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Thermoregulation

Definitions

- homeothermic = where body temp is actively maintained within tight limits (mammals)
- pokilothermic = body temp fluctuates with changes in ambient temp (reptiles)
- interthreshold range (ITR) =
  - range of **core** temps that does not trigger autonomic thermoregulatory responses (0.2-0.5 degC)
  - within ITR we are effectively poikilothermic
- thermoneutral zone (TNZ)= range of **ambient** temps where VO2 is a minimum (autoreg by vasoC or vasoD alone):
  - prem = 34-36
  - term = 32-34
  - adults = 22-28

↳ another definition = environmental temp range which body temp is normal and remains normal while heat production & evaporative heat loss both remain at minimum (usually referring to naked body)

- within TNZ heat production = heat loss.
  - achieved by using minimal VO2
    - by vasoC / vasoD
    - **not** by shiver/sweating/exercise
- neutral temp = ambient temp where VO2 = minimum:
  - prem = 34
  - term = 32
  - adult = 28
- critical temp = ambient temp where naked, non anaesthetised, cannot maintain normal core temp:
  - prem = 28
  - term = 23
  - adult = 1
- heat = a form of energy. Can be transferred from hotter to colder substance ie down a gradient
  ↳ analogous to a solute

  ↳ measured in calories: 1 calorie (standard international unit) = amount of energy required to ↑temp of 1g of pure water by 1deg celcius
- temperature = measure of thermal state of a substance/body/environment which will determine whether heat will transfer to or from substance/body/environment
  ↳ analogous to a concentration

- solutes & concentrations:
  - if you add more solute (ie heat) to a solution then measured concentration (ie temperature) will increase.
  - the concentration (temp) will determine whether solute particles (heat) will move to an area of lower conc (temp) or vice versa
  - if you halve a substance with a temp x: will get 2 halves with same temp (conc) but with half the heat (quantity)
- specific heat capacity:
  - = amount of heat required to raise the temp of a 1kg substance by 1 kelvin (J/kg/K)
  - specific = quantity expressed in terms of units mass
  - examples of SHC:
    - man = 3.5 kJ/kg/C
    - water = 4.18
    - blood = 3.6
    - gasses = very low ∴ small heat transfer can cause significant temp change in gas

  - air = 1.01
- heat capacity = amount of heat required to raise temp of given object by 1K (J/K)
  ↳ ∴ SHC = heat capacity x mass
- mean body temp = 2/3 core temp + 1/3 average skin temp
- body heat content = heat capacity x mean body temp
- latent heat:
  - latent heat of vaporisation = heat needed to change liquid to vapour without a change in temperature
    ↳ latent heat of vaporisation of water = 0.58kcal/g
  - latent heat of fusion = heat needed to change solid to liquid without a change in temp
  - latent heat of crystallisation = solid dissolving on or out from a liquid
- specific latent heat
  - = heat needed to convert 1kg of a substance from one phase to another at a given temp (J/kg)
  - ∴ lower starting temp = ↑ed energy needed
  - water at 37 C = 2.42 MJ/kg
  - water at 100C = 2.26 MJ/kg
- critical temp = temperature, above which a substance cannot be liquefied, no matter how much pressure is applied

Intro

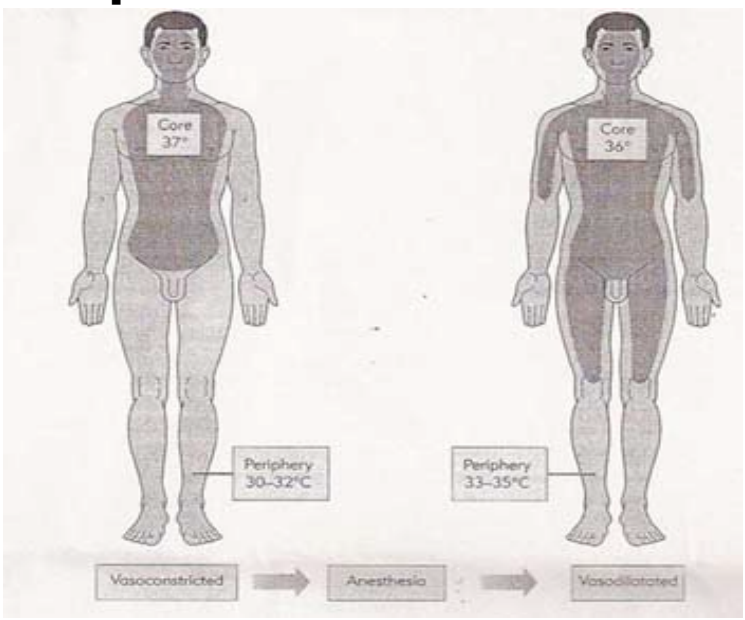
- norm core body temp maintained within 0.5-0.8 (usually 36.5-37.3) with slight variations:
  - diurnal -
    - circadian fluctuation = 0.5-0.8
    - lowest asleep, rises with activity
  - gender:
    - female show menstrual monthly variation - ovulation ⟹ ↑up to 1deg
  - individual
- tight range of norm temp aka set point range:
  - if temp moves outside this range ⟹ physiological effector mechanism activated to counteract change

Anaesthesia Summary

- anaesthesia = challenge to thermoregulatory mechanisms:
  - removal of behavioural responses
  - loss of tonic peripheral vasoC ⟹ redistribution of heat to peripheries (away from core)
  - ↓threshold of effector responses
    ↳ ↑size of ITR - to ~5degs
  - ↓BMR by 20-40%

Physiology

Compartment Model



- body heat distributed unevenly
- 2 main compartments
  - central (core):
    - major trunk organs
    - brain = 2/3 body's heat
    - temp narrow range 36.5 - 37.3
  - peripheral compartment:
    - limbs, skin, sub cut tissue = 1/3 body heat content
    - wide temp swings from close to zero - 40deg
      - norm room conditions = av temp 30-32
      - gradient of ~6deg maintained by tonic vasoC in vessels supplying periphery
    - anaesthesia:
      - heat moves peripherally = ↓core temp by ~1deg
      - = dilutional heat loss effect rather than NET heat loss

Heat Production vs Loss

Heat production

- metabolism:
  - basal metabolism ~40kcal/m2/hr (~2000kcal/day)
  - = indep of thermoreg mechanisms ie ↑ed in:
    - kids
    - ↑growth hormone
    - thyroxine
    - febrile illness
  - amount of heat generated by metabolism depends on substrate:
    - glucose & aa's ~ 4kcal/kg
    - fat ~ 9.3kcal/kg
  - products of metab:
    - 2/3 energy ⟹ dissipated as heat
    - 1/3 ⟹ ATP generation

- shivering:
  - ↑heat production by x6
  - autonomically mediated
  - infants <3/12 cannot shiver
- exercise - ↑x20 heat production
- non-shivering thermogenesis:
  - ↑x3 heat production esp impt in neonates
- vasoC -
  - autonomically mediated
  - ↑s temp gradient between core & periphery
- behaviour:
  - putting on more clothing
  - quantitatively the most imp factor!!!!

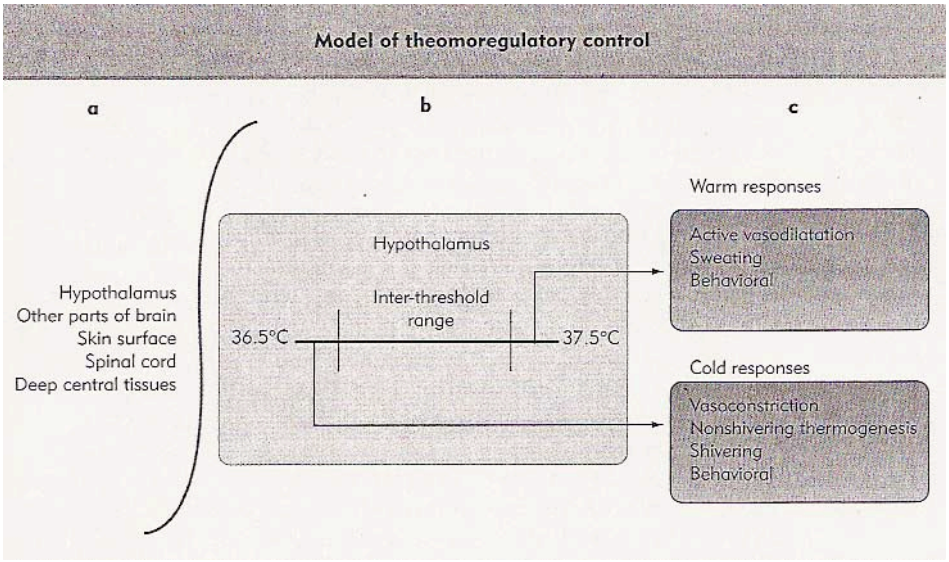
Heat Loss

- radiation (40%):
  - infrared electromagnetic wave transfer of heat from warm object to a distant cooler surface
  - further ↑ed by vasodilation
  - depends on 4th power of temp difference:
    - ↑OT temp by 2 deg ⟹ ↓heat loss by 2^4 = 16 fold
- convection:
  - = motion of liquid or gas which carries energy from warm area to cool area
  - when layer of air next to skin moves/disturbed ⟹ removing insulating properties
  - heat exchange = proportional to
    - temp difference between skin & surrounding air = as much as 15deg
    - square root of air velocity
- evaporation: (25% - skin 15%, lung 10%)
  - each kg of water (sweat) ⟹ dissipation of 0.58kcal/g of heat from body with evaporation
    ↳ = latent heat of vaporisation of water
  - <10% heat loss but can ↑↑ with open surgery (evap skin prep & open wound)
  - more impt in neonates/prems due to:
    - ↑skin permeability
    - ↑BSA
  - = only way to lose heat if environment is warmer than core temp
- conduction (5%) -
  - = 2 material objects in direct contact. Temp of one is higher than the other ∴ they equalise
- behaviour = undress, seek cooler environment

- overall:
  - vasoC = main physiological way of preventing heat loss ie ↓radiation & ↓evap
  - respiration = contribute ~10% heat loss
    - 8% evap of water
    - 2% heating of air

Physiological Control of Body Temp

- similar to other homeostatic control systems
- thermoreg control system =
  - afferent
  - central CNS integration
  - efferent effector limb



Afferent Limb

- temp sens organs:
  - =naked nerve endings found all over body in:
    - skin -
      - located in sub-epithelium
      - predominant location (20% all afferent thermal info)
    - s/c tissues
  - respond to changes in temp by changing rate of firing ⟹ CNS
- 2 types of temp sens neurons:
  - cold receptors:
    - bulbs of Krauss (*santa Krauss*)
    - outnumber warm receptors 10:1
    - respond to changes in temp range 10-36deg
    - most afferent cold input from skin/periph compartment
    - input to A delta fibres
  - warm receptors:
    - bulbs of Ruffinian (*Roof on fire*)
    - response range 30-45deg
    - input to unmyelinated C fibres
- thermally sensitive neurons can undergo adaptation:
  - occurs between 20-40deg
  - sensation of heat/cold will gradually fade to thermal neutrality
  - temp >40 ⟹ tissue damage ⟹ warm sensation ⟹ pain sensation
- ascending thermal traffic via lateral spino-thalmic tract in ant cord
- some signals modified at spinal level:
  - spinal injured pt regulate temp better than expected

Central integration

- hypothalamic = main integrator
- ant hypothalamus:

    - integrates inputs in pre-optic area
        ↳ contains temp sensitive cells
- general rule =
    - cold input from periphery
    - warm input from core
- posterior hypothalamus:
    - compares aggregated input with pre-determined set point temp range 36.5-37.3
    - instigates effector responses
- BUT human thermoregulation also occurs at multi other levels eg NRM in pons, PAG in spinal cord

Efferent Limb

- posterior HT ⟹ autonomic effector response to cold ie vasoC & shivering
- ant HT ⟹ responses to warm ie sweating & vasoD

Characteristics of Thermoregulatory Effectors

- 3 main chars:
    - threshold
    - gain
    - max response intensity
- each mechanism contains all 3 chars
- General Anaesthetic effects:
    - ↓thresholds
    - no effect on gain + max response intensity
    - removes ability to mount behavioural response:
        - in extreme cold: vasoC & shivering have limited efficacy and vice versa in extreme heat
- range of ambient temps tolerated is ↓ed if effector mechs are inhibited:
    - neurological disease ⟹ ↓shivering
    - drugs eg atropine ⟹ ↓sweating

    ↳ ∴ ↑ed min tolerable temp, ↓ed max tolerable temp

Threshold

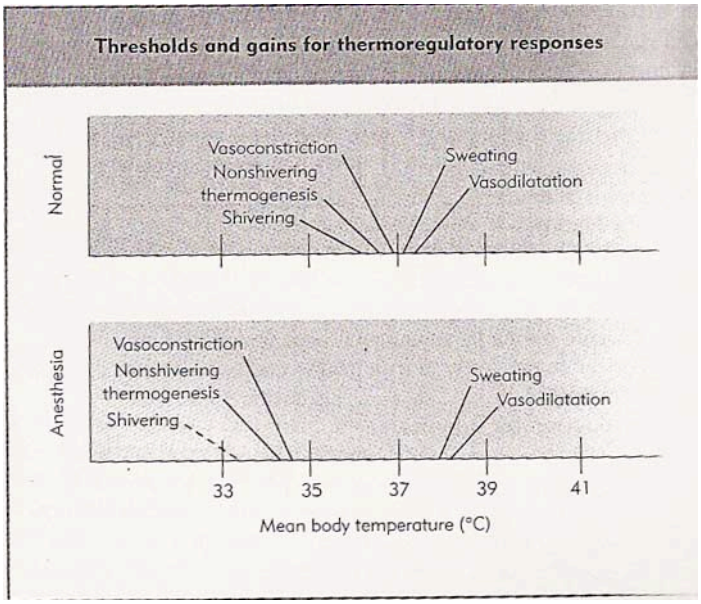
- core temp at which response triggered
- thresholds can be altered by:
    - diurnal rhythm
    - gender
    - exercise
    - food
    - infection
    - disease
    - drugs/anaesthesia
- vasoC threshold = 36.5
- shivering = 36-36.2
- GA's effect on ↓threshold ⟹ an ↑ed interthreshold range (norm 0.2-0.5) to ~5degs

Gain

- =rate of change of effector response with given change in temp
    ↳ ie = slope of response curve
- ∴ gain of shivering = rate of ↑shivering as core temp continues to ↓ below shivering threshold
- vasoC = very high gain ie max vasoC reached after small ↓in temp below threshold
- shivering = less gain ie takes larger in temp to reach max response

Max Response intensity

- =upper limit (plateau) of effector response



Effector Responses

- Non shivering Thermogenesis (NST)
- Sweating
- VasoConstriction
- Vasodilation
- Shivering

Non shivering Thermogenesis (NST) (see paeds)

- includes (non restricted to) metabolism of brown fat
- brown fat = specialised fat:
  - multinucleated cells
  - many mitochondria
  - abundant blood supply
  - abundant autonomic nerve supply
  - catecholamines mediate metabolism
  - substrate used mostly = FA's
- cold stimuli ⟹ NA release ⟹ uncoupling of oxidative phosphorylation ⟹ ↑heat production /gram of fat (rather than ATP production)
- no mechanical work done
- brown fat found in
  - abdomen esp perinephritic
  - around large blood vessels
  - interscapular area
  - base of neck
- brown fat = 2-6% neonate total body weight
- ↑brown fat metab redirects CO to brown fat (by ↑~25%) ⟹ direct heating of blood as well
- NST needs O2 ∴ cold & hypoxia = v bad
- x3 heat production in neonate (in adult has v little effect)

Sweating

- mediated by symp ns postganglionic **cholinergic** nerves
- ∴ prevented by:
  - nerve blockers
  - antocholinergics eg atropine

- vital as = only mechanism which can dissipate heat if environ temp > core temp
- latent heat of vaporisation = 0.58kcal/kg water (= 2.42 MJ @ body temp)
- sweating rate can > 1litre/hr for short periods
  ↳ = heat loss up to x15 BMR
- <37/40 prem baby unable to sweat

VasoConstriction

- =1st autonomic response to cold
- skin blood flow autoreg consists of components:
  - thermoregulatory
  - nutritional
- skin flow regulated via A-V shunts in distal vasculature (finger/toes/palms/earlobes:
  - =well innverated anastomotic connections between arterioles + venules
  - anatomically + functionally distinct from nutritional capillary network
    ↳ ∴ A-V constriction does not compromise nutritional needs of periphery)
  - innervated by α-adrenergic SNS
    ↳ minimally affected by circulating catecholamines
  - up to 10% of CO can flow through these shunts
    ↳ doesn't usually effect haemodynamic changes as larger arterioles control MAP are un-influenced
- blood flow vary from 1ml/100g skin/min ⟹ 150ml/100g/min via A-V anastomotic system

Vasodilation

- mediated via A-V shunts
- max cutaneous vasoD at temp above that which causes max sweating intensity
  ↳ ie max sweating reached before max vasoD
- extreme heat stress:
  - blood flow through skin 7 l/min ie whole resting CO
- vasoD ineffective if ambient temp > core temp

Shivering

- =involuntary oscillatory pattern of skeletal muscle activity that occurs once cold core threshold (for shivering) is reached (~35.9)
- vigorous shivering ⟹ ↑metabolic heat production:
  - briefly = x6
  - sustained shiver = x2
- components of shiver:
  - rapid frequency component = 200Hz
  - slow frequency = 4-8Hz synchronous waxing & waning mm contraction which centrally mediated
- shiver motor centre =
  - located between ant & post HT
  - inhibited by impulses from heat sensitive area (ant HT)
- efferent pathway has multiple connections:
  - RF in mesencephalon
  - pons
  - medulla
  ↳ ends on spinal α motor neurons
- see ↑ed mm tone prior to shivering
- infant <3/12 cannot shiver

Peri-Operative Shivering

- common & distressing for pt ie can ↑pain

- causes are complex but hypothermia is most impt
- not assoc with hypoxaemia (hypoxia inhibits it)
- prevention of hypothermia is best Rx
- other options =
  - pethidine 0.33mg/kg IV
  - tramadol 25mg
  - fentanyl 1mcg/kg
  - clonidine 2mcg/kg
  - ondansetron 0.1mg/kg

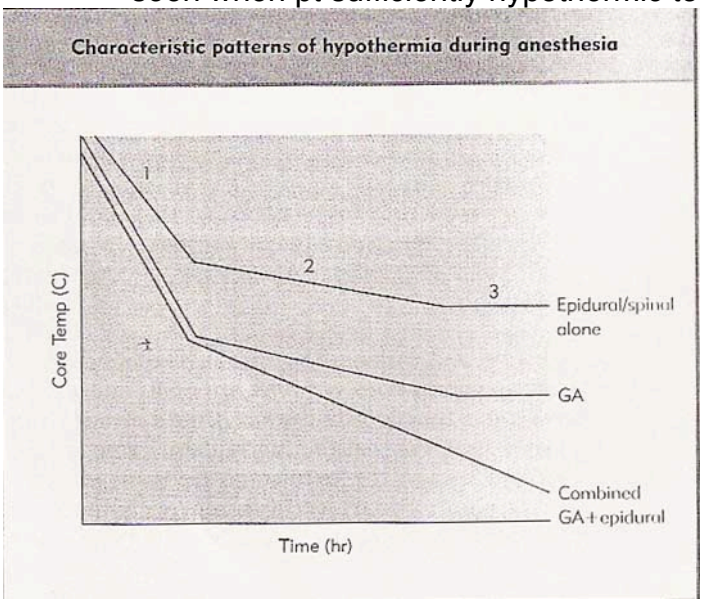
Paediatrics

- thermoregulatory responses well developed in term neonates BUT hypothermia develops rapidly if compensatory mechanisms overwhelmed
- neonates have min insulating s/c fat
- neonates have large BA : volume ratio ie x2.5 adults
- open/flaccid posture neonates $\Longrightarrow$ ↑heat loss
- large head (with ↑ed relative cerebral flow) $\Longrightarrow$ ↑heat loss
- large min ventilation $\Longrightarrow$ ↑heat loss
- infants <3/12 dont shiver
- term baby can sweat >37.2 BUT prems <37 week unable to sweat
- principle heat production mechanism = NST
- poorly developed behavioural responses ie max = crying

Anaesthesia & Thermoregulation

General Anaesthesia

- effects:
  - behavioural responses totally abolished
  - significant ↓autonomic regulation -
    - specifically thresholds ⟹ ↑ITR x10-20
      - warm response threshold ↑ed,
      - cold response threshold ↓ed
        ↳ all anaesthetic agents ↓cold threshold in dose dependant fashion
- GA usually ⟹ mild, inadvertant hypothermia in 3 phase pattern:
  - phase 1 (1st 30-45min) =
    - rapid ↓core temp 1-1.5 deg
    - due to
      - redistribution & dilution of core heat ⟹ periphery
      - vasoC cold threshold ↓ed
  - phase 2 (2-3hrs):
    - gradual linear ↓core temp of ~1deg over 2-3hrs
    - due to heat loss > heat production
    - BMR during GA ↓ by x20-40%
    - loss of heat via radiation, convective, evaporative
  - phase 3
    - = plateau where heat loss = metabolic heat production
    - seen when pt sufficiently hypothermic to reach vasoC cold threshold



Regional Anaesthesia

- mechanisms:
  - redistribution of heat = main mechanism
  - ↓ed afferent temp input to CNS - due to block
    - pt may deny feeling cold but be hypothermic & shivering
  - ↓ed thresholds (as GA) -
    ↳ partially due to co-sedative drugs given
  - shivering -
    - less effective as less mm mass to shiver ie only upper limbs/body

  - gain & max intensity ↓ed by ~50%
- overall effect is less than GA as vasoD restricted to lower body/limbs
  ↳ see ~0.5 degree drop in temp
- pattern of response similar to GA phase 1 & 2
- phase 3 =
  - not seen as vasoC not possible via blocked nerves
  - may see passive plateau in well insulated pts during minor surg
    ↳ serious hypothermia possible in major surgery
- combined regional/GA = exceptional high risk of hypothermia:
  - ↓effector response - ↓shivering & ↓vasoC
  - ↓afferent inputs

Consequences of PeriOperative Hypothermia

- drop of 1-2 deg below norm:

• Cardiac morbidity	→	increased **X 3**
• Periop wound infections	→	increased **X 3**
• Periop blood loss	→	increased by **30%**

- cardiac M+M due to:
  - ↑circulating catecholamines ⟹
    - ↑MAP (↑afterload)
    - ↑cardiac irritability = ↑arrhythmias
- periop wound infections:
  - directly related to s/c wound tissue O2 tension
    ↳ compromised by hypothermia induced vasoC
  - mild hypothermia directly impairs immune function:
    - ↓B cell mediated antibody production
    - ↓non specific oxidative bacterial killing by neutrophils
- periop blood loss:
  - impaired platelet function - via ↓thromboxane release
  - ↓clotting factor enzymes function
  ↳ NB lab coag tests = norm as performed at 37 deg in lab

PeriOperative Hypothermia & Drug Metabolism

- drug enzyme systems = temp sensitive
- muscle relaxants half lifes:
  - vecuronium =
    - <35 = ↑100%
  - atracurium =
    - <33 = ↑60% duration

    - (less temp dependant)
- volatiles:
    - hypothermia ⟹ ↑tissue solubility
    - MAC halothane & isoflurane: ~5% ↓ with each 1deg ↓core temp
    - (at brain temp 20deg no anaesthesia required)
- IV drugs - ↓1deg =
    - ↑plasma conc:
        - propofol by 10%
        - fentanyl by 5%

Prevention PeriOp Hypothermia

- 3 strategies:
    - minimise heat redistribution
    - cutaneous warming during anaesthesia
    - internal warming

Minimise Heat Redistribution

- preop warming of periph compartment - eg forced convective warm air (Bair hugger)
    - need ~1hr prewarming to be effective
    - difficult to logistically achieve
- preop pharm vasoD:
    - facilitates core ⟹ peripheral redistribution of heat
    - does not effect core temp as pts other (ie not vasoC) thermoreg responses are intact
    - eg nifedipine ⟹ ↓s extent of initial redistrbution hypotermia by 50%

Cutaneous Warming During Anaesthesia

- passive insulation:
    - eg space blanket
    - ↓s cutaneous heat loss by ~30% by trapping layer of still air
    - additional layers of passive insulation do little else
- active warming:
    - much more effective
    - initially: core heat ⟹ periph compartment
    - only way to correct is to ↑heat in periph compt > core ∴ reversing gradient
    - Most effective = forced air convective warming (Bair):
        - warm air replaces cold air
        - convection ⟹ ↑ed heat gain as forced air is warmer than skin
        - must be directly next to skin with no intervening layers
        - larger area covered = more effective
        - blankets on top of Bair hugger ⟹ ↓efficacy by preventing air circulating
        - NB: if ↓ed lower limb bloody supply (aortic clamp) then should avoid LL warming in order to ↓effects distal ischaemia

Internal Warming

- warmed IVF:
    - 1 litre fluid at room temp ⟹ ↓core temp ~0.25deg
    - ∴ always use warm fluids or fluid warmers esp if major haemorrhage
    - needs to be used in combo with other techniques - not successful alone
- airway humidification:
    - limited use

    - <10% metabolic heat lost via this route
- cardiopulmon bypass: transfers heat at rate & magnitude more greatly than any other route
- peitoneal dialysis/lavage = very effective but not usually applicable
- amino acid infusions:
    - can give during anaesthesia ⟹ ↑metabolic rate
    - ml for ml compared to crystalloid will lead to ↓ed hypothermia
    - not really used in practise due to concerns about cardiac outcome with ↑ed metabolic rate

Electrical Measurement

Non Electrical

- aka direct reading
- categories:
  - liquid filled
  - dial
  - chemical

Liquid

- generic advs:
  - simple
  - linear expansion with temp
- generic disadvs:
  - slow
  - breakable/injury
  - non-remote
  - intermittent
  - non recording

Mercury Thermometer

- adv: reliable, cheap, familiarity, can be made in maximum reading form
- disadvantage:
  - slow - 2-3mins
  - risk of injury high
  - cannot read colder than -39C

Alcohol Thermometer

- adv:
  - cheaper than mercury
  - better at v low temps
- disadv:
  - unsuitable for high temp readings (alcohol boils at 78.5deg)
  - scale is less linear

Dial Thermometers

- bimetallic strip:
  - 2 dissimilar metals fixed together in coil which expands/contracts by different amounts based on temp changes
  - causes coil to tighten/relax $\Longrightarrow$ change on indicator scale
  - used commonly in TEC-vaporizers
- Bourdon gauge:
  - gauge attached to a sensing element containing small tube of mercury or volatile liquid
  - works on 3rd Gas law: temp change $\Longrightarrow$ for fixed volume, absolute pressure of gas varies with absolute temp
  - this then recorded on calibrated scale

Chemical

- single use:
  - strip containing rolls of cells which contain dye & melt at certain temp
  - higher temp $\Longrightarrow$ more cells melt $\Longrightarrow$ more dye released
- reusable:
  - cells have diff long chain polymers whose optical properties change with temp

- chloresteric liquid crystals which change colour with temp

Electrical Techniques

- aka remote reading thermometer

Resistance Thermometers

- based on fact that electrical resistance of metal ↑s linearly with ↑temp
- configuration:
  - platinum wire resistor
  - battery
  - ampmeter to measure current (calibrated for temp display)
- but:
  - system is too simple
  - would be too sensitive
  - needs a Wheatstone bridge

  ↳ ∴ not really used

Thermistors

= what is used in theatres everyday

- small bead of metal oxide (eg cobalt)
- resistance falls exponentially as temp rises (opposite to platinum resistor)
- adv:
  - can be made very small eg end of flexible probes
  - cheap to make
  - accurate
  - greater change in resistance with smaller temp changes (compared to resistance thermometers) ie ↑sensitivity
  - quick response time -
    - cos is small ∴ has small heat capacity
    - essential for use in CO measurement via thermal dilution technique
- disadv:
  - calibration may change if exposed to severe temp changes eg heat sterilised
  - hysteresis
  - ageing

Infrared Thermometers

- body gives off thermal electromagnetic radiation over range of wavelengths
- objects at body emit primarily infrared radiation
- intensity of radiation & wavelength depend on temp
- lens focuses infrared thermal radiation onto a detector
- detector is a concentrated area of many thermocouples. Called a thermopile
- detector converts radiant power to an electrical signal which can then be displayed in temp units
- needs to account for ambient temperatures
- used for tympanic & skin probes

ThermoCouples

- at a junction of 2 dissimilar metals ⟹ small voltage produced
- magnitude of voltage depends on temp at this junction

  ↳ = Seebeck effect
- junction = thermocouple
- use metals eg copper & constantin
- 2nd junction is needed as
  - reference junction AND

    - complete circuit
- reference junction needs to be kept at constant temp while other junction = temp probe
- adv:
    - measuring probe can be made in form of a needle
    - small heat capacity ∴ rapid response
    - calibration does not change even if couple needs to be replaced
    - accurate to 0.1C

Clinical Aspects of Temp Measurement

- core temp can be measured directly or indirectly at various sites:
    - pulmon artery (via PAC)
        - = gold standard
        - not practical unless PAC indicated
    - tympanic membrane:
        - accurate as is close to ICA
        - probe can damange TM
        - more suitable for single measurements
        - indirect infrared TM monitors are safer & used more frequently (lie approx 1cm from TM)
    - axillary - reflects core temp if placed close to axillary artery with arm adducted
    - nasopharynx:
        - reasonable reliable - close to ICA
        - easy to access
        - disadv:
            - bleeding - esp old or anticoag
            - inaccurate if exposed to airflow eg too deep & lying next to ETT/LMA
    - lower oesophageal:
        - ideally needs to be lower 1/3 to avoid false readings from gas flow in trachea
        - oesophageal stethoscope with integrated thermistor = sit behind LA, very accurate
    - rectal/bladder:
        - close to core temp but is a lag as organs are not well perfused
        - affected by faeces/rate of urine flow
        - bladder > rectal at reflecting core temp
    - skin:
        - useful in neonates - sensor on ant abdo wall
        - useful in detecting core:periph gradient
        - affected by
            - perfusion
            - hydration status
            - sweating

- indirect measurement of CO = simultaneous recording of periph & core temp:
    - ↓CO ⟹ compensatory ↑vasoC ⟹ ↑SVR ⟹ ↓periph temp ⟹ ↑core:periph gradient
      ↳ ∴ ↑core:periph gradient = ↓CO

Examples of Temps at Various Sites

Site	Temp c/f core	Problems
Buccal	0.2 – 0.4 below	
Nasopharyngeal	~ core	bleeding
Tympanic	~ core	perforation, wax / obstruction
Axilla	0.4-0.7 below	
Rectum	~ or > core	perforation, cultural, slow
Lower oesophagus	0.5 below	cooling by trachea if too high
Pulmonary artery	~ core	
Bladder	~ core	
Skin	< core	dependent on skin perfusion