I. Helium advantages: Small-bore tube

Definition

Gas flow through a tube is either **laminar** (parabolic velocity profile) or **turbulent** (flat velocity profile). The nature of flow is dependent on several physical properties of the gas (density, viscosity) as well as of the flow itself (velocity, length of tubing), all of which can be combined mathematically into the Reynold's number, Re (Re = ρUL/visc., where ρ is the density of the fluid, U is the mean flow velocity, L is length of flow, and visc. is the viscosity). **When Re > 2100, gas flow becomes turbulent**

During laminar flow, resistance depends on gas viscosity (laminar flow is modeled as concentric shells sliding across each other, thus their "stickiness" would be important), however **during turbulent flow, resistance depends on gas density** (turbulent flow is modeled as semi-random movement of gas molecules [which is energetically inefficient], thus the more dense the molecules, the more energy which is required to move them).

Gas Flow: Summary

- Reynold's Number: Re = ρUL/visc, < 2100 is laminar, > 2100 is turbulent
- Laminar (concentric shells): resistance depends on gas *viscosity* (air and Heliox are the same viscosity)
- Turbulent (semi-random movement): resistance depends on gas *density* (Heliox much less dense than air)

Heliox (70% helium, 30% oxygen) therefore **affects gas flow in two ways – first, the Reynold's number is lower** (because density is lower), and thus flow is more likely to be laminar, and **second, if flow IS turbulent, resistance to flow will be lower**, because Heliox is less dense (~ 0.5 g/L versus 1.2 5g/L).

Note that in laminar flow, Heliox offers no advantages, as it has approximately the same density as air. Also **note that Heliox is ~ 70% helium, thus the potential benefit of improved gas flow must be balanced by the knowledge that a lower FiO2 may be delivered**

Heliox: Summary

- ~ 70% helium, ~ 30% oxygen
- Significantly less *dense* than air (0.5 vs 1.2 5g/L), but *viscosity* is about the same
- Improves gas flow by lowering Reynold's number (converting to laminar flow) or decreasing resistance when flow is turbulent (lower density)

II. **Hypothermia: Cold OR mechanism**

Definition

In humans, heat (or "thermal energy") is more concentrated in the core than it is in the extremities. This is why your hands or feet may be cold even though you core is normothermic. Thus, the core temperature may be 37 but the mean body temperature might be 36 or 35.5. General anesthesia (and neuraxial regional anesthesia) destroy this process by re-distributing heat (thermal energy) equally about the body and core temperature begins to approach mean body temperature. **Redistribution of body heat from the core to the periphery is the most common etiology of hypothermia in the first hour after induction of anesthesia and this reduction in temperature is commonly 1-1.5 °Celsius.** It should be noted, and may not have been clear in the question, that this is NOT due to heat loss – merely a redistribution of existing heat. **After that point heat is lost to the environment through mechanisms such as radiation, convection, evaporation, and conduction.**

Four types of heat loss from a patient to the relatively cold environment:

1. Radiation
2. Convection
3. Conduction
4. Evaporation

The main mechanism of heat loss is radiation, which was established in a cohort of 13 normal young women who were exposed and awake in a calorimeter chamber measuring basal metabolic rates and perceptions in response to a controlled temperature change from 22-35 C. Radiation accounted for 67% in the cold zones, evaporation 17%, and conduction/convection approximately 16%.

Radiative heat losses occur anytime an object is above absolute zero. The magnitude of the radiation is proportional to the fourth power of the difference between the two sources. Conduction is less important in the OR, because the patient is usually lying on foam or rubber which is well insulated.

Convection can play an important role as air turnover constantly removes heat as the patient's body exists in equilibrium of heat transfer between itself and the surrounding "layer" of air.

Patients under anesthesia typically do not sweat which is the main way that heat is lost due to evaporation.

Two mechanisms of undesired heat loss in the OR.

1. Impaired thermoregulation secondary to anesthesia.
2. Low ambient temperature of the operating theatre.

Of these two mechanisms, the anesthetic impairment is the more important mechanism.

Hypothermia – Prevention

Definition

Inhaled anesthetic gases will substantially reduce the body's ability to vasoconstrict and shiver in order to preserve and generate body heat. They will also reduce the ability of infants to undergo non-shivering thermogenesis. Prevention of hypothermia is necessary, as hypothermia leads to increased risk of infection, myocardial morbidity, and coagulopathies, to name several disadvantages.

Redistribution of heat to the peripheral tissues via vasodilation is responsible for the first 0.5-1.5o C drop in core body temperature. **Prevention or mitigation of this can be accomplished by pre-warming the patient's extremities, most importantly the lower extremities, for at least 30 minutes or more prior to the induction of general anesthesia.** This will decrease the temperature gradient between the body core and the peripherals, thus decreasing the redistribution of heat.

OR room temperature plays the largest role in maintaining normothermia. To prevent heat loss to the surrounding atmosphere, insulation of the skin is necessary, as 90% metabolic heat is lost via the skin. Heat loss is proportional to the surface area exposed. Blankets, plastic sheeting, etc., are effective; however, each subsequent layer of insulation is less and less effective. The use of active warming, with circulating air warmers may be is most effective in reducing heat loss and may actually warm the patient. Finally, increasing the temperature of the OR can be somewhat effective. The OR needs to be >23degrees C in adults (73.4F), and >26degrees C in infants (78.8F) in order to prevent heat loss.

Fluid warmers are generally helpful only when large amounts of fluid is infused. While warm fluid will do very little to warm a patient, it is effective at preventing further cooling.

Pediatric warming techniques

Definition

Temperature regulation is important in pediatric patients, particularly neonates, as they are prone to greater heat loss in the operating room when compared to adults. This is because of their larger surface area per kilogram, thinner skin and lower fat content. Temperature regulation is made even more difficult in the operating room because of cold air, administration of IV fluids, dry anesthetic gases, wound exposures and the direct effect of anesthetic gases on temperature regulation.

In neonates, heat generation by shivering is somewhat limited during the first three months of life. **This makes nonshivering thermogenesis, which consists of metabolism of brown fat, a primary means of heat production.** Temperature regulation can become difficult because this process is inhibited by the use of volatile anesthetics. Poor temperature regulation can lead to a number of adverse events, including increased oxygen consumption, which in turn can cause a metabolic acidosis. In addition, one may see delayed awakening, respiratory depression, increased pulmonary vascular resistance and cardiac irritability.

There are several mechanisms for maintaining the temperature of the pediatric patient during anesthesia but it is also important to maintain temperature during transport to and from the operating room as well. To decrease conductive temperature losses, the operating room should be warmed (80 degrees or warmer) in advance and heated air mattresses should be used. Convective heat loss can be prevented by keeping the infant in an incubator, covered in blankets. Heat lost from radiation can be minimized by using a double-shelled Isolette when transporting the patient. Evaporative heat loss can be decreased by humidifying inspired gases, using plastic wrap to prevent water loss through the skin and warming skin disinfecting solutions. The most effective way to warm pediatric patients involves the use of forced air blankets. One should also take care to keep the head covered when possible.

III. Hypothermia: pH stat management

Definition

pH-Stat

During pH-stat acid-base management, the patient's pH is maintained at a constant level by managing pH *at the patient's temperature*. pH-stat pH management *is* temperature-corrected. Compared to alpha-stat, pH stat (which aims for a pCO2 of 40 and pH of 7.40 at the patient's actual temperature) leads to higher pCO2 (*respiratory acidosis*), and *increased cerebral blood flow*. **Often CO2 is deliberately added to maintain a pCO2 of 40 mm Hg during hypothermia.**

Alpha-Stat

During alpha-stat acid-base management, the ionization state of histidine is maintained by managing a standardized pH (measured at 37C). Alpha-stat pH management is *not* temperature-corrected – as the patient's temperature falls, the partial pressure of CO2 decreases (and solubility increases), thus a hypothermic patient with a pH of 7.40 and a pCO2 of 40 (measured at 37C) will, in reality, have a lower pCO2 (because partial pressure of CO2 is lower), and this will manifest as a relative *respiratory alkalosis* coupled with *decreased cerebral blood flow*. During alpha-stat management you have no idea what the patient's pCO2 is, your goal is to maintain a constant dissociation state of histidine.

Alpha Stat vs. pH Stat

A study by Kiziltan et al., in which 52 patients were randomized to alpha-stat versus pH stat management, showed that **pH stat management led to increased jugular venous oxygen concentrations**, implying increased CBF. A study by Sakamoto et al., comparing pH stat to alpha stat during repair of cyanotic neonatal congenital heart disease, demonstrated that pH stat management led to less pulmonary collateral circulation as well as higher oxyhemoglobin and lower deoxyhemoglobin levels on cerebral near-infrared spectroscopy, suggesting greater cerebral oxygenation through improved oxygen delivery with pH stat. A prior study by Murkin et al. comparing pH stat to alpha stat showed that **during pH stat, CBF and CMRO2 become uncoupled** (CBF is pressure-dependent), whereas **during alpha-stat CBF is related to metabolic needs (CMRO2) and *not* to cerebral perfusion pressure**. **The major concern with pH stat is the potential for increasing the cerebral embolic load**.