normothermia and avoid hypothermia, a variety of perioperative warming techniques have been designed.

Table 2. Devices for Warming and Prewarming

Bair Hugger (3M)
Geratherm (Geratherm)
HotDog (Augustine Temperature Management)
Inditherm (Inditherm)
Medi-therm (Gaymar)
PerfecTemp (Medline)
Snuggle Warm (Smiths Medical)
ThermaCare (Gaymar)
WarmAir (Cincinnati Sub-Zero)
WarmTouch (Covidien)

Prewarming

Many patients are hypothermic from the induction of anesthesia to the end of surgery, despite the use of intraoperative warming. Patients begin cooling preoperatively (the average preinduction temperature loss is 0.61°C).[41-50] Anesthesia itself causes clinical hypothermia by inducing peripheral vasodilatation and a free flow of warm blood from the core to the cooler legs. This results in a rapid drop in core temperature, or redistribution hypothermia. An analysis of various studies found a post-induction redistribution temperature loss of 1.11°C.[46-54] Active warming typically begins immediately following the preparation and draping, but it may not prevent the initial combined 1.72°C drop in temperature.

Without active warming, patients continue to lose heat to the OR environment and continue to slowly drop their temperatures after the initial redistribution drop. The use of forced-air warming (FAW) reverses the temperature loss during surgery. An analysis of 10 studies found that intraoperative FAW rewarms the patient 0.1°C per hour.[44-50,54-56] Although much better than continued cooling, this warming rate means that patients may be hypothermic during their surgery. Intraoperative warming alone, therefore, may not reliably prevent intraoperative hypothermia.

In the 1990s, the concept of prewarming was proposed. Prewarming the legs prior to induction substantially prevented redistribution hypothermia resulting from anesthesia.[41,50,56-58]

With prewarming, heat is applied for about 30 minutes to the normally hypothermic legs and arms before surgery. Once the legs and arms are warm, no peripheral compartment can cool the warm blood from the core. If prewarming is followed by intraoperative warming, the patient may be maintained at normothermia throughout surgery. Prewarming can be accomplished by any active warming technology applied to the legs and arms, such as FAW and conductive fabric warming (CFW) blankets (Table 2).

a

b

Figure 2a. **Bair Hugger forced-air warming device.**

2b. **Bair Hugger Underbody blanket.**

Figure 3. **The HotDog conductive fabric warming device.**

Prewarming alone may be sufficient to prevent hypothermia in some short cases. Continuous temperature monitoring perioperatively allows adjusting warming to maintain normothermia while avoiding overheating.

One impediment to prewarming may be cost. Reusable prewarming systems and metrics (described below) to help select patients who would most benefit from prewarming may make the procedure more cost-effective.

Warming

FAW is by far the most commonly used perioperative active warming technology and is the standard against which all other warming technologies are compared (Figures 2a and 2b). Reported injuries are rare, and serious injuries most frequently are caused by misuse.

The effectiveness of FAW results from its ability to maximize the heat transfer area in contact with the patient's skin. It does so by surrounding the patient's body with 1,000 watts of heated air that extends well past the disposable blanket, often warming the space under the surgical drapes. The extended contact area makes FAW easy to use, but also results in the release of excessive amounts of waste heat (around 950 watts).[59]

Kurz et al showed that use of FAW dramatically reduced soft tissue surgical site infections (SSI) during colon surgery.[60] Therefore, any potential airborne contamination caused by FAW waste heat must have a negligible effect on soft tissue SSIs. However, patients undergoing surgeries involving implanted foreign materials, especially for orthopedics, may be at higher risk for infection from airborne contamination.[61]

Studies have shown that comparable FAW and CFW blankets provide roughly equal patient warming effectiveness.[46,62-68] The CFW allows multiple blankets and a heated mattress to be used simultaneously (Figure 3).

Hypothermia Risk Index

A significant challenge in hypothermia, whether preoperatively or from accidental or intentional exposure to extreme cold, is to determine when and how to warm. The complications of attempting to bring a patient from a state of hypothermia to normothermia are potentially serious.

Warming may provoke cardiovascular responses, such as increased myocardial oxygen demand or core temperature afterdrop, which may trigger syncope, and even ventricular fibrillation in some cases, resulting from vasodilation and reversal of temperature gradient once the patient is warmed.[69] Hence, adequate temperature monitoring and observation of physiologic responses coupled to proper use of warming techniques may allow obtaining the maximum benefit of prewarming and warming.

The personalized Hypothermia Risk Index (pHRI; Table 3) addresses the challenge of managing hypothermia due to both accidental cold exposure as well as in the perioperative setting. In anesthesia settings, the pHRI provides physiologic and thermal metrics for helping to evaluate the potential risk that a patient will develop complications from hypothermia intraoperatively and postoperatively, and helps guide the use of interventions to avoid thermal disturbances.

Values are assigned to 3 types of temperature-related input: autonomic responses such as shivering, vasoconstriction (finger/toe pallor), and piloerection; behavioral responses, as reflected by patients stating if they are cold; and either brain or core temperature.

The gradation of values of pHRI follows the temporal sequence of activation of autonomic changes by the CNS—at 35°C peripheral nerve conduction velocity decreases progressively[70] and at temperatures below 34.5°C brain electrical activity show changes in frequency and significant attenuation of signals.[71,72] The pHRI may provide a marker that can identify in advance patients likely to experience more intense and longer durations of hypothermia intra- and postoperatively, but further studies are needed to confirm its utility.

Conclusion

The maintenance of perioperative normothermia has clearly been demonstrated to improve patient outcomes.[60,73] Continuous temperature monitoring intraoperatively enables identification of thermal disturbances and adjustment of warming levels to achieve normothermia. Moreover, continuous monitoring also may

Table 3. The Personalized Hypothermia Risk Index

Parameter	Y/N	Value	Insert Value of Y Responses
Autonomic responses			
Piloerection		1	
Shivering—mild or cold hands/feet (pallor)		2	
Shivering—pronounced		3	
Behavioral response			
Cold?		1	
Hot?		0	
Neutral?		0	
Unresponsive/unable to communicate		1	
Core/brain temperature			
<34.5°C		4	
≥34.5°C to <35.5°C		3	
≥35.5°C to <36°C		2	
≥36°C to <36.5°C		1	
≥36.5°C		0	
Total:			

Patients with a score of ≥4 are at increased risk for developing complications from hypothermia and should be closely monitored during and after surgery.

help to prevent excessive warming, and thus may avoid cardiac complications due to increased metabolic rate and oxygen utilization, as well as increased neuronal injury and death that occurs at hyperthermic levels.

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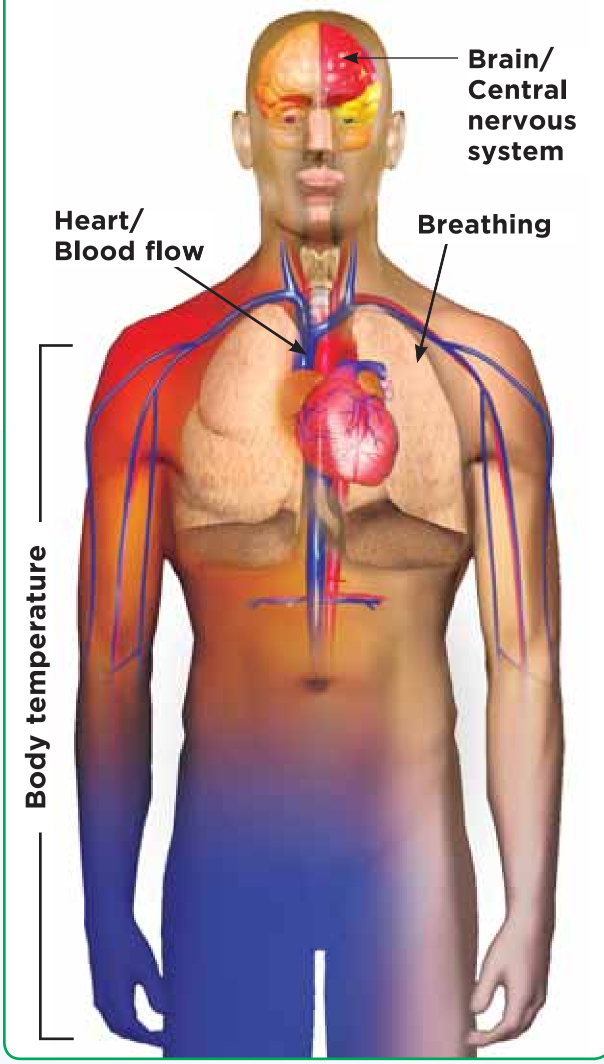
Patient Guide to ANESTHESIA

You are being given this patient guide to help you understand the care you will receive from your anesthesiologist while you are asleep during your surgery or medical procedure.

The job of the anesthesiologist is to guard your safety during surgery. The anesthesiologist must anticipate any potential difficulties you might experience—for example, difficulty in breathing or an unusual response to the anesthetics or other drugs you receive—and react quickly and effectively.

Knowing which drugs to give you, at exactly the right dose and time, is the anesthesiologist's responsibility. It is the anesthesiologist who ensures that you do not move during surgery, do not shiver excessively or become overheated, and do not become dehydrated. The anesthesiologist must also monitor your blood pressure and level of sedation. In addition, the anesthesiologist administers drugs to prevent nausea and vomiting (frequent side effects upon awakening after anesthesia) and relieve pain.

The anesthesiologist will monitor your vital signs.



Four Questions You May Want To Ask Before Undergoing Surgery and Anesthesia

1. Are there risks associated with my anesthesia?

2. Why do I need to fast the night before my operation?

3. Do I need to tell my anesthesiologist the names of all medications that I take regularly?

4. Am I allowed to choose my anesthesiologist?

RESOURCES

American Society of Anesthesiologists
http://lifelinetomodernmedicine.com
www.asahq.org/PatientEducation

National Patient Safety Foundation
www.npsf.org

Agency for Healthcare Research and Quality
www.ahrq.gov/consumer

From the office of ______________________________

Directions/comments ______________________________

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