Body Temperature, Hydration and Aging (F1038)

Daniel Richardson, Emeritus Professor of Physiology, Univ of Kentucky

1056 West Johnson Blvd
Tonto Village
Payson, AZ 85541
Email – danrichardson0510@gmail.com

Class dates: Tuesday Oct 15 and Thursday Oct 17: 10:00-11:30

Copy of full Presentation in web site “danielray.site”
File name: *body temp and water regulation.pdf*

The Arizona Republic, Sept 16, 2019

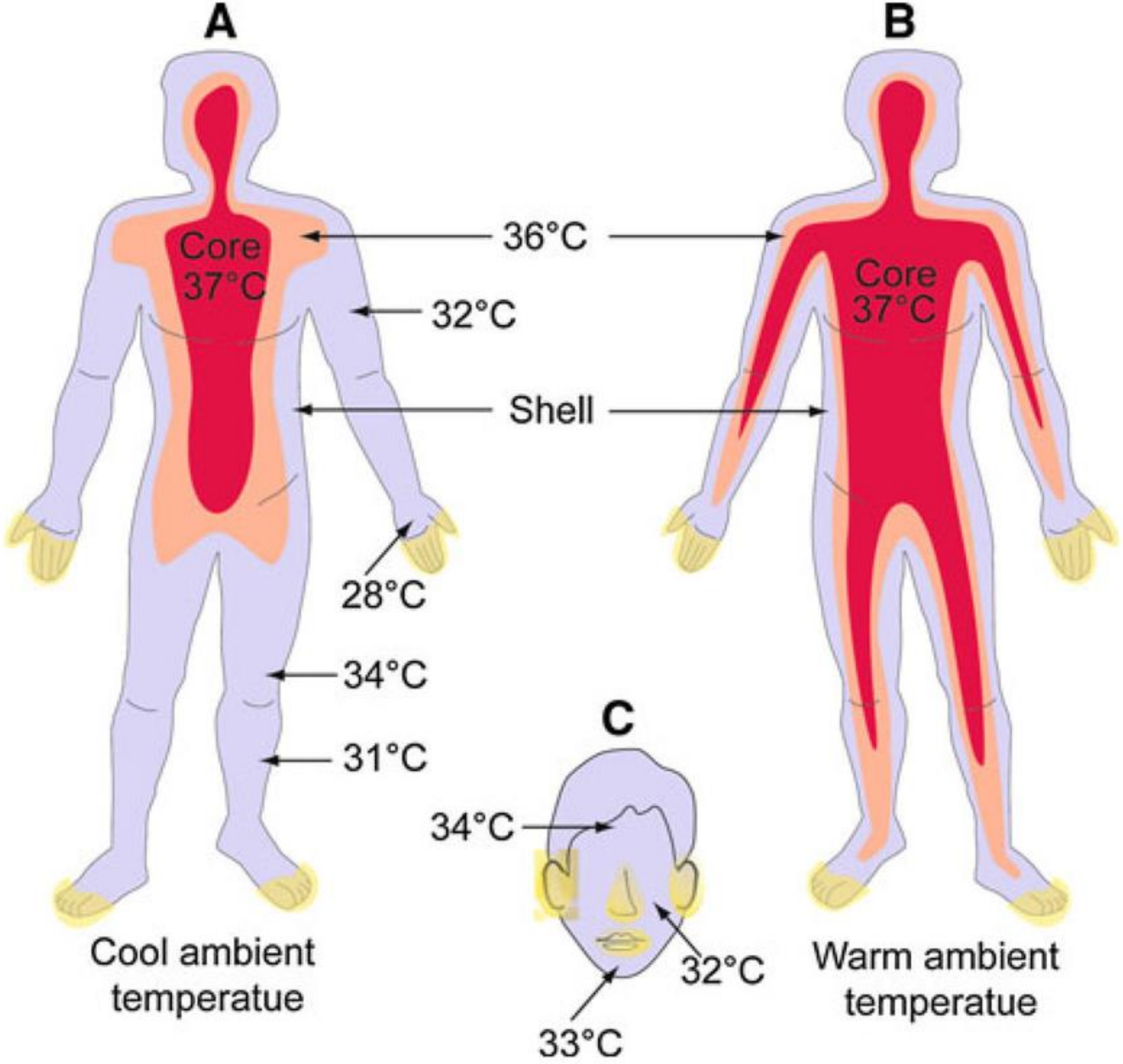
"Humans are much more adapt at battling the cold instead of the heat."

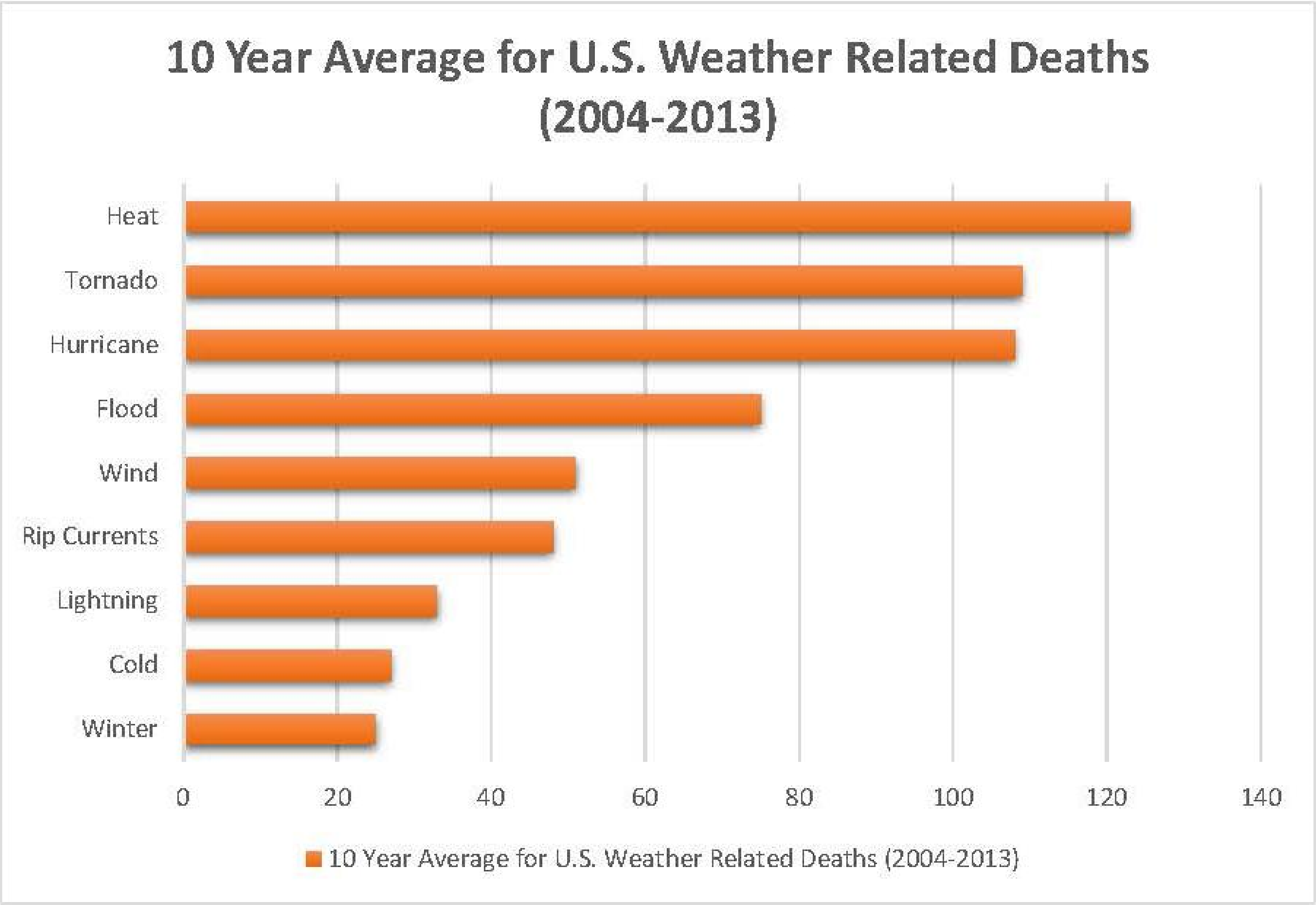
At a body temp of 98 deg F, are you more comfortable at:

123 deg F(25 deg above body temp)?

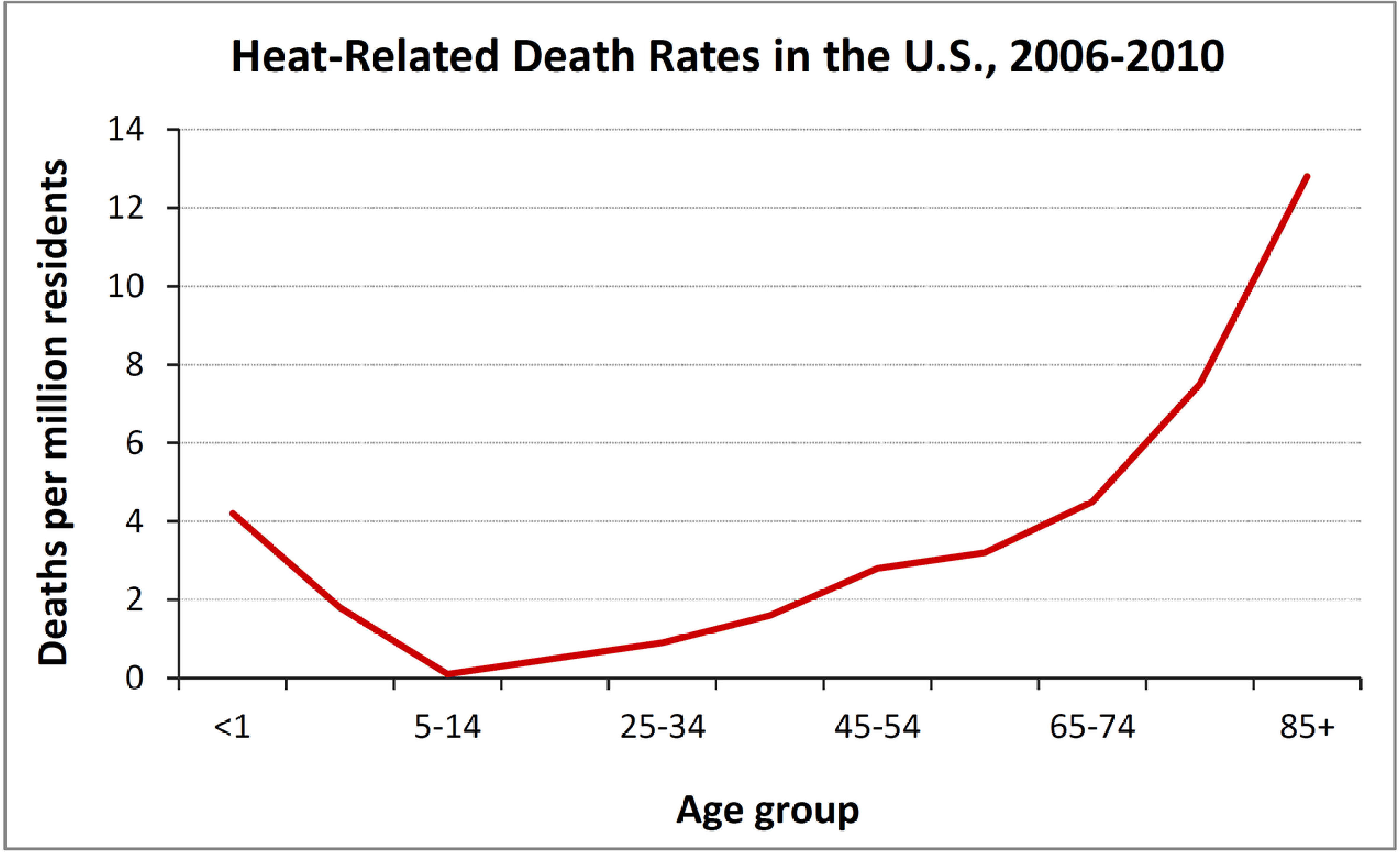
or

73 deg F (25 deg below body temp)?


A
B
C
Core
37°C
36°C
32°C
Shell
28°C
34°C
31°C
Core
37°C
34°C
32°C
33°C
Cool ambient temperatue
Warm ambient temperatue

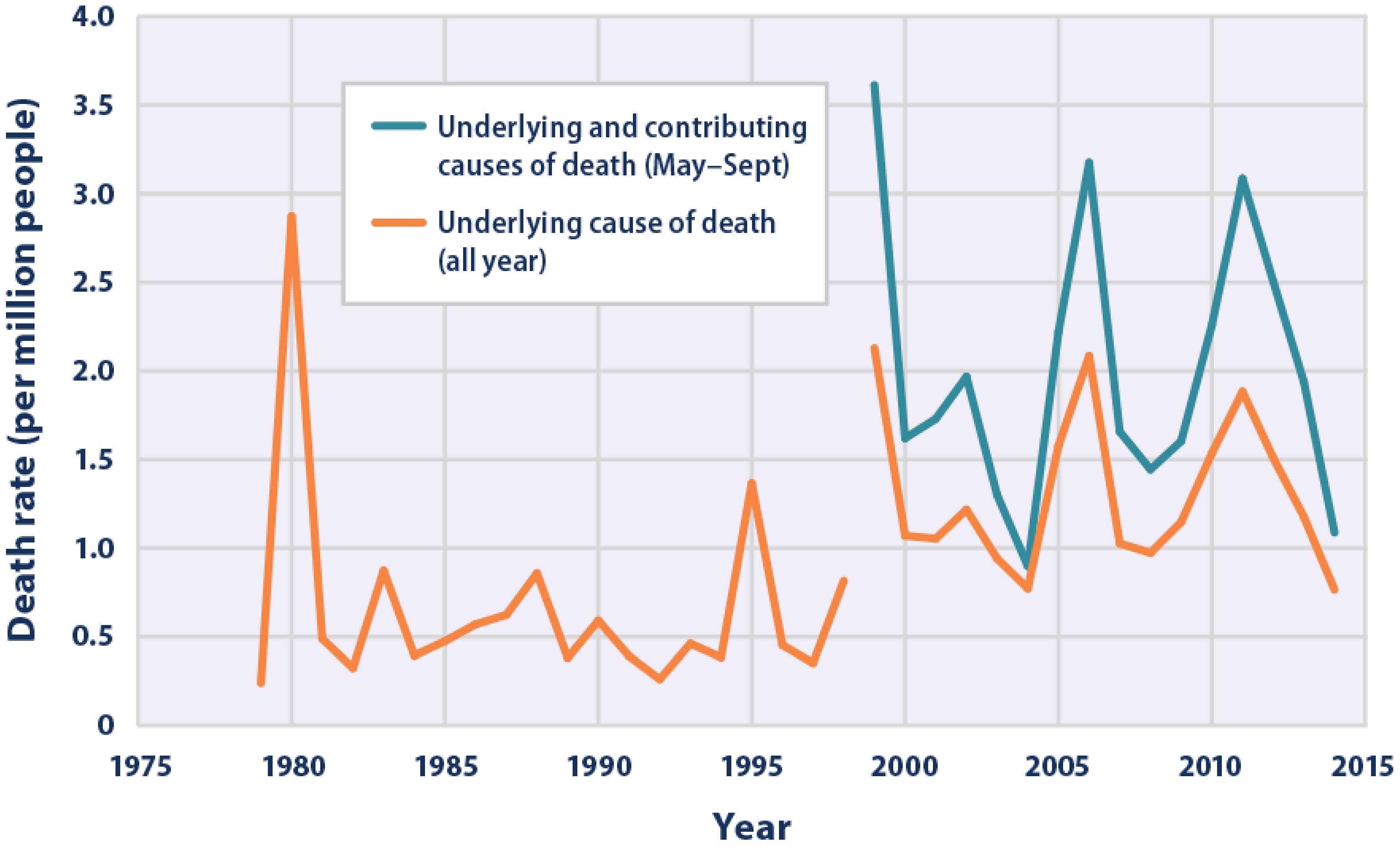


182 heat related deaths in the Phoenix metropolitan area in 2018.



Heat-Related Death Rates in the U.S., 2006-2010
Deaths per million residents
0
2
4
6
8
10
12
14
<1
5-14
25-34
45-54
65-74
85+
Age group

Heat related deaths in the United States

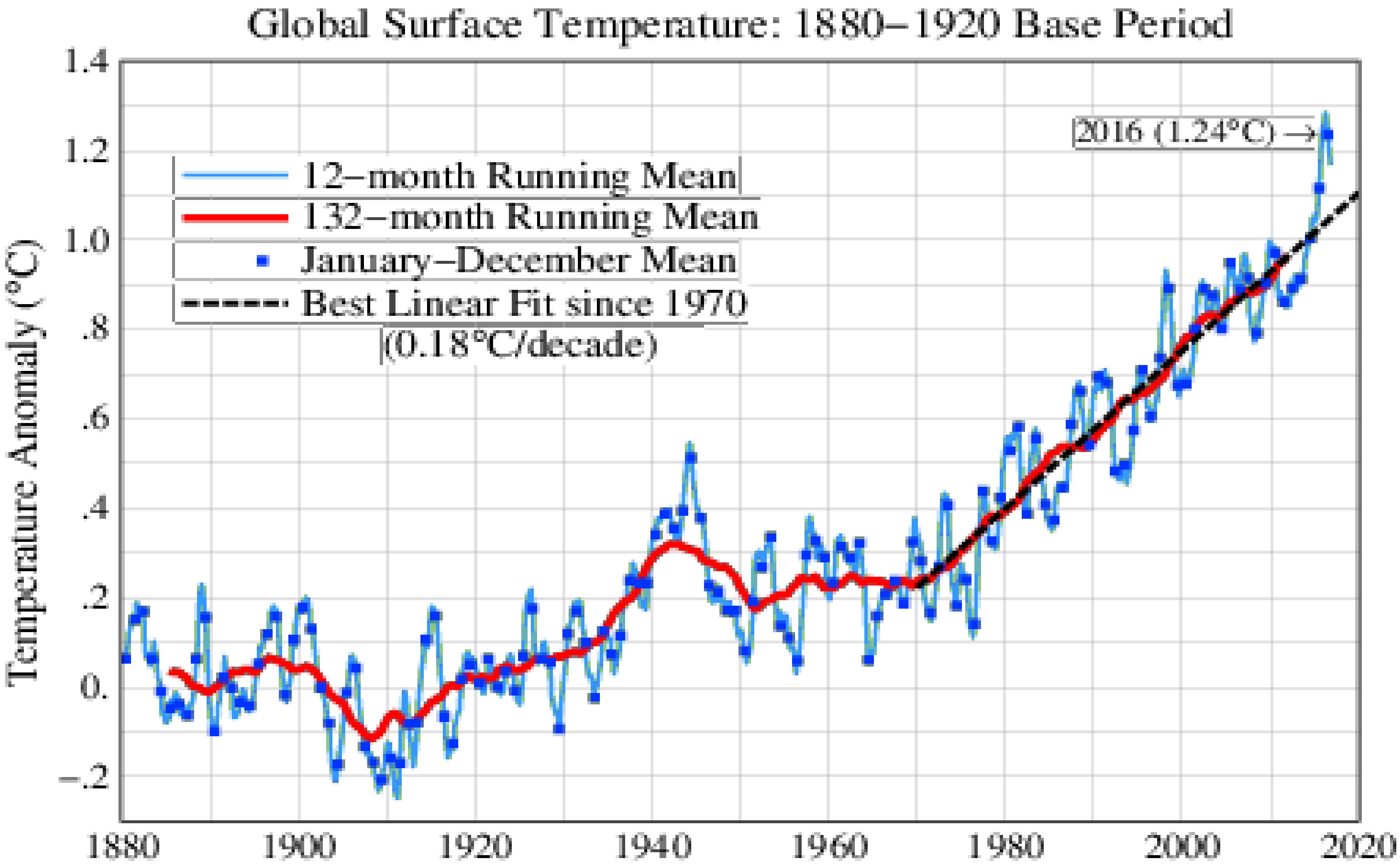


Heat-Associated Deaths by Year

Graph 1. There were 182 heat-associated deaths reported in 2018.

Data Sources: Maricopa County, Office of Vital Registration and Office of Medical Examiner; Arizona Department of Health Services, Office of Vital Registration

Anomaly = deviation from average over a given period of time.



The Regulation of Body Temperature

body metabolism $\longrightarrow$ heat production

heat production = heat loss (balance)

heat loss > heat production (hypothermia)

heat production > heat loss (hyperthermia)

Which of the following is the *best* answer?

Sweating occurs when:

The body needs to loose heat.

Sweat glands contract.

Heat exhaustion:

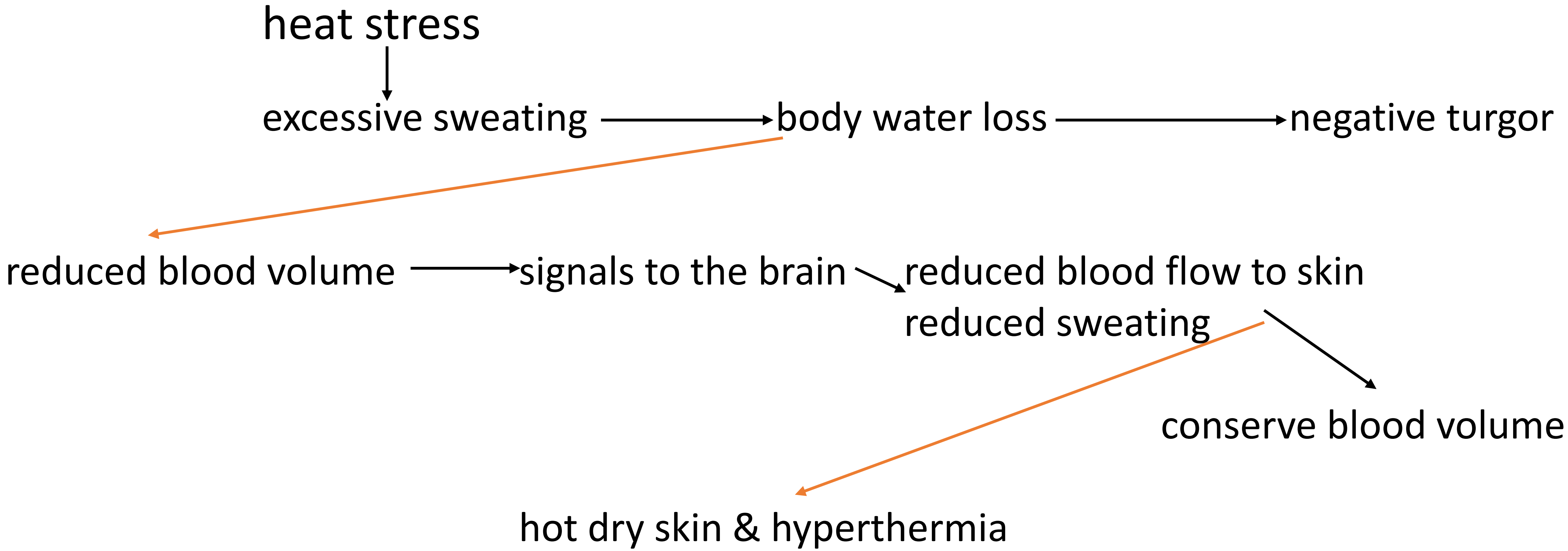
- Heavy sweating resulting in:
  - Cool moist (clammy) skin
  - Goose bumps
- Dizziness and fatigue
- Rapid pulse
- Headache
- Nausea

Heat stroke:

- Hot dry skin
- Severe hyperthermia (102-104)
- Dizziness and fatigue
- Rapid pulse
- Headache
- Nausea and vomiting
- Negative turgor test

Decreased (negative) turgor
a sign of dehydration

Scenario of heat stroke:



Modes of body temperature regulation:

Physiological

Totally maintains body temp in cool to warm environments

Behavioral + Physiological

Maintains body temp in cold and hot environments

Environmental temperature

Too cold | The Goldilocks zone | Too hot

Evolutionary adaptation in body temperature regulation

Desert Fox

Artic fox

Mechanisms of body temperature regulation

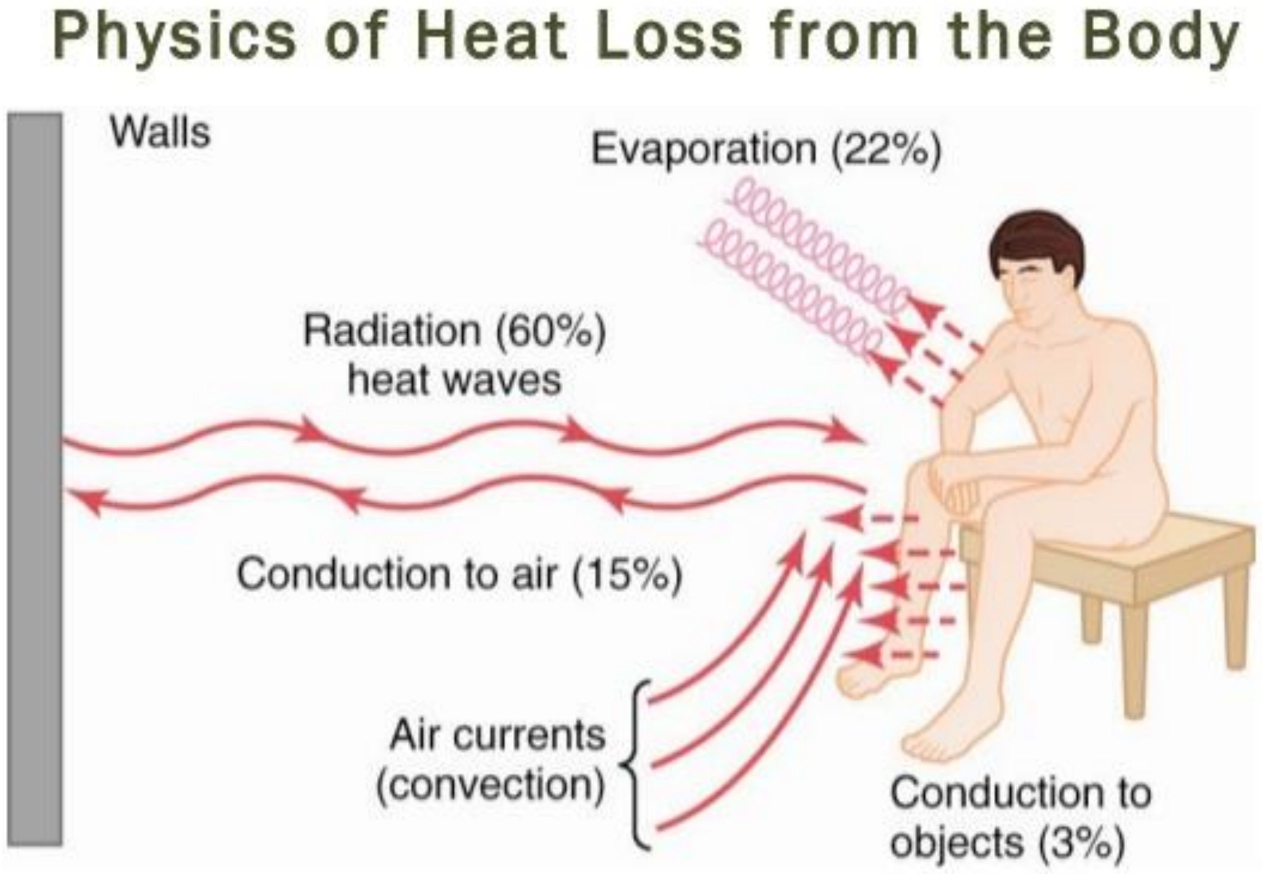
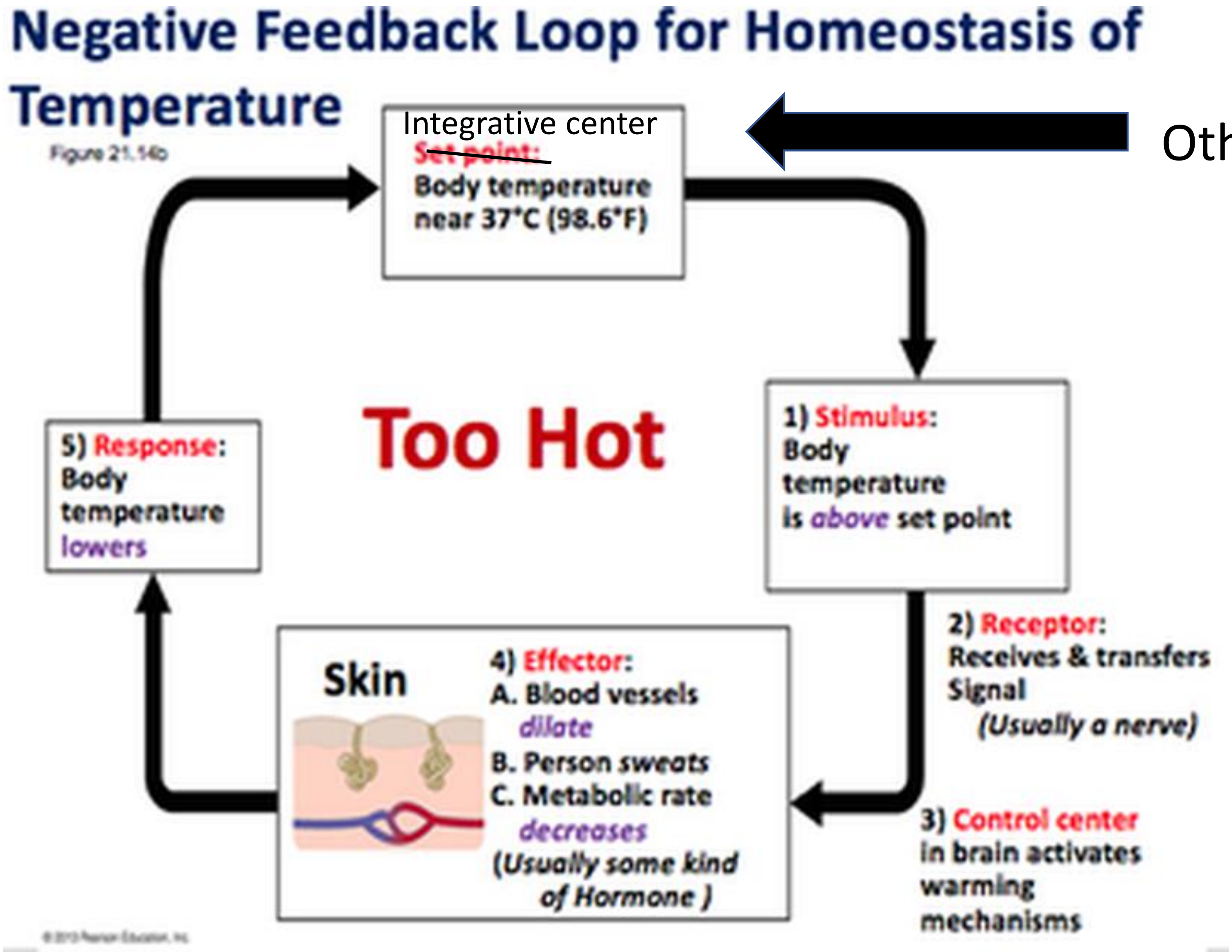


Figure 73-4; Guyton & Hall

Mechanisms of heat loss from the body

Humans sweat, dogs pant and cats lick their fur for evaporative cooling.

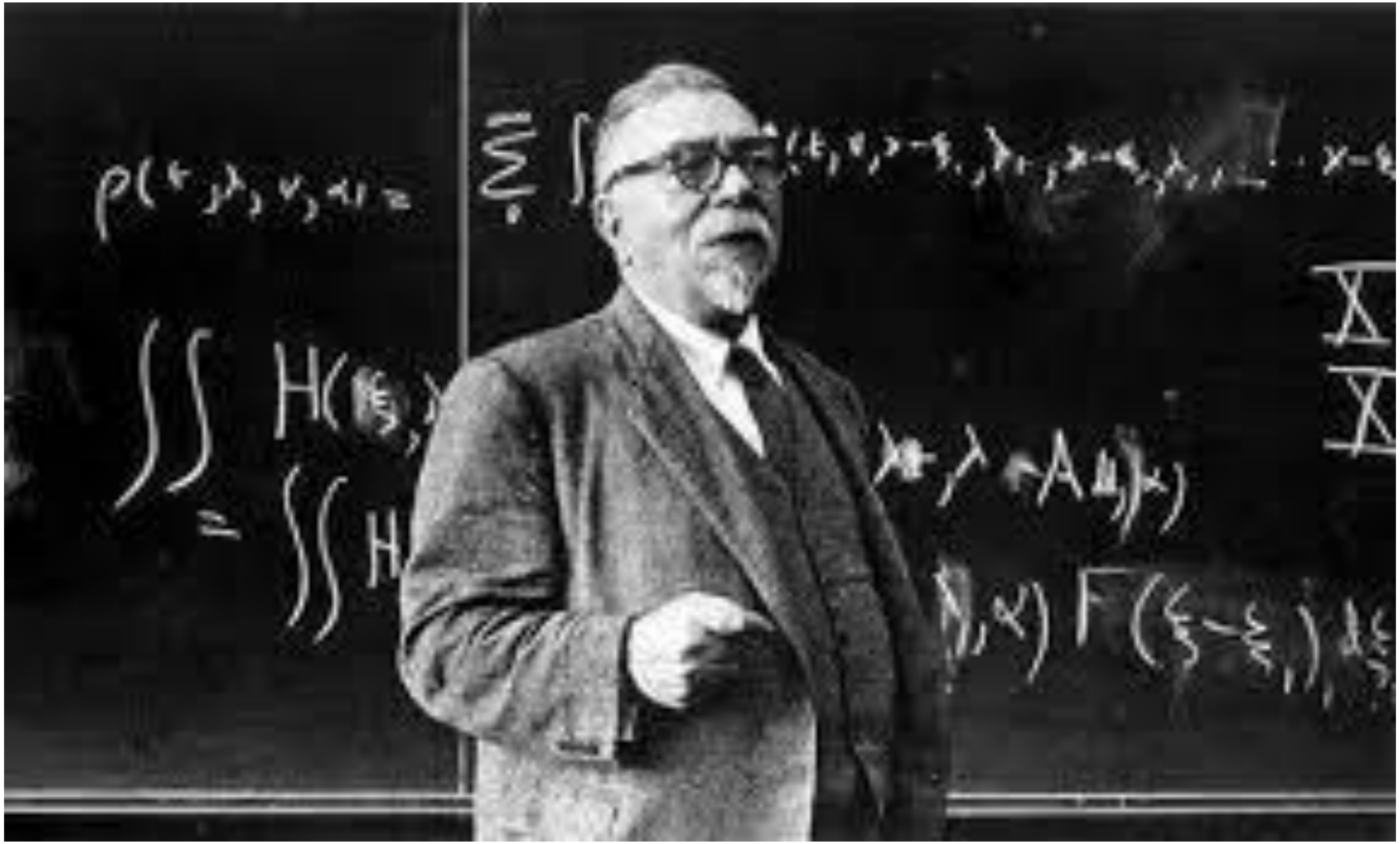
Physiological regulation



Other inputs

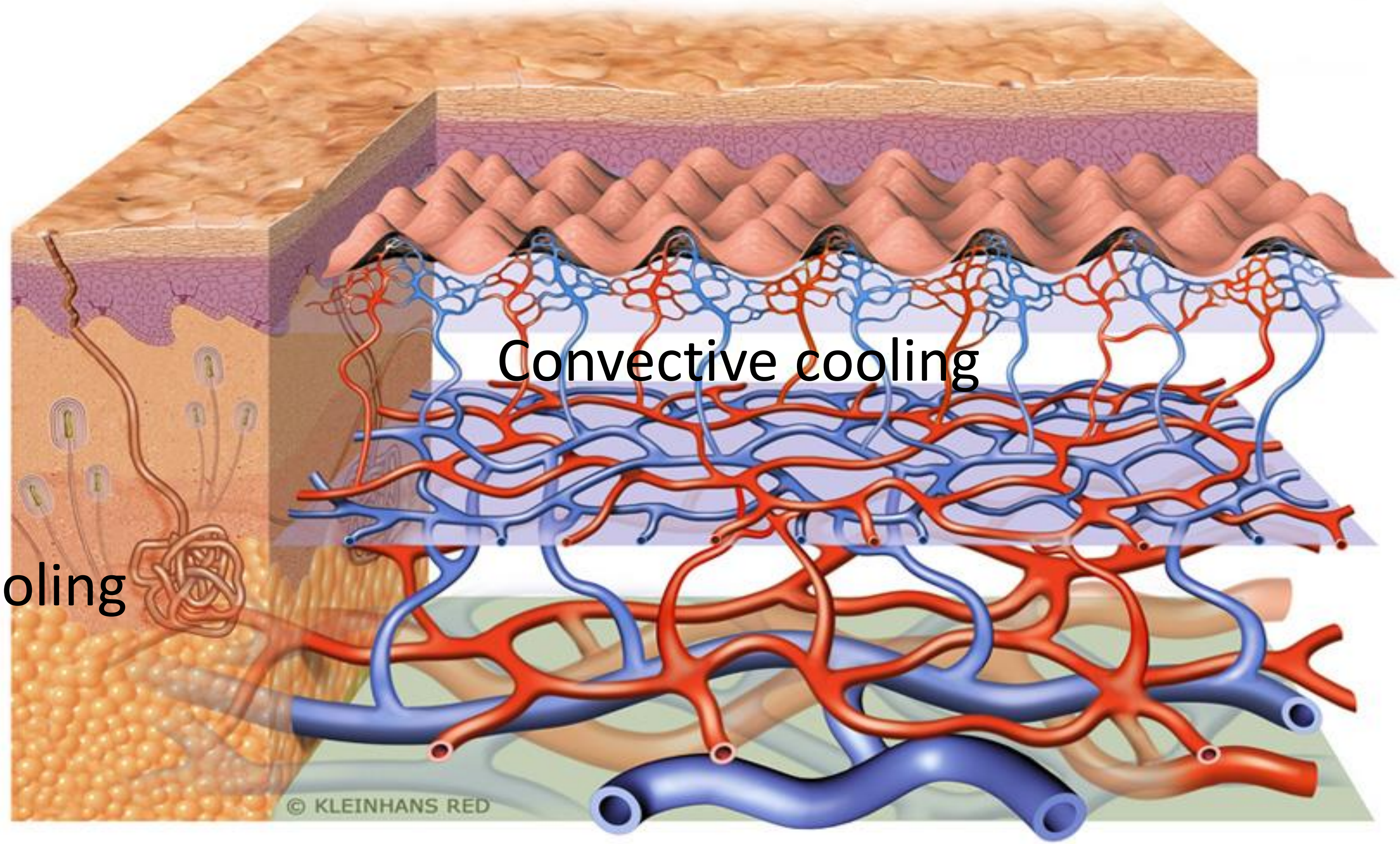
- Physical activity
- Blood chemistry
- Food intake
- Emotional state
- etc

Norbert Weiner, Professor of Math at MIT,
formalized concept of feedback control (circa 1940)

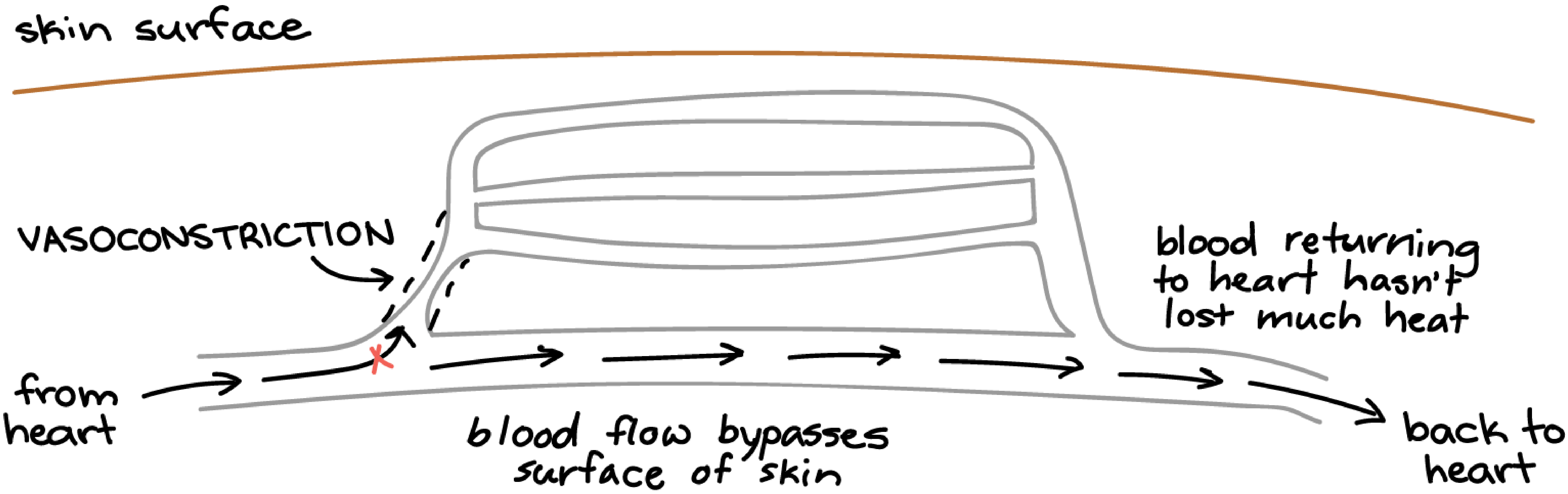


Walter Cannon, Professor of Physiology at Harvard,
applied feedback control to the regulation of physiological variables (circa 1942)

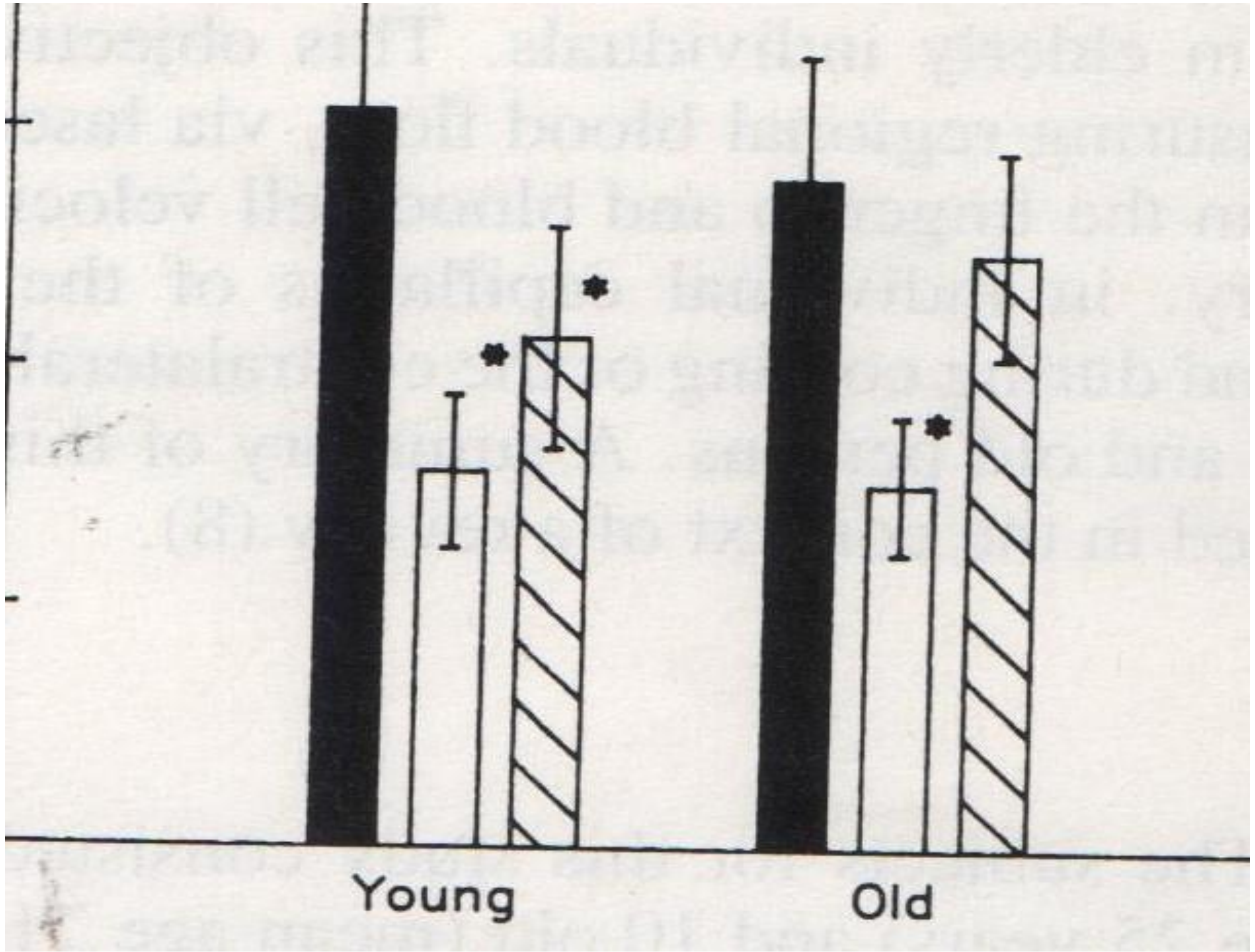
Heat exchange occurs across the skin



Temperature regulation in response to cold



Skin blood flow in the fingers of young (av 25 yr) and older (av 75 yr) subjects in response to cooling (15 deg C) of the opposite hand.

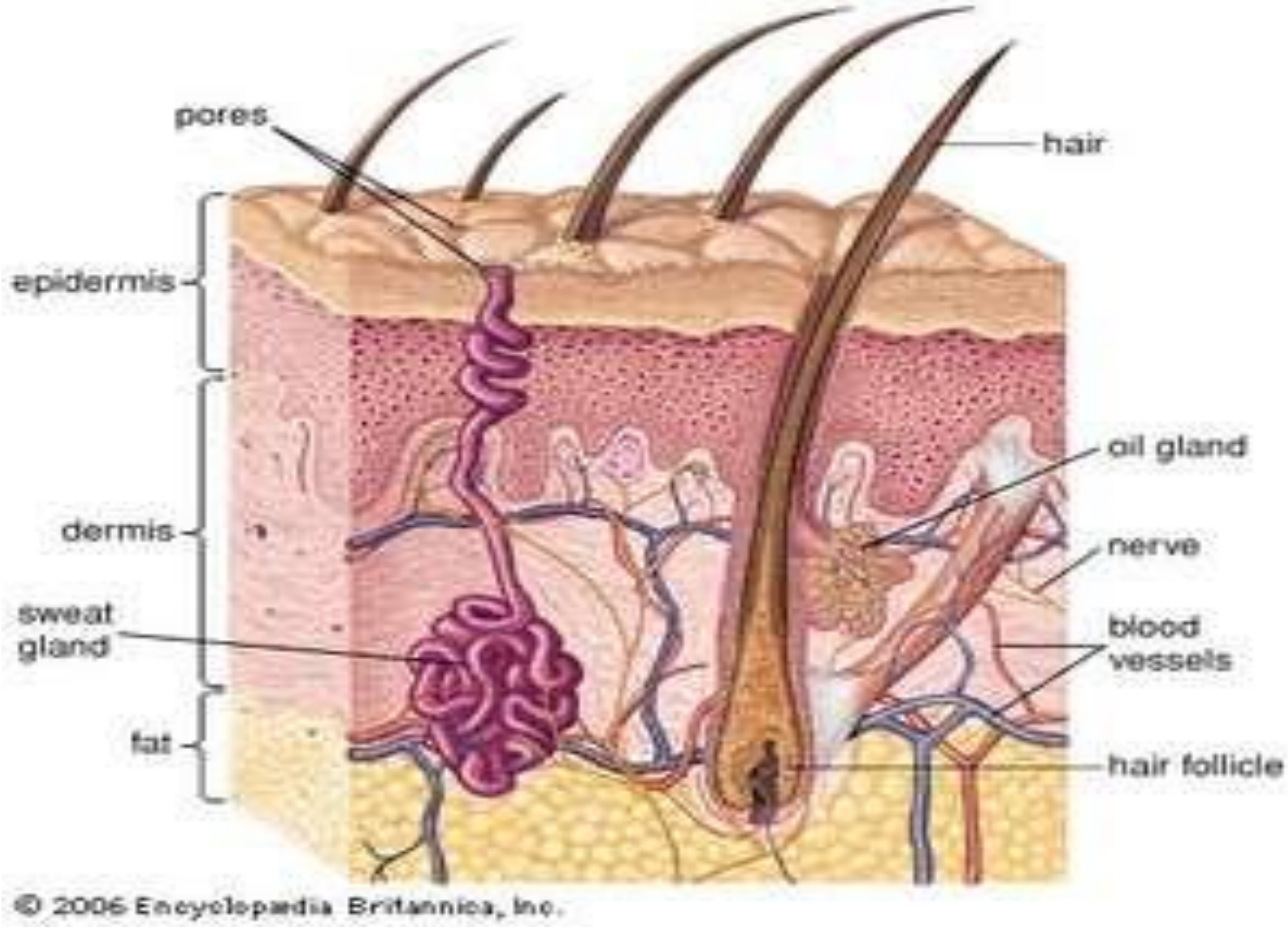


Solid bar = room temp control

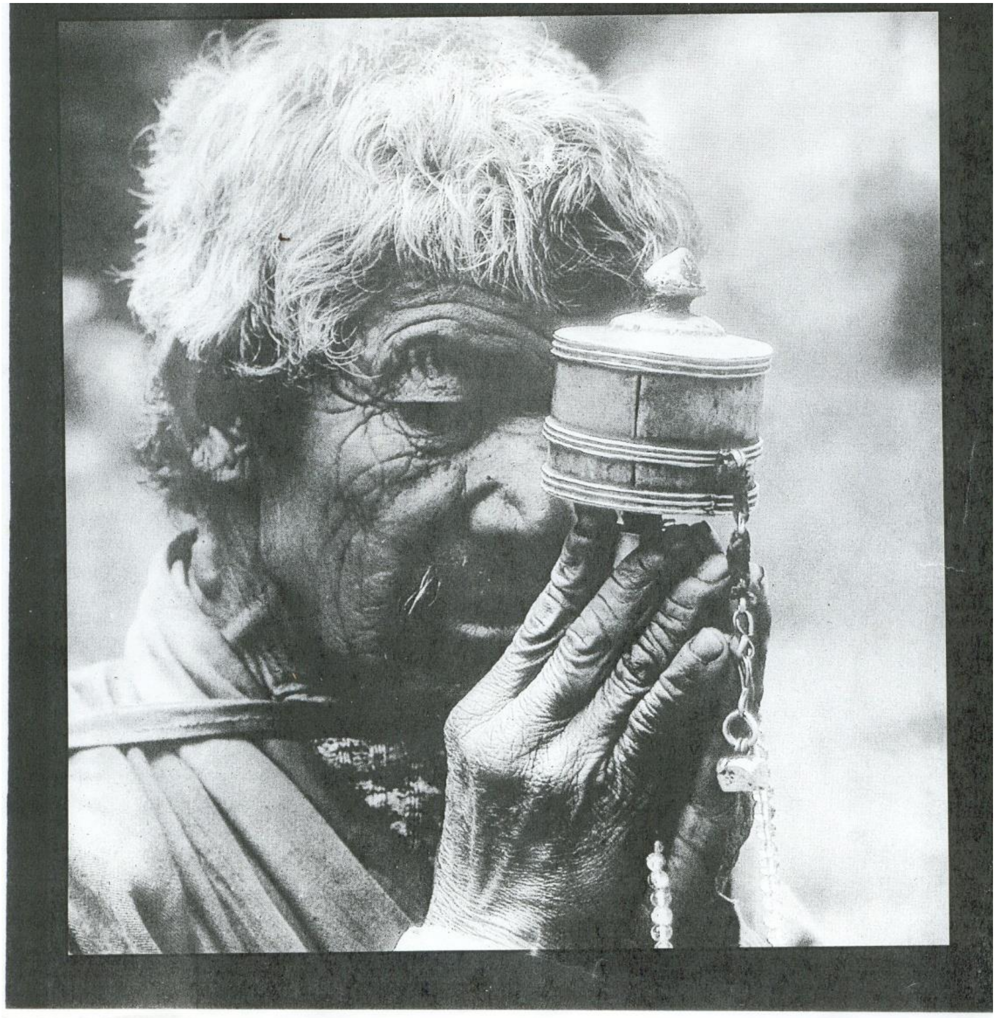
Open bar = 1 min of cooling

Hashed bar = 5 min of cooling

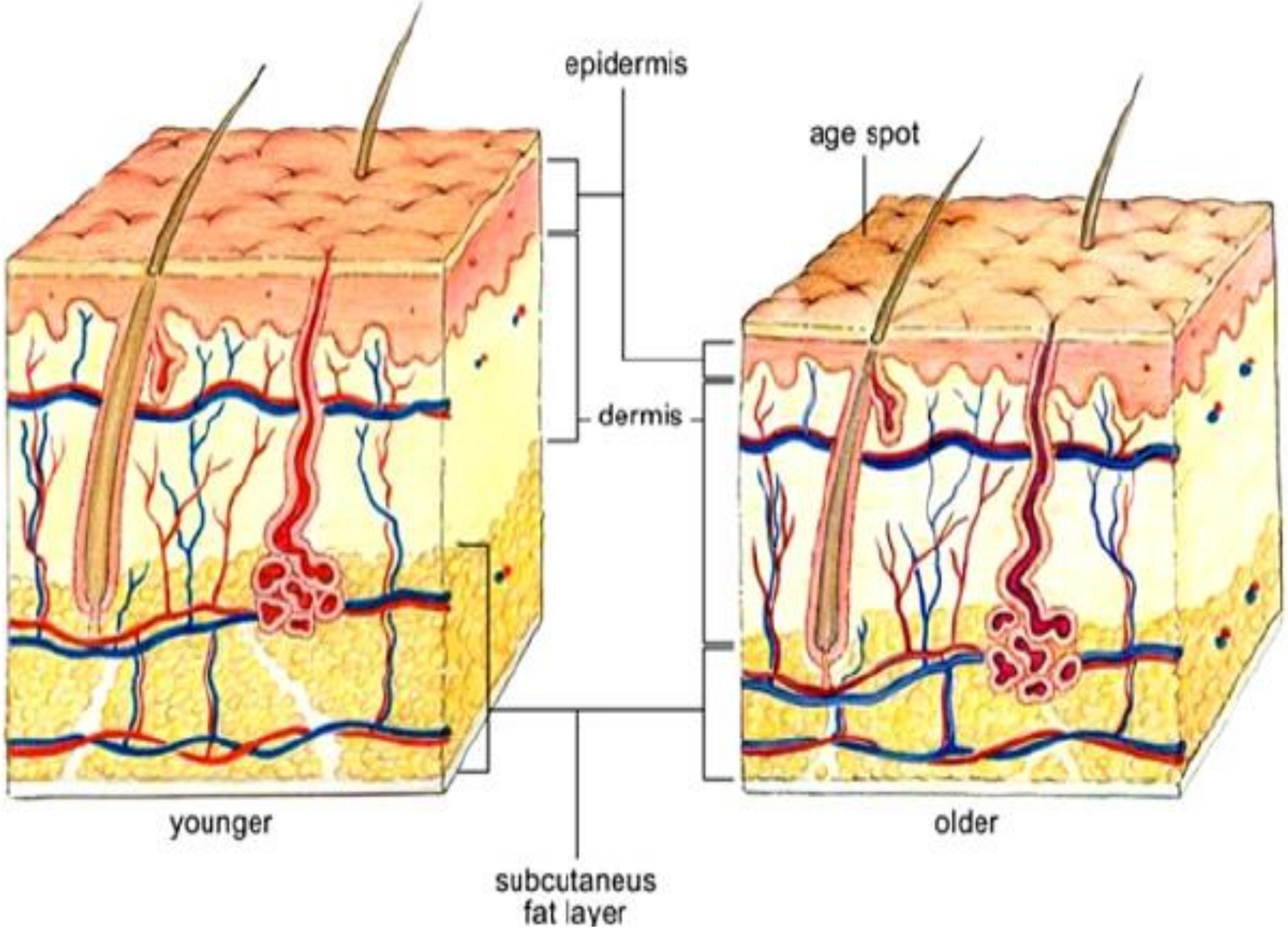
J. Gerontology, 47: M211-M214, 1992


pores
hair
epidermis
dermis
oil gland
nerve
sweat gland
blood vessels
fat
hair follicle
© 2006 Encyclopædia Britannica, Inc.

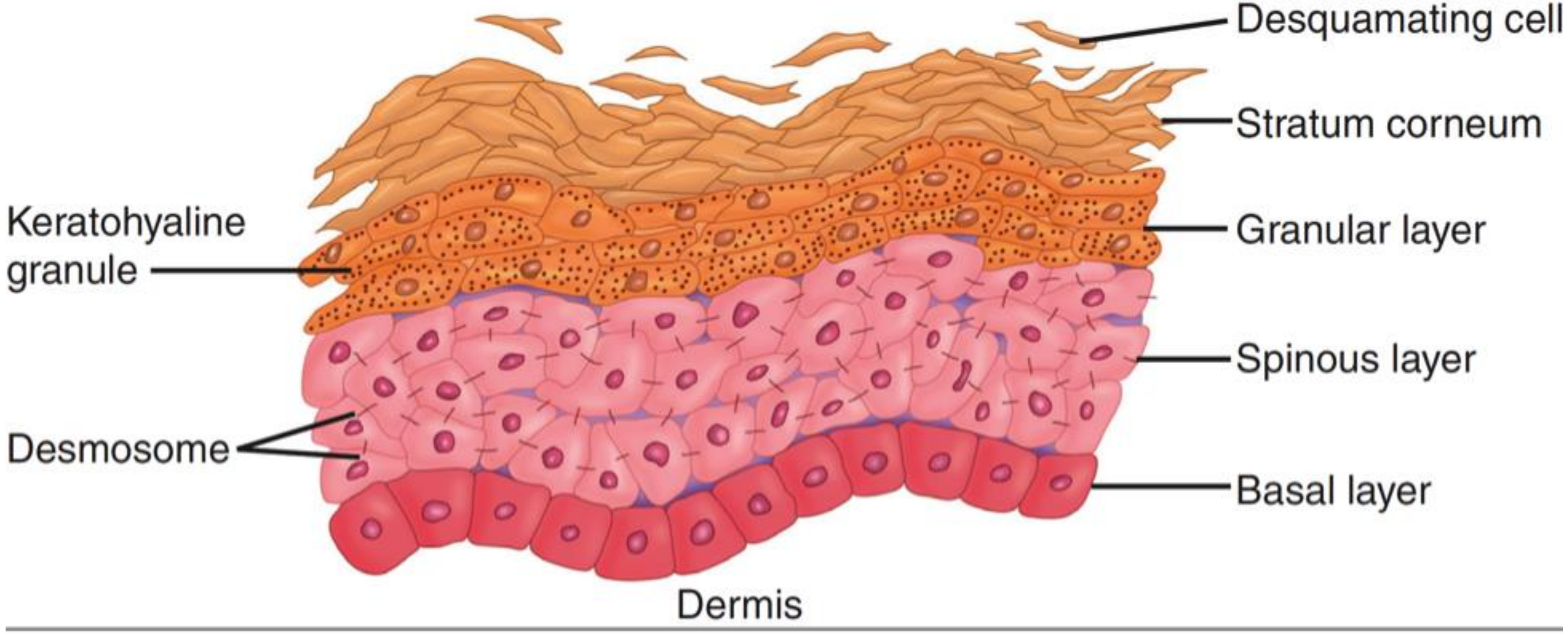
Aging of the skin is what is most associated with aging. However, nobody ever died of old skin! True, but --------



EFFECT OF AGING ON SKIN STRUCTURE



The epidermis of skin



Layers of the epidermis

Basal Cells – undergo cell division (mitosis)
    Blood supplied from subepidermal vascular plexus

Spinous layer – formed as basal cells migrate up
    Loose connection to blood supply
    Begin to loose mitotic activity
    Become loosely connected via desmosomes
    Start to produce keratin

Layers of the epidermis: Continued

Keratinocytes – full blown keratin producing cells

- Store provitamin D3
  - Converted to Vit D3 via UV rays
    - Conversion ability decreases with age
- Secrete thymopoietin
  - A hormone involved in formation of immune T cells
    - Decreases with age
      - Contributes to age related immune dysfunction

Cornified cells – dead keratinocytes

- Total loss of cell to cell connections
  - Upper most cells flake away: Process called exfoliation

Decrease in thickness of epidermis with age:
- Due to decrease in metabolism of basal cells
  - Results in decrease in epidermis turnover
    - *Exfoliation exceeds formation of new basal cells*

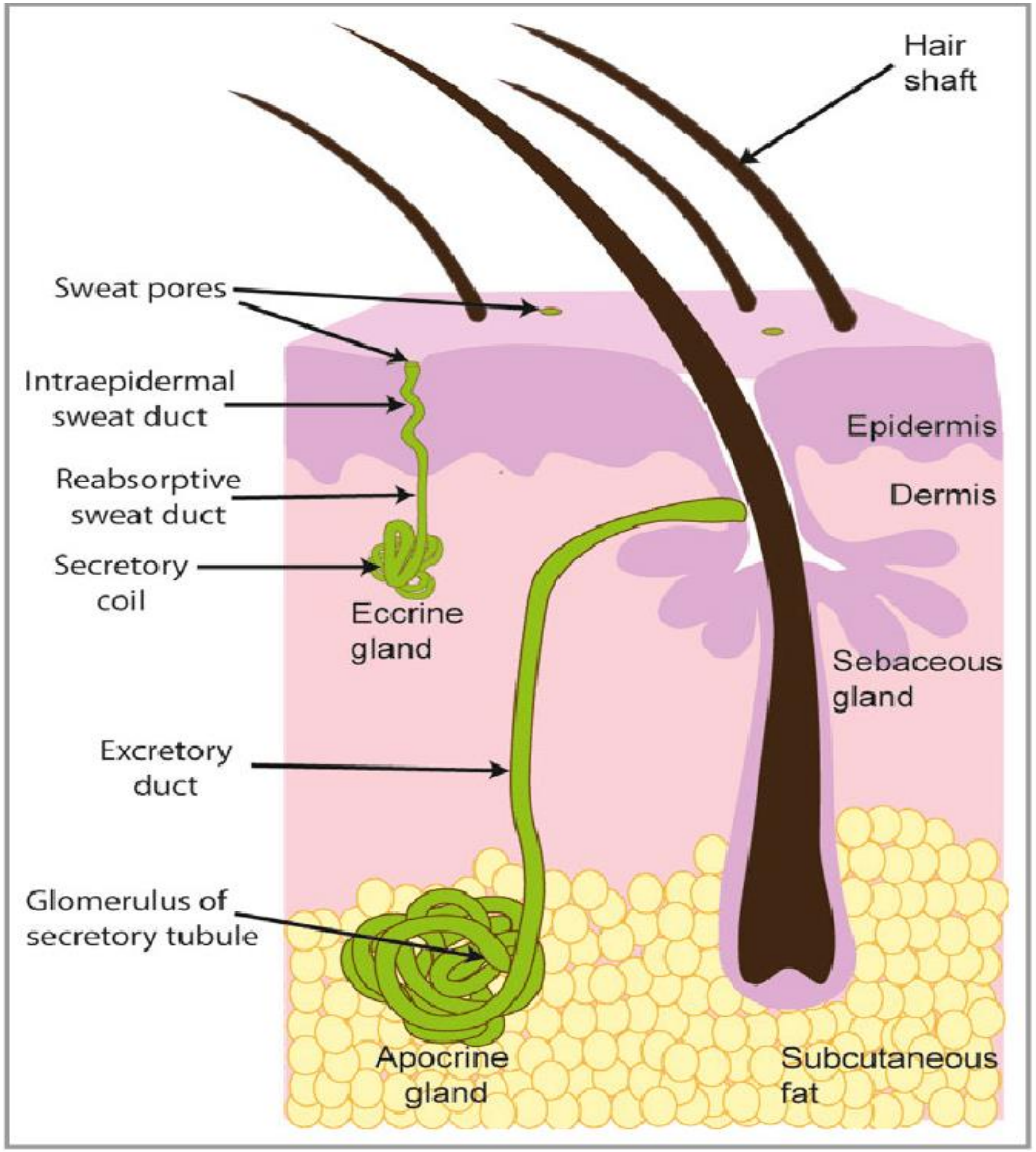
Thinning of the epidermis:
- Results in sub-epidermal blood vessels being closer to the surface
  - Assists in convective cooling in warm environments
  - Exacerbates heat loss in cold environments

Sweat glands

Humans have from 2 to 5 million sweat glands

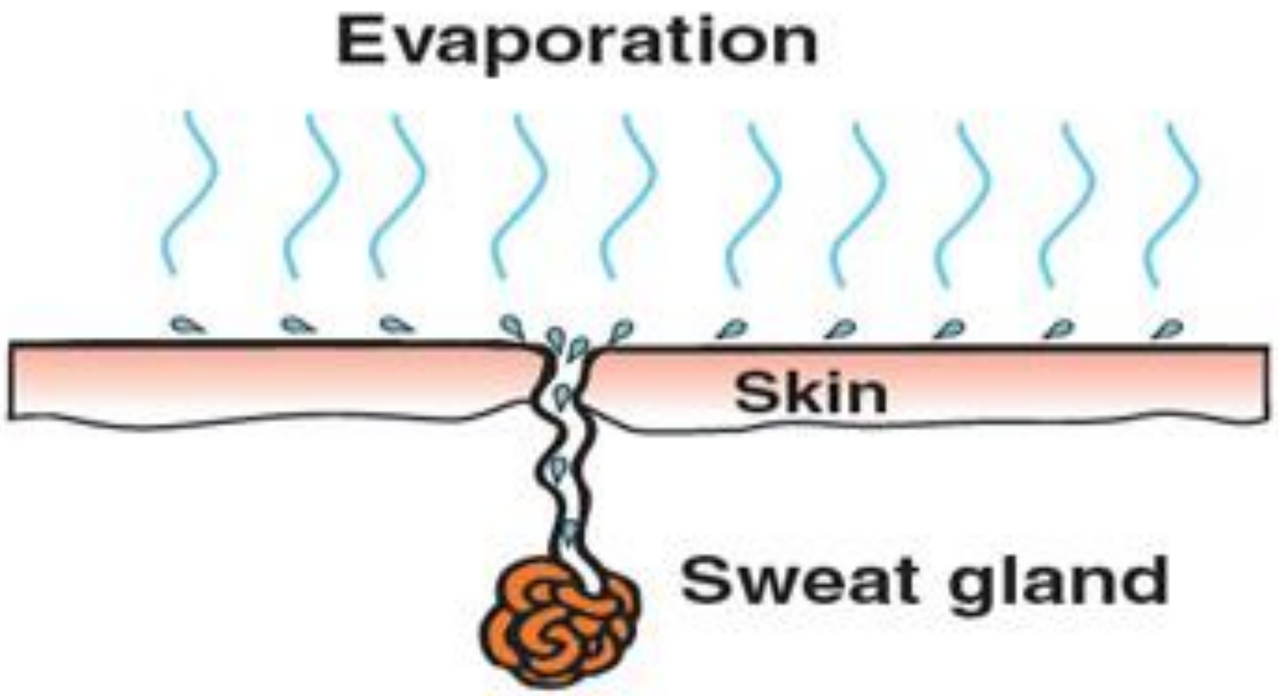
Eccrine glands are the vast majority
- Occur throughout the skin
  - most numerous in hands, feet & forehead
- Secrete a watery sweat
- *About a 15% loss with age*

Apocrine glands occur in arm pits and genital regions
- Secrete an oily sweat in response to:
  - Heat and/or emotional stress
    - Broken down by bacteria
      - Produce a musty odor



Evaporative heat loss (sweating)

REMEMBER, sweat that drips off your body can't keep you cool. Sweat has to evaporate from your skin to cool you off.



How sweating works to take away body heat:

Sweat glands secrete water onto surface of the skin

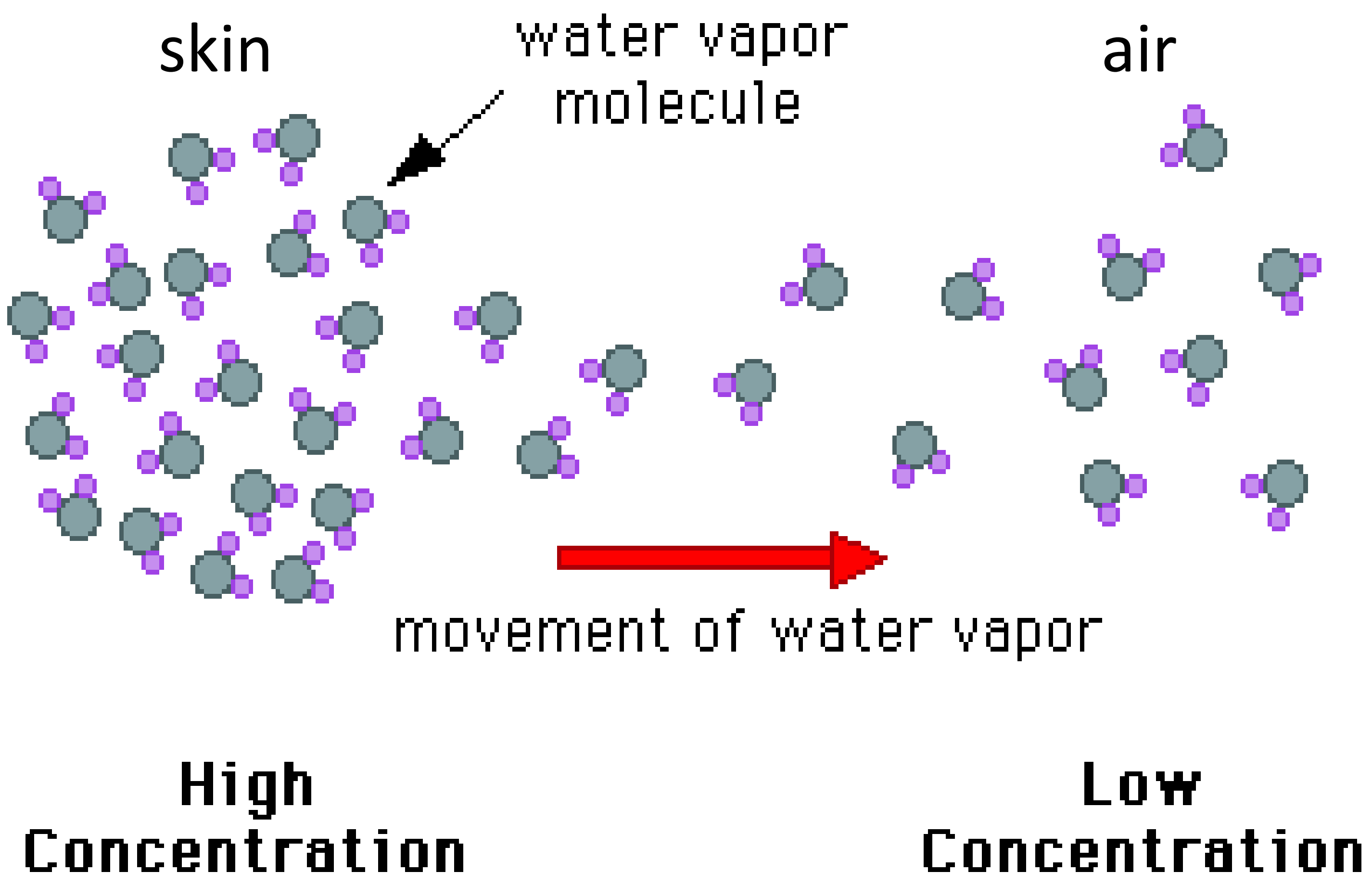
The water then draws heat from blood near surface of the skin

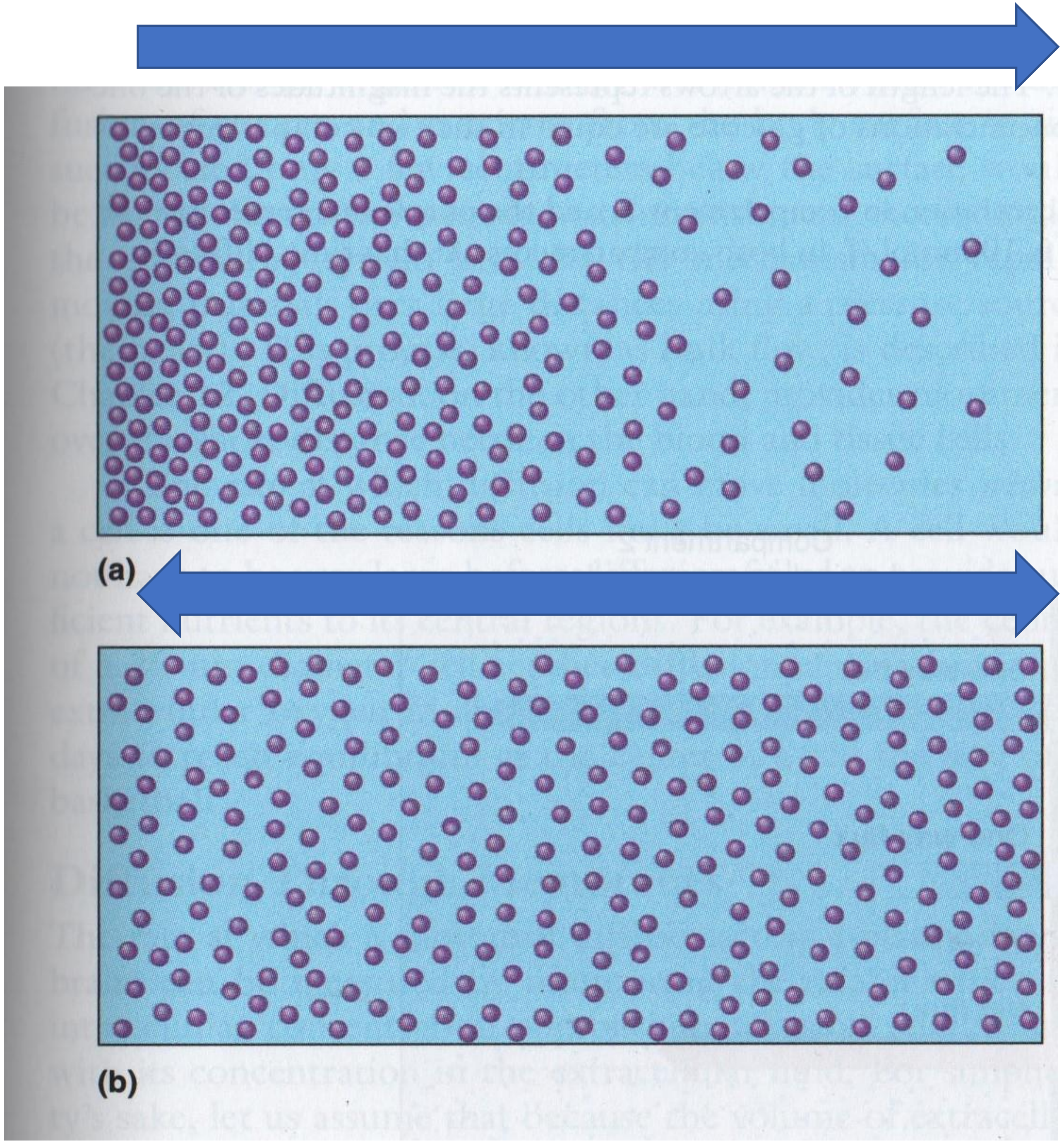
Causes the water to evaporate

Displaces heat from the body to the environment

The evaporation of sweat is inhibited by high humidity

Diffusion of Water Vapor

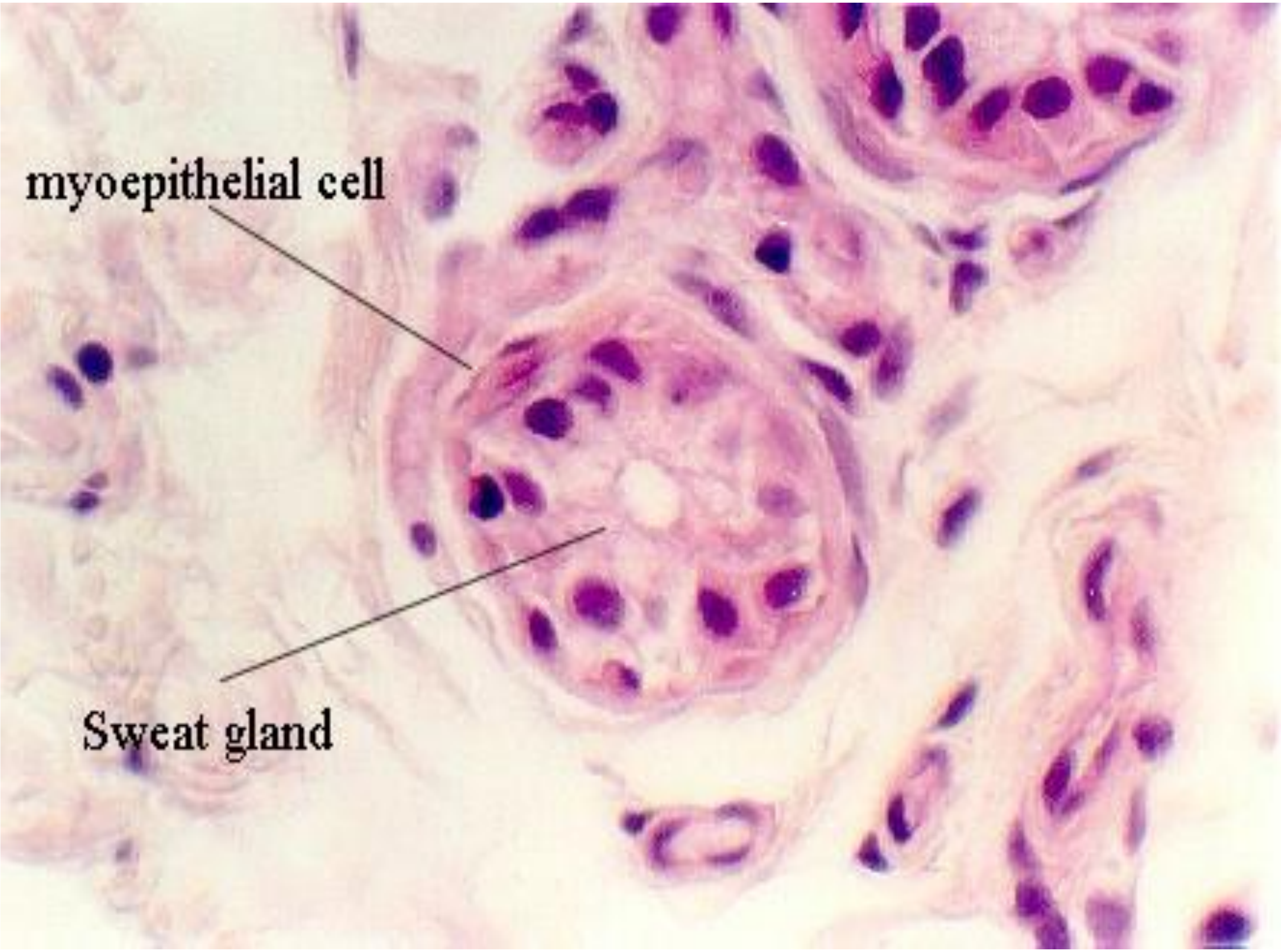



(a)
(b)

Evaporation is assisted by wind currents (convective cooling)

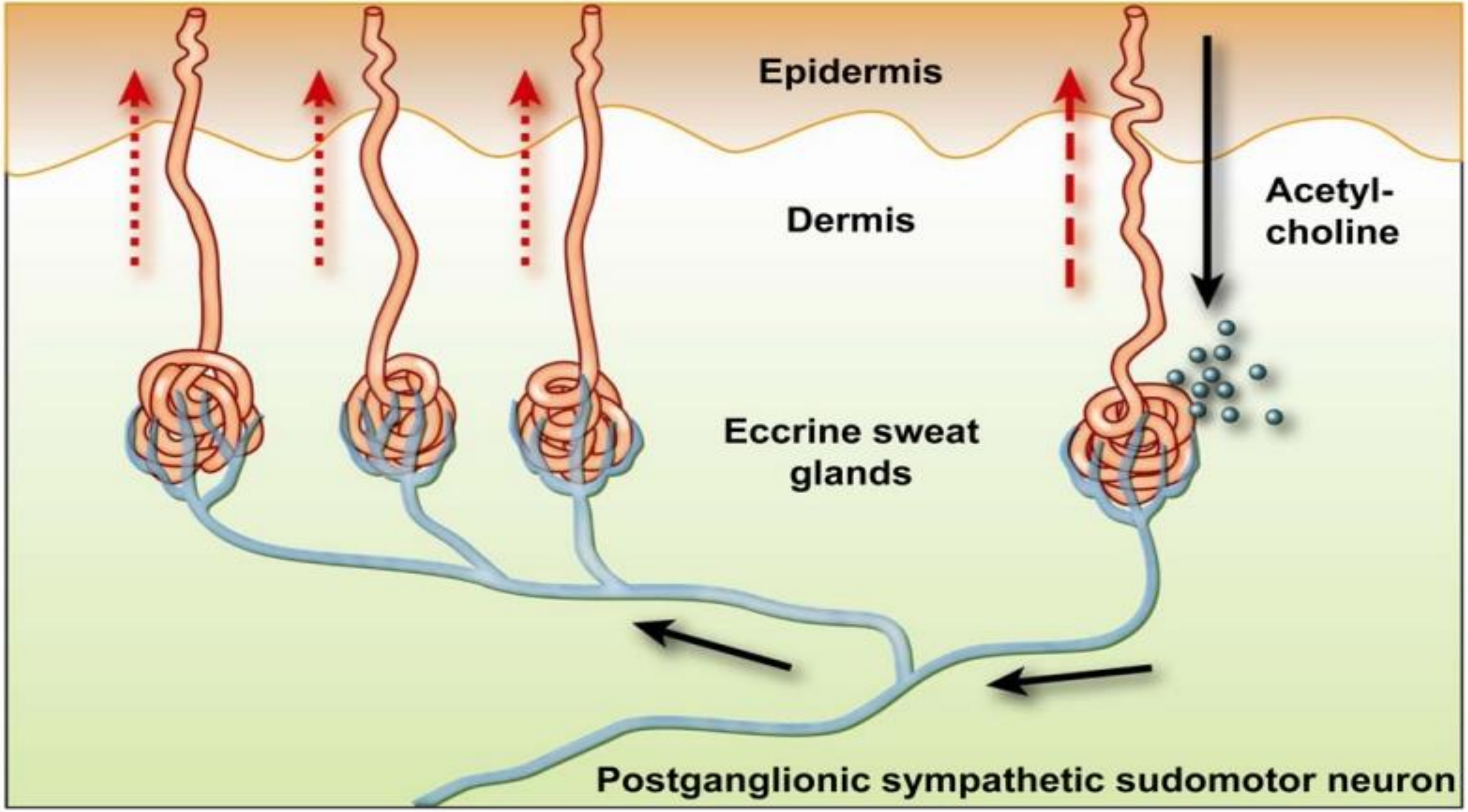
more rapid removal of water vapor from surface of skin

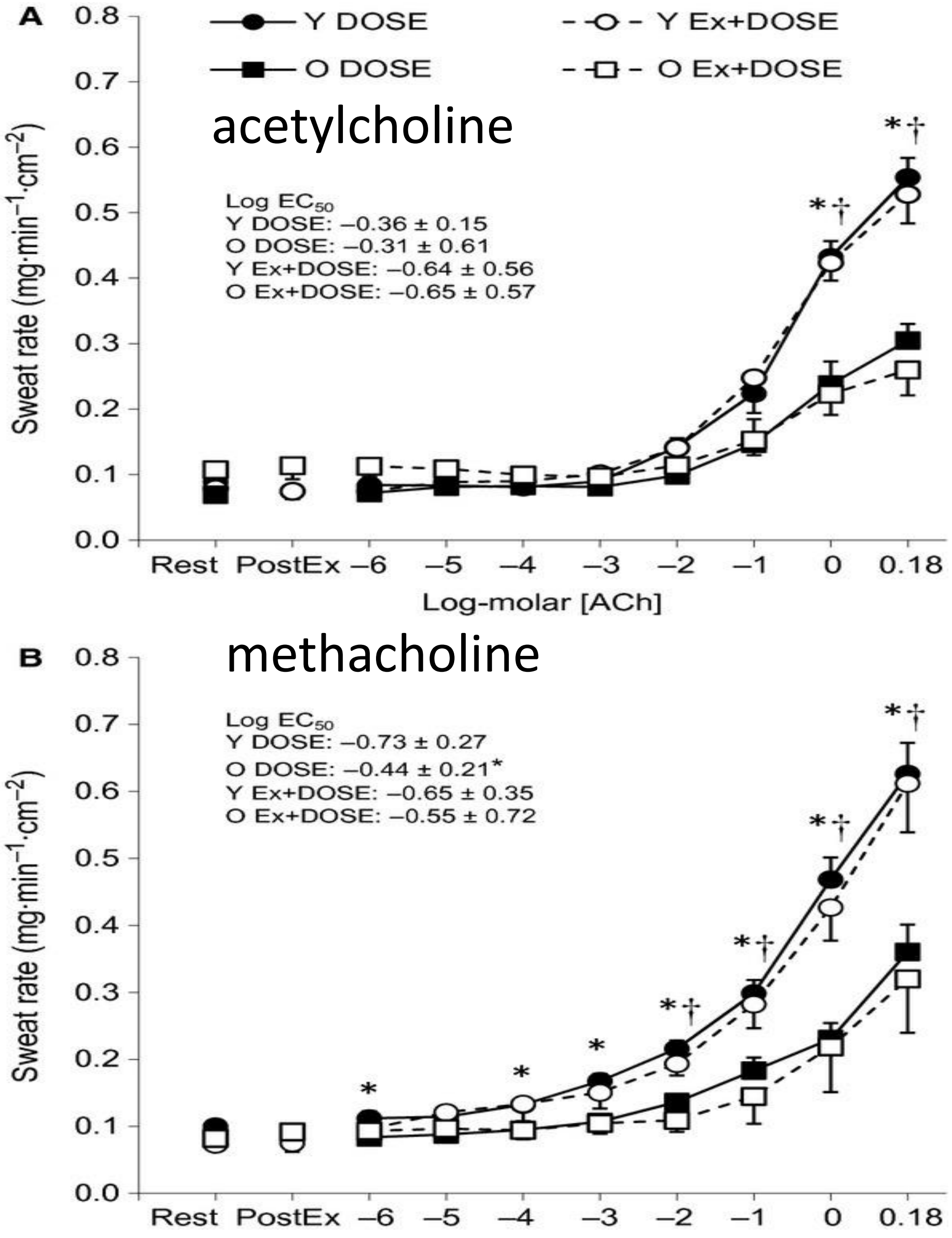
Contraction of myoepithelial cells on sweat glands elicits sweating



Sudomotor neurons elicit contraction of myoepithelial cells on sweat glands

heat stress ⟶ body temperature ⟶ brain ⟶ sudomotor neurons





Log-molar MCh

Physiological Reports, July 2, 2014

Y = 19-25 yr old men
O = 62-68 yr old men

Ex = dose given after 30 min exercise

Contributors to a lower sweat gland response with age:

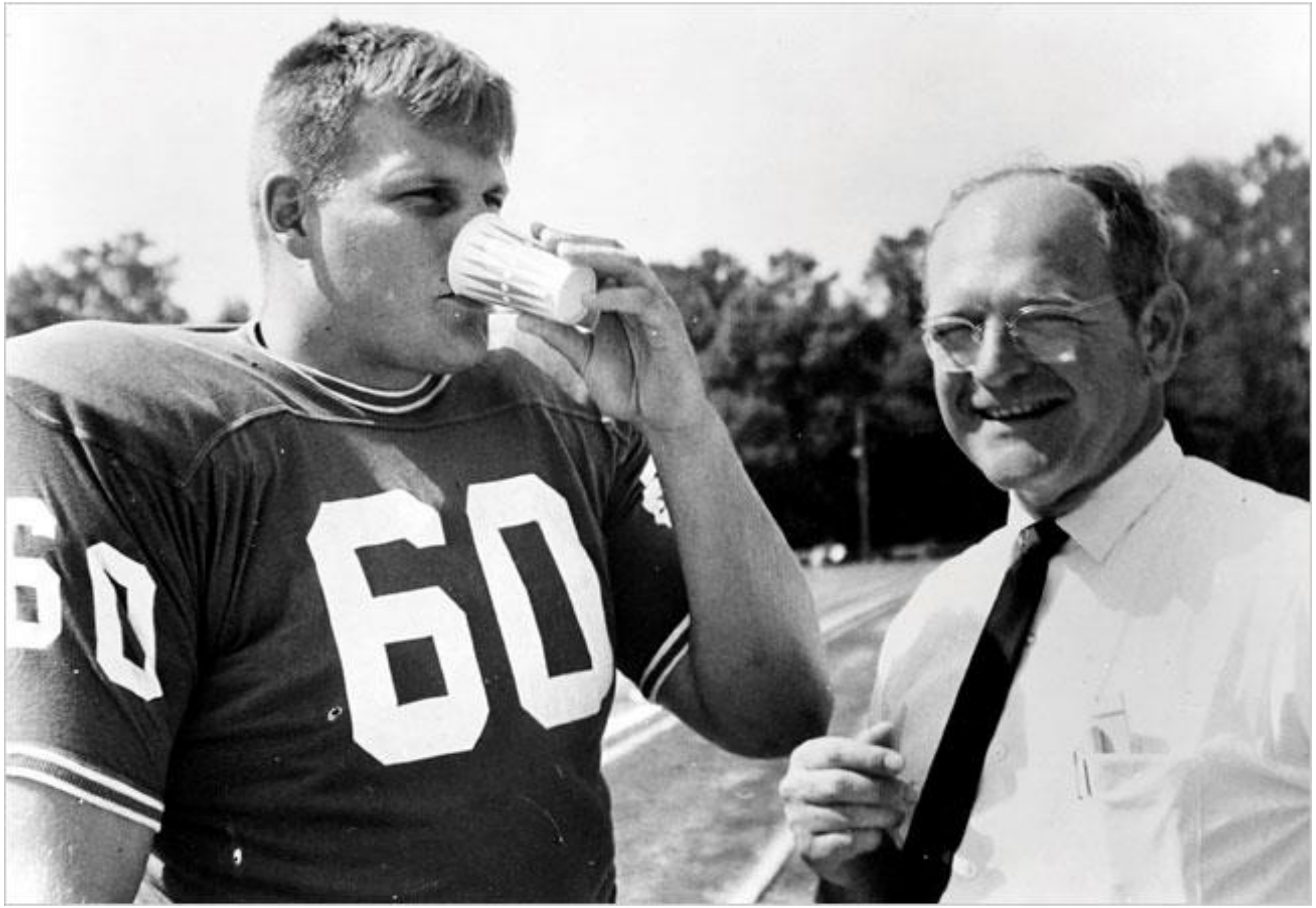
- Decreased number of eccrine glands
- Decrease in response of eccrine glands to stimulation
- Lower total body water
- Lower blood volume

Blood plasma concentration

Mg^{++} 2.0 mEq/L
Ca^{++} 2.0
K^{+} 4.0
Na^{+} 140.0

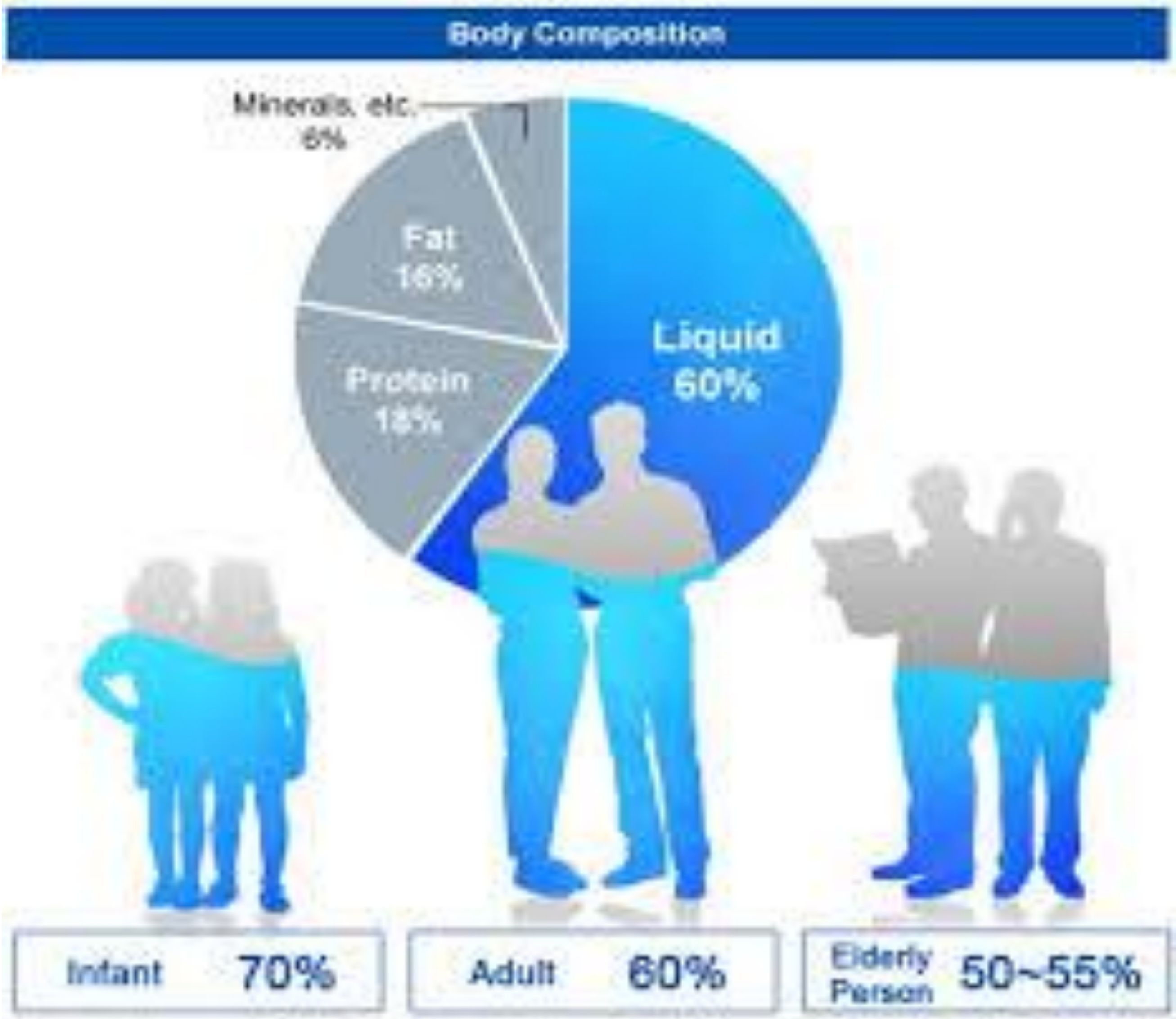
mEq = milliequivalence = (milligram/molecular wt) X # + or - charges

Robert Cade, Professor of nephrology, University of Florida (circa 1965)




Gatorade

Body water decreases with age



Contributors to lower body water with age

Medical

Anatomical

Behavioral

Physiological

Medical

Increased use of diuretics for BP control

Anatomical

As we age our percent body fat increases while percent muscle tissue decreases:

Fat holds less water than muscle:

Accordingly, percent body water decreases with age.

Behavioral

- Less water consumption
  - Reduced sensation of thirst (behavioral/physiological)
  - Desire to reduce daily urine volume
    - urinary incontinence
    - difficulty in toiletry
  - Social isolation

- Reduced food intake
  - Lower body metabolism (behavioral/physiological)
  - Social isolation

Physiological

Reduced blood volume

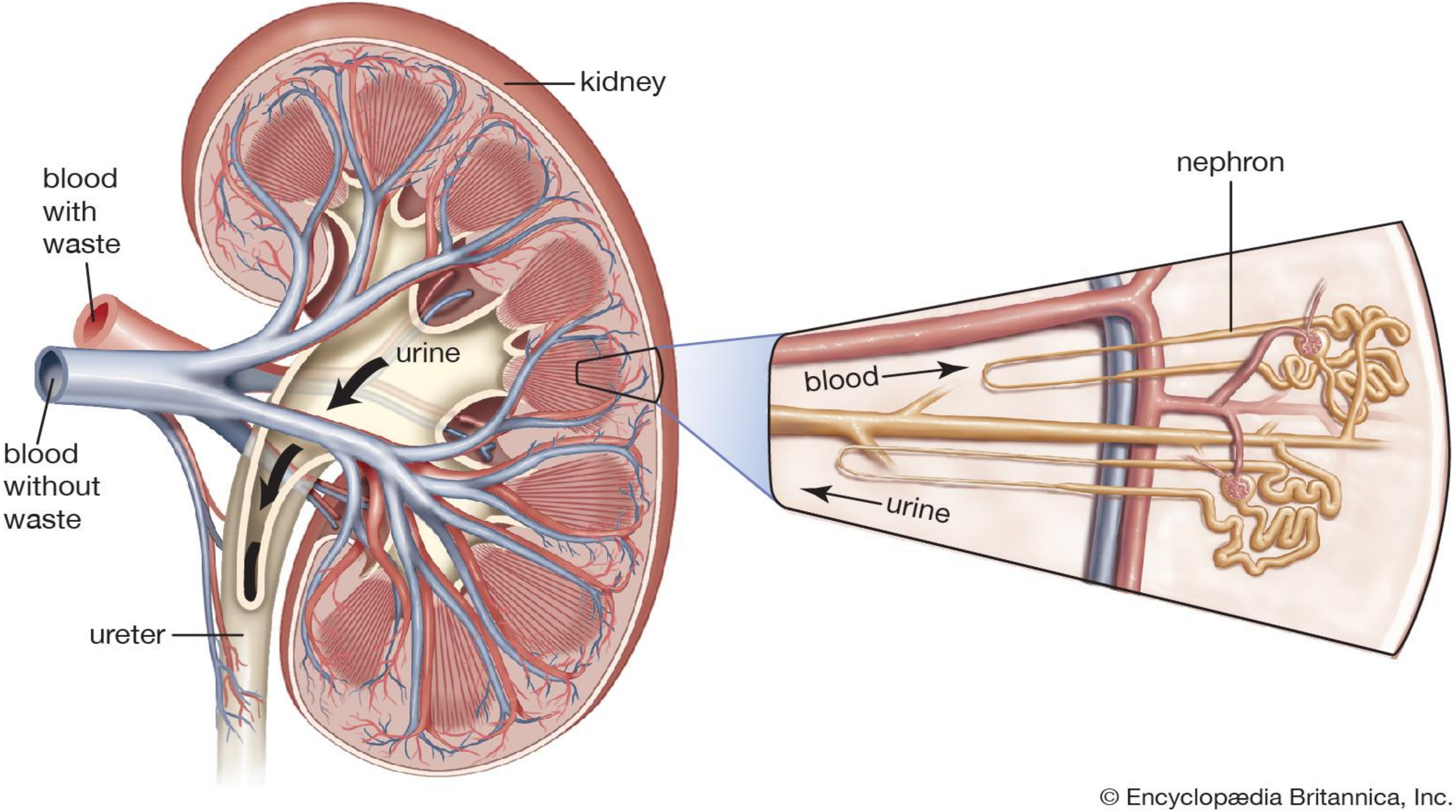
    21% lower plasma volume*

    28% lower red blood cell volume*

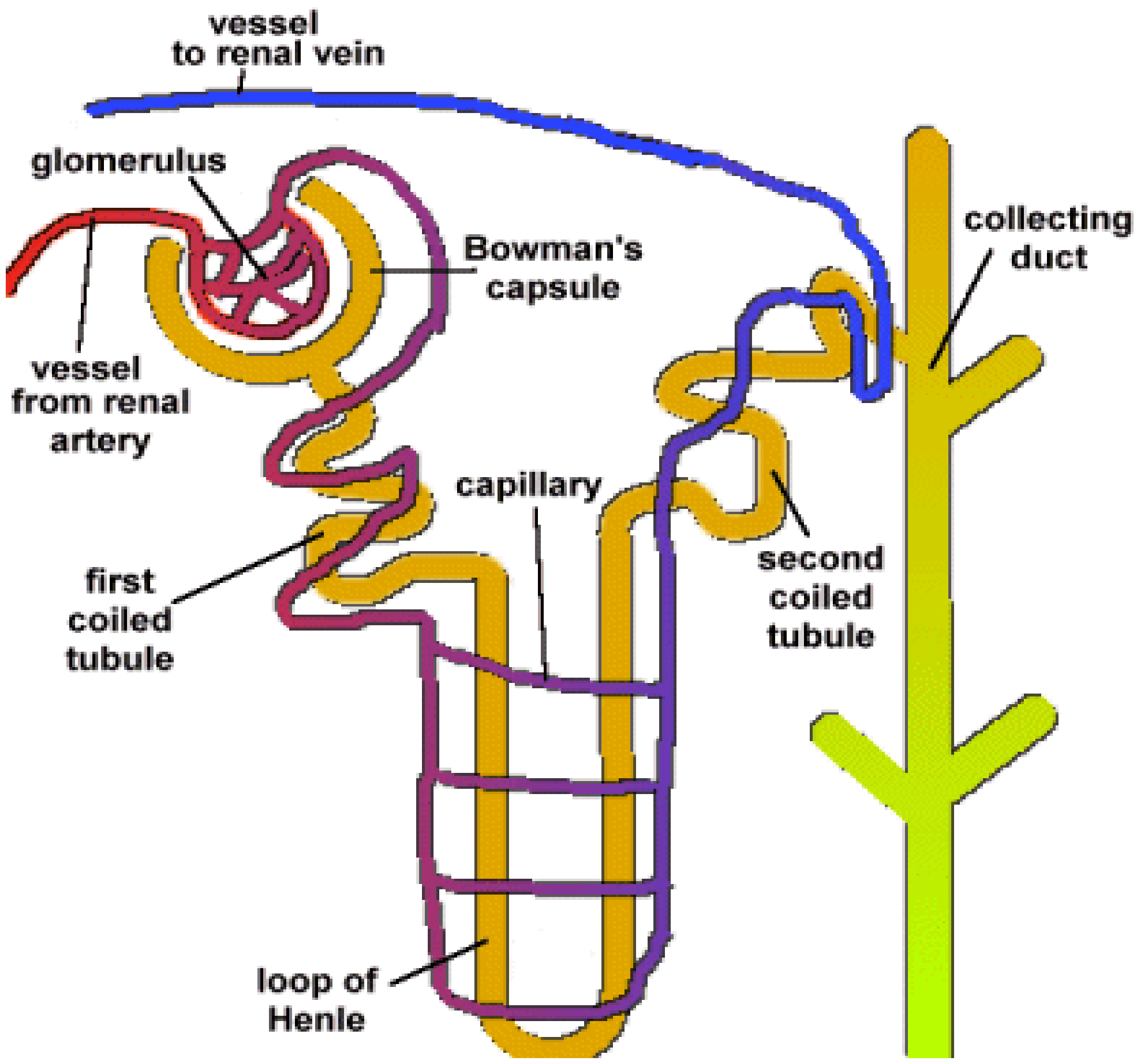
Reduced renal (kidney) function

* 25yr vs 66yr men - J. Applied Physiology 76:1994

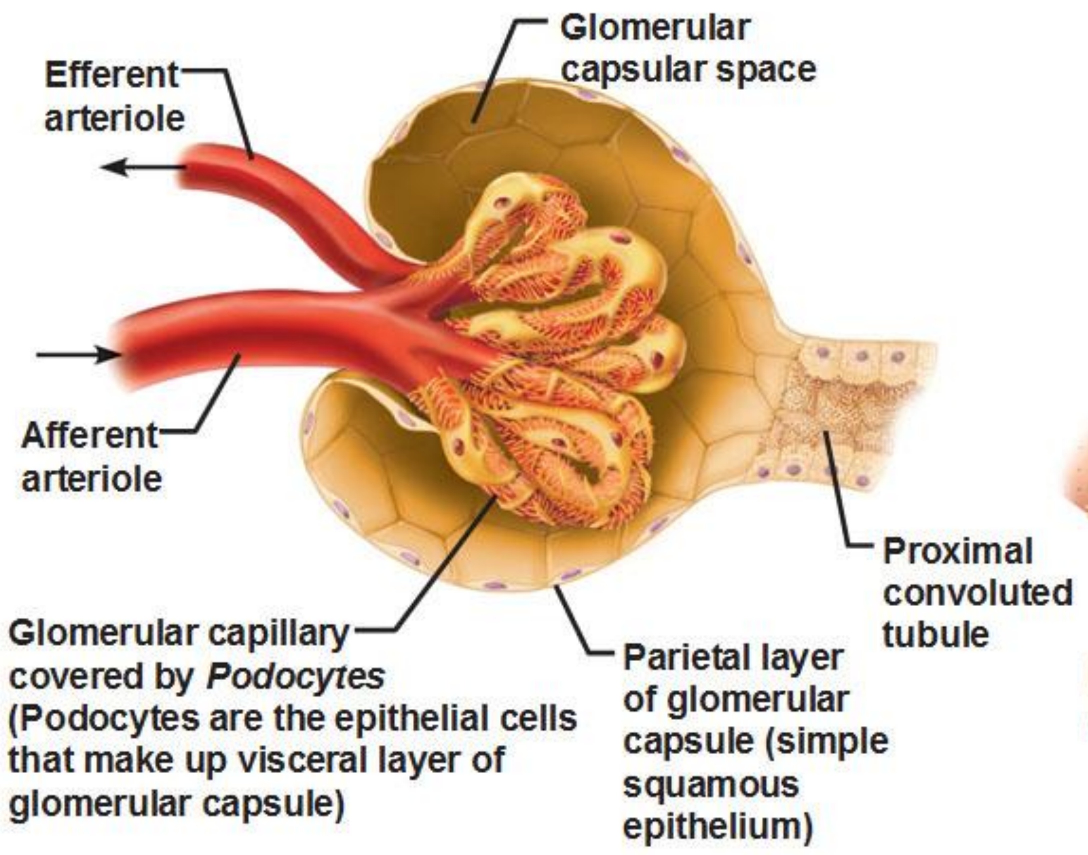
Anatomy of the kidney



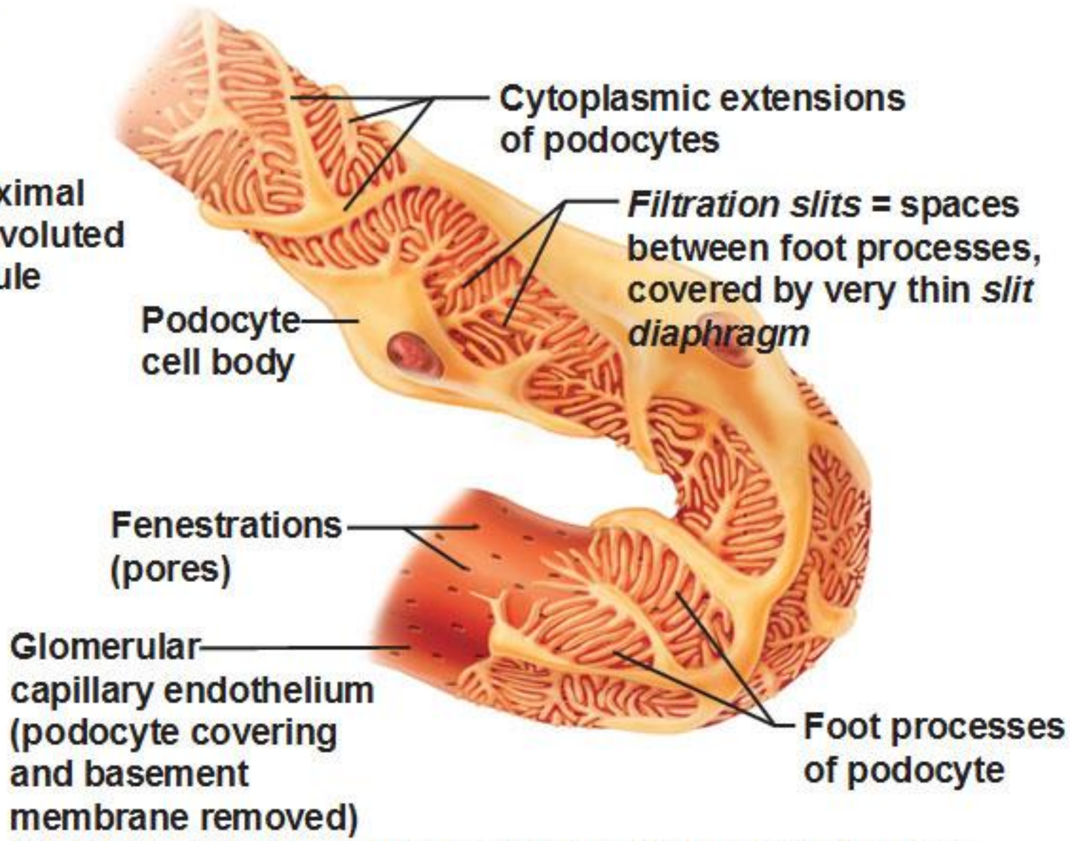
Nephrons: The functional units of the kidney



Renal Corpuscle and the Filtration Membrane



(a) Renal corpuscle



(b) Glomerular capillary surrounded by podocytes

Relative Concentrations of Substances in the Plasma, Glomerular Filtrate, and Urine

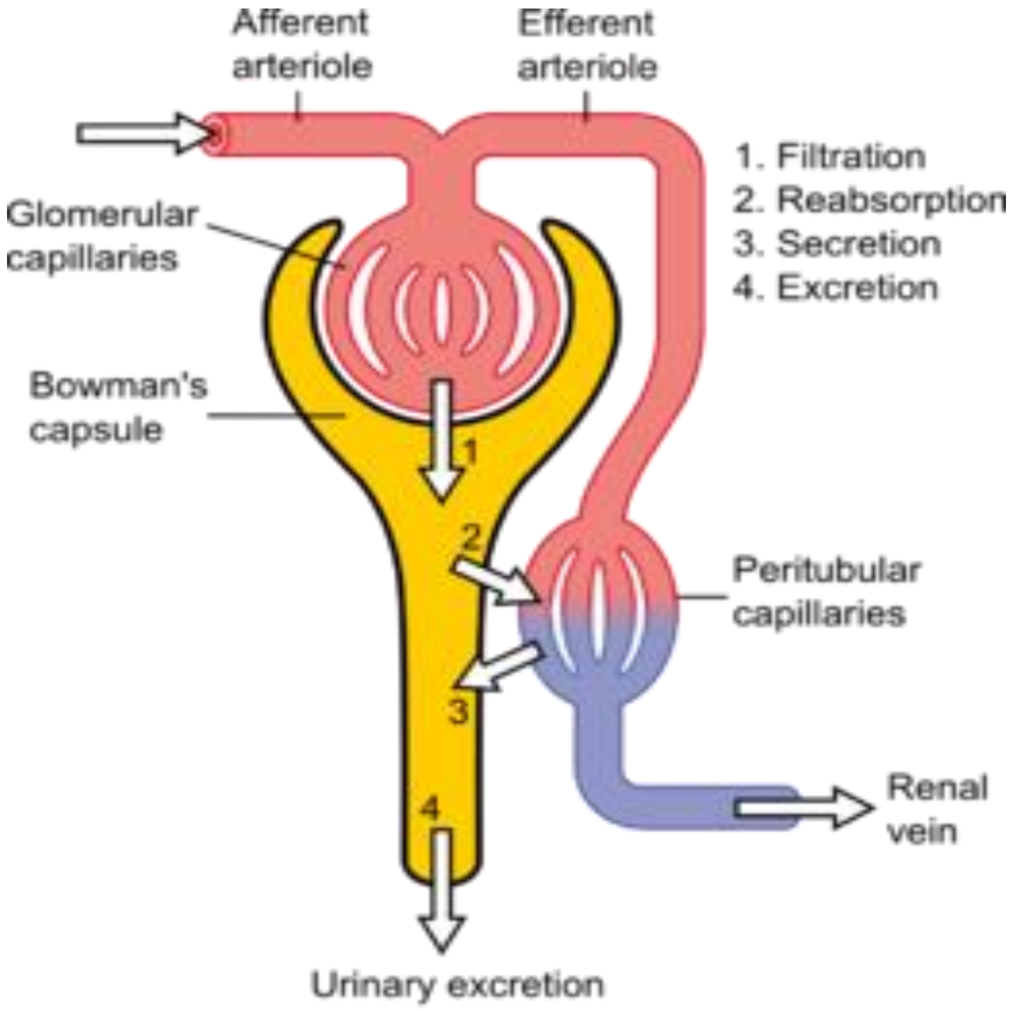
Concentrations (mEq/1)			
Substance	**Plasma**	**Glomerular filtrate**	**Urine**
Sodium (Na^+)	142	142	128
Potassium (K^+)	5	5	60
Calcium (Ca^{+2})	4	4	5
Magnesium (Mg^{+2})	3	3	15
Chloride (Cl^-)	103	103	134
Bicarbonate (HCO_3^-)	27	27	14
Sulfate (SO_4^{-2})	1	1	33
Phosphate (PO_4^{-3})	2	2	40

Concentrations (mg/100ml)			
Substance	**Plasma**	**Glomerular filtrate**	**Urine**
Glucose	100	100	0
Urea	26	26	1820
Uric acid	4	4	53

Note: mEq/1 = milliequivalent per liter.

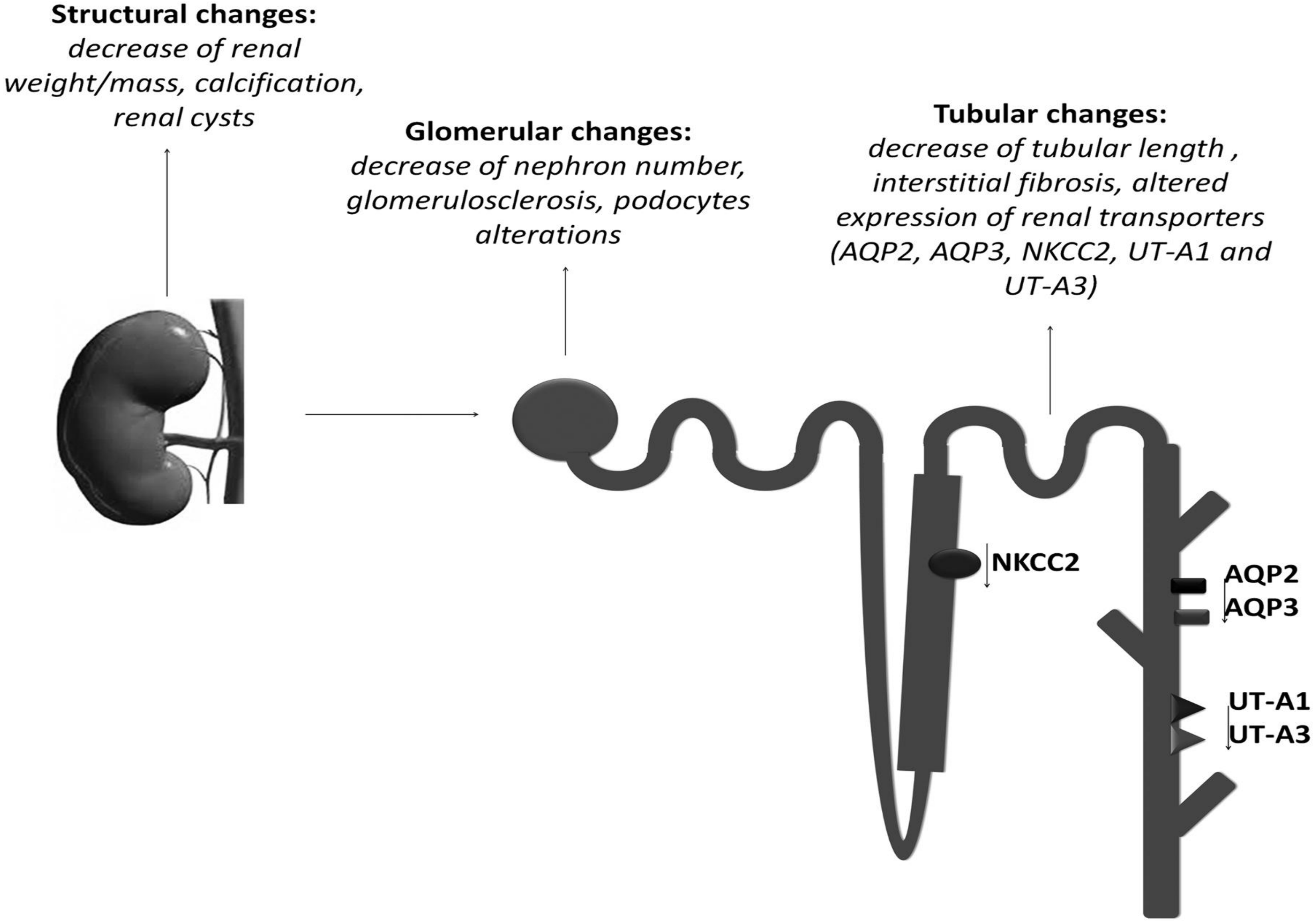
Protein	7%	0

Functions of nephrons

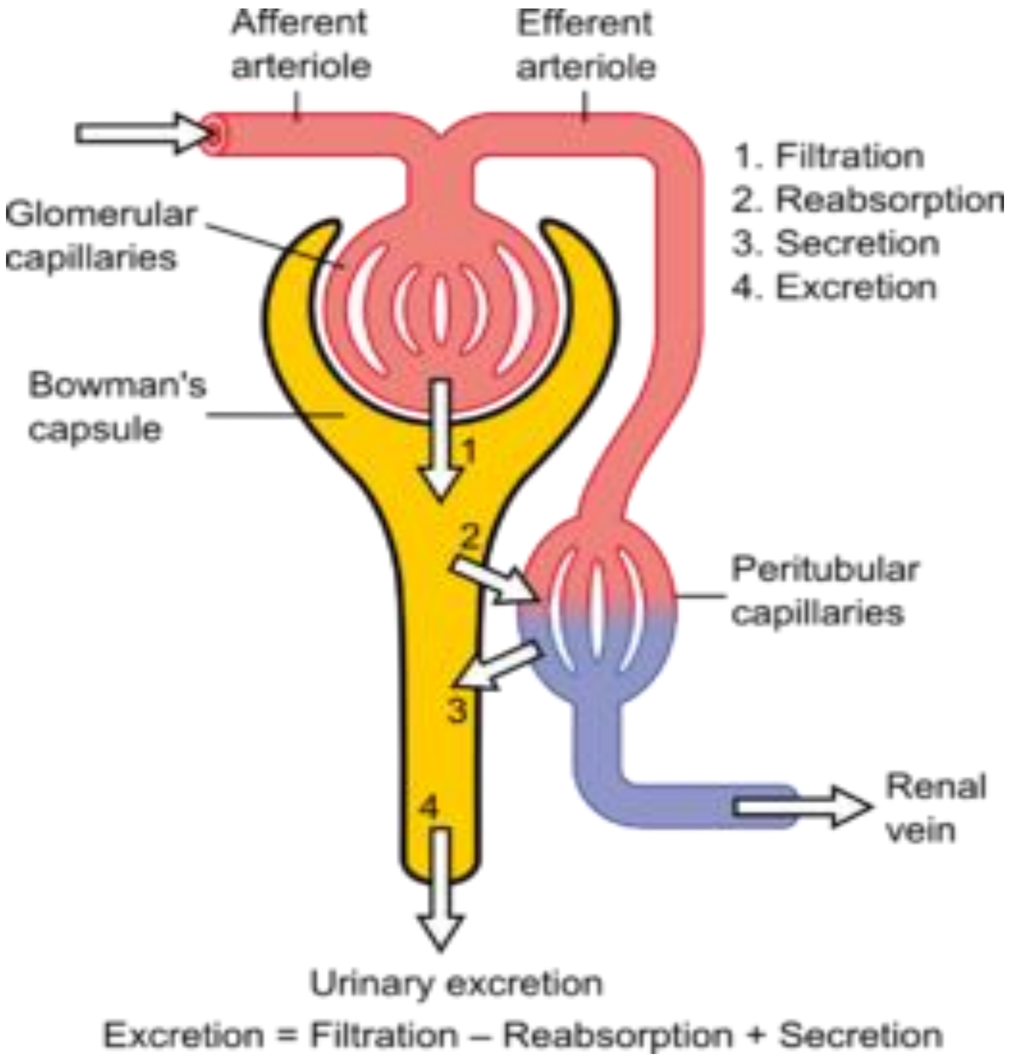


Excretion = Filtration – Reabsorption + Secretion

Kidney dysfunctions in aging.



Endocrinology, Volume 156, Issue 3, 1 March 2015, Pages 777–788,
https://doi.org/10.1210/en.2014-1812



If a substance is filtered (1) but not reabsorbed (2) or secreted (3), then excretion (4) can be used to measure filtration.

Glomerular Filtration Rate (GFR):

A common clinical test obtained by measuring the excretion of creatinine, a natural substance that is filtered but not significantly reabsorbed or secreted.

Amount filtered = GRF (ml/min) X plasma conc. (mg/ml) = mg/min

Amount excreted = urine flow (ml/min) X urine conc. (mg/ml) = mg/min

For creatinine (Cr): amount filtered = amount excreted

GFR X plasma conc of Cr = urine flow X urine conc of Cr

GFR = (urine flow X urine conc of Cr)/ plasma conc of Cr

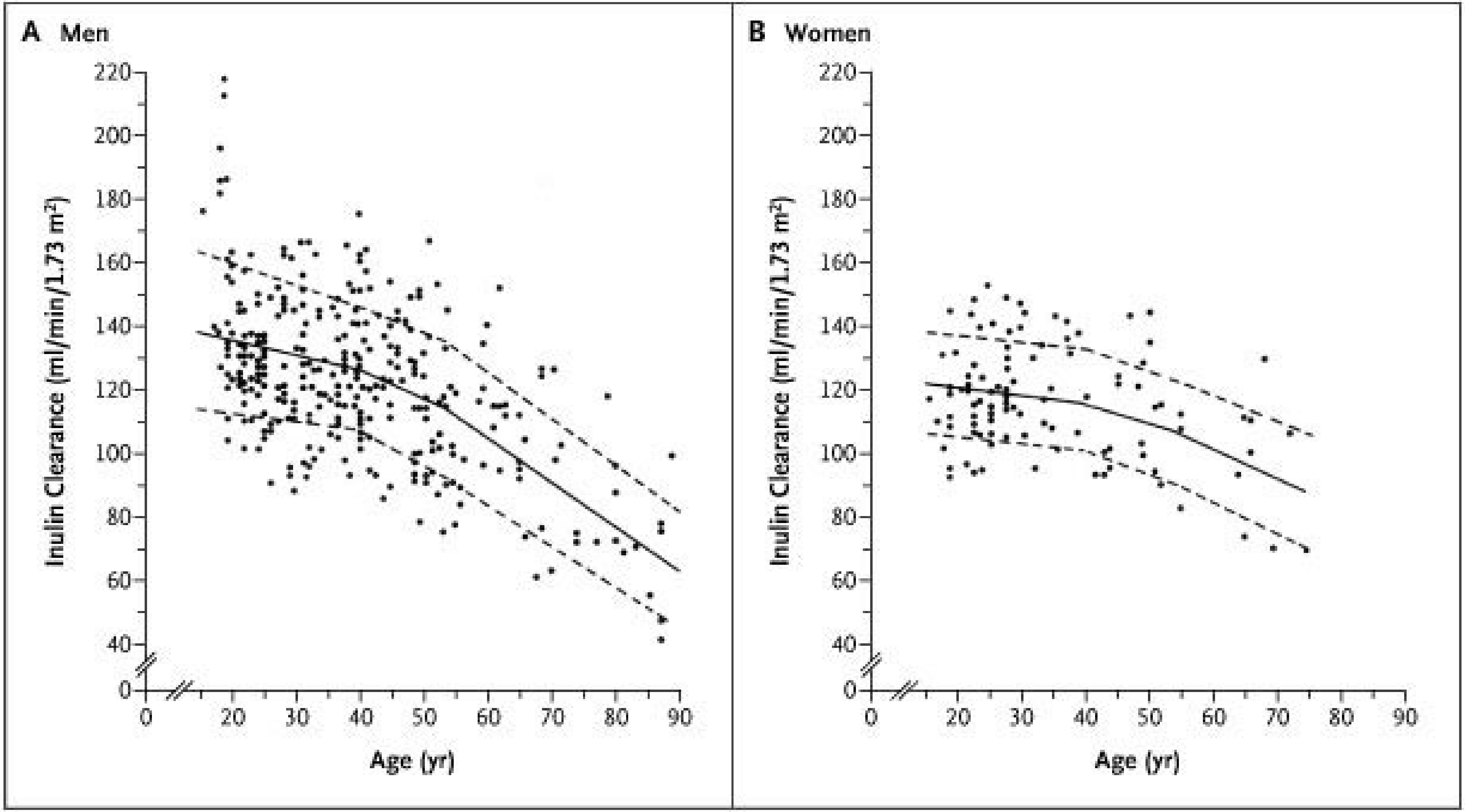
GFR as measured by substances that are filtered only is also a measurement of the *virtual* volume of blood plasma from which the substance was removed.

This is known as ***clearance***

GFR as measured by creatinine is a close approximation of clearance

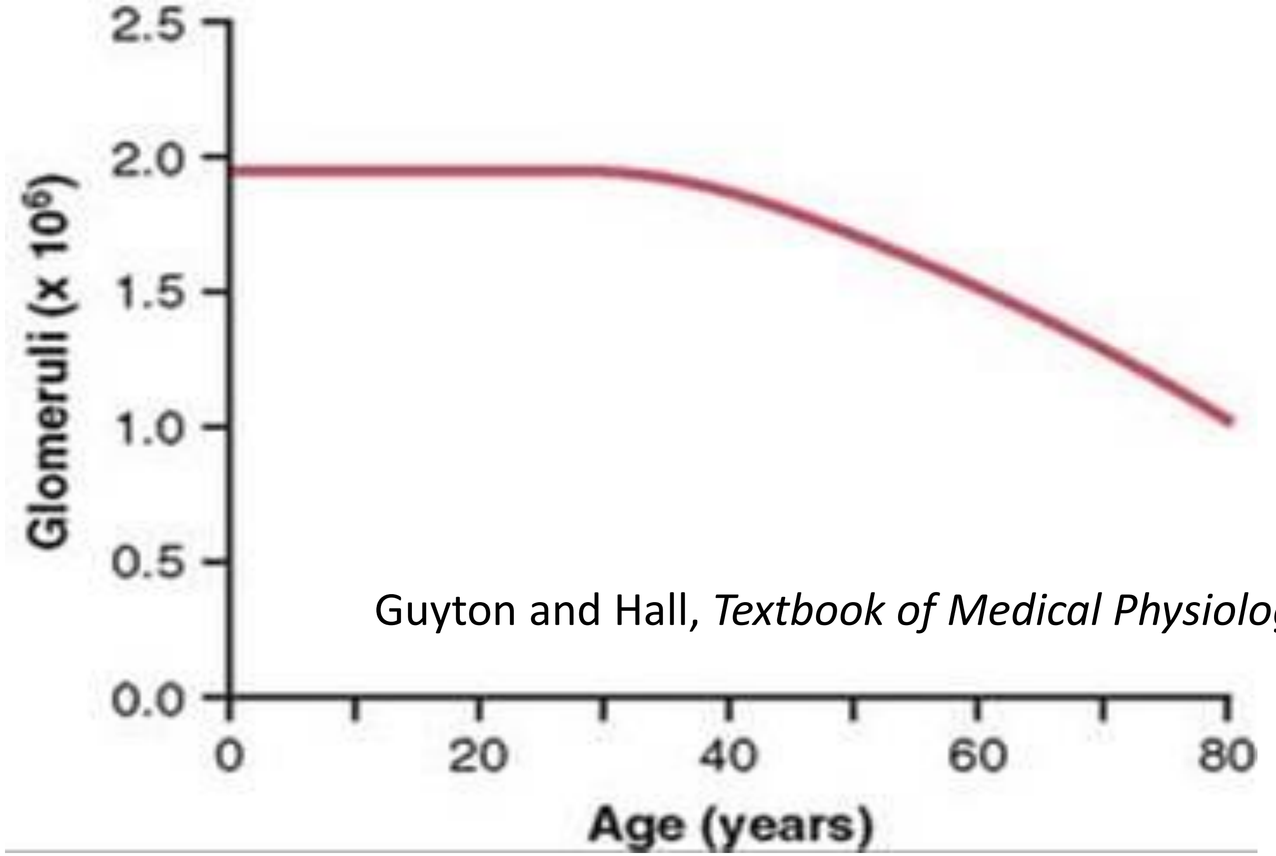
GFR as measured by inulin, a synthetic, is an accurate measurement of clearance

Decline in GRF with age as measured by inulin clearance



New England J. Med. 354: 2473, 2006

Decrease in number of glomeruli with age: A mechanism of decreased GFR



Guyton and Hall, *Textbook of Medical Physiology,* 12th ed, Ch 31, 2011

Other mechanisms:
Decrease in filtration per Glomeruli (sclerosis of glomeruli capillaries)
Decrease in renal blood flow (constriction of arteries supplying glomeruli)

Use of PAH Clearance to Estimate Renal Plasma Flow

Paraminohippuric acid (PAH) is freely filtered and secreted and is almost completely cleared from the renal plasma

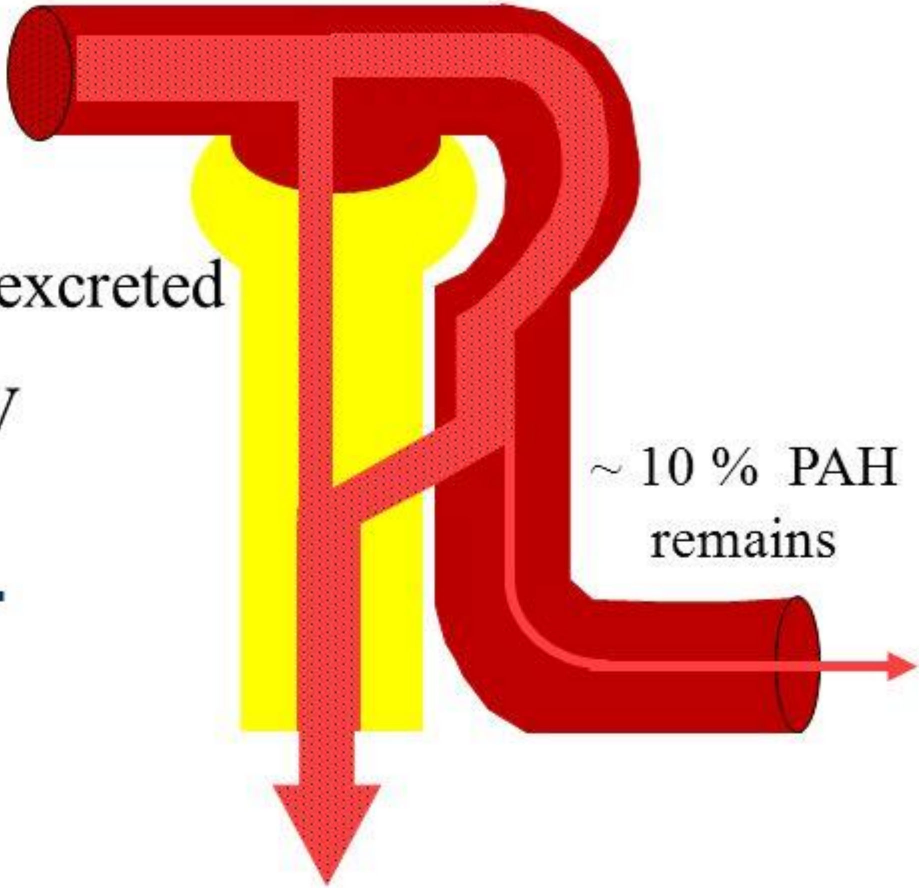
1. amount enter kidney = $RPF \times P_{PAH}$

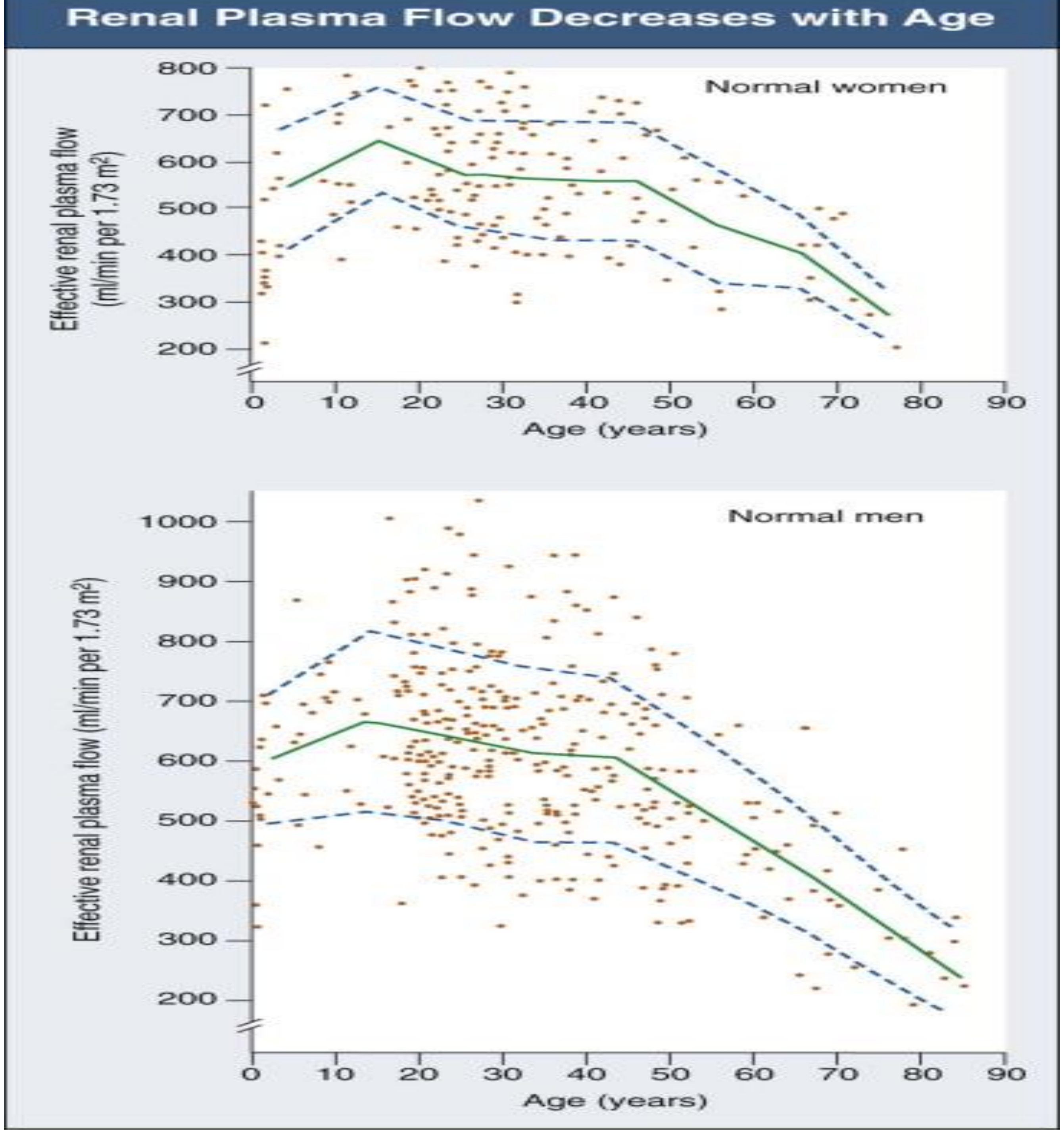
2. amount entered $\cong$ amount excreted

3. $ERPF \times P_{pah} = U_{PAH} \times V$

$$ERPF = \frac{U_{PAH} \times V}{P_{PAH}}$$

ERPF = Clearance PAH





Kidney plasma flow: Science Direct.com

24 hr urine flow rates and volumes*

Young subjects (mean age 26 yr)

(day) 75 ml/hr X 16 hr = 1,200 ml
(night) 35 ml/hr X 8 hr = 280 ml
Total = 1,480 ml (1.03 ml/min)

Older subjects (mean age 52 yr)

(day) 50 ml/hr X 16 hr = 800 ml
(night) 70 ml/hr X 8 hr = 560 ml
Total = 1,360 ml (0.94 ml/min)

*American Society of Nephrology: Geriatric Nephrology Curriculum, Ch 17, 2009

Some relevant math estimates

Renal plasma flow is about 600 ml/min

Total volume of blood plasma is about 3.0 liters

Glomerular filtration rate (GFR) is about 130 ml/min

Urine flow is about 1.0 ml/min

From the above the kidneys:

filter about 22% of renal plasma flow per min (4% of total blood plasma)

excrete less than 1% of GFR

Therefore, the kidneys are responsible for the lion's share of body water conservation

How do the kidneys conserve water?

Mainly by the reabsorption of filtered sodium and chloride.

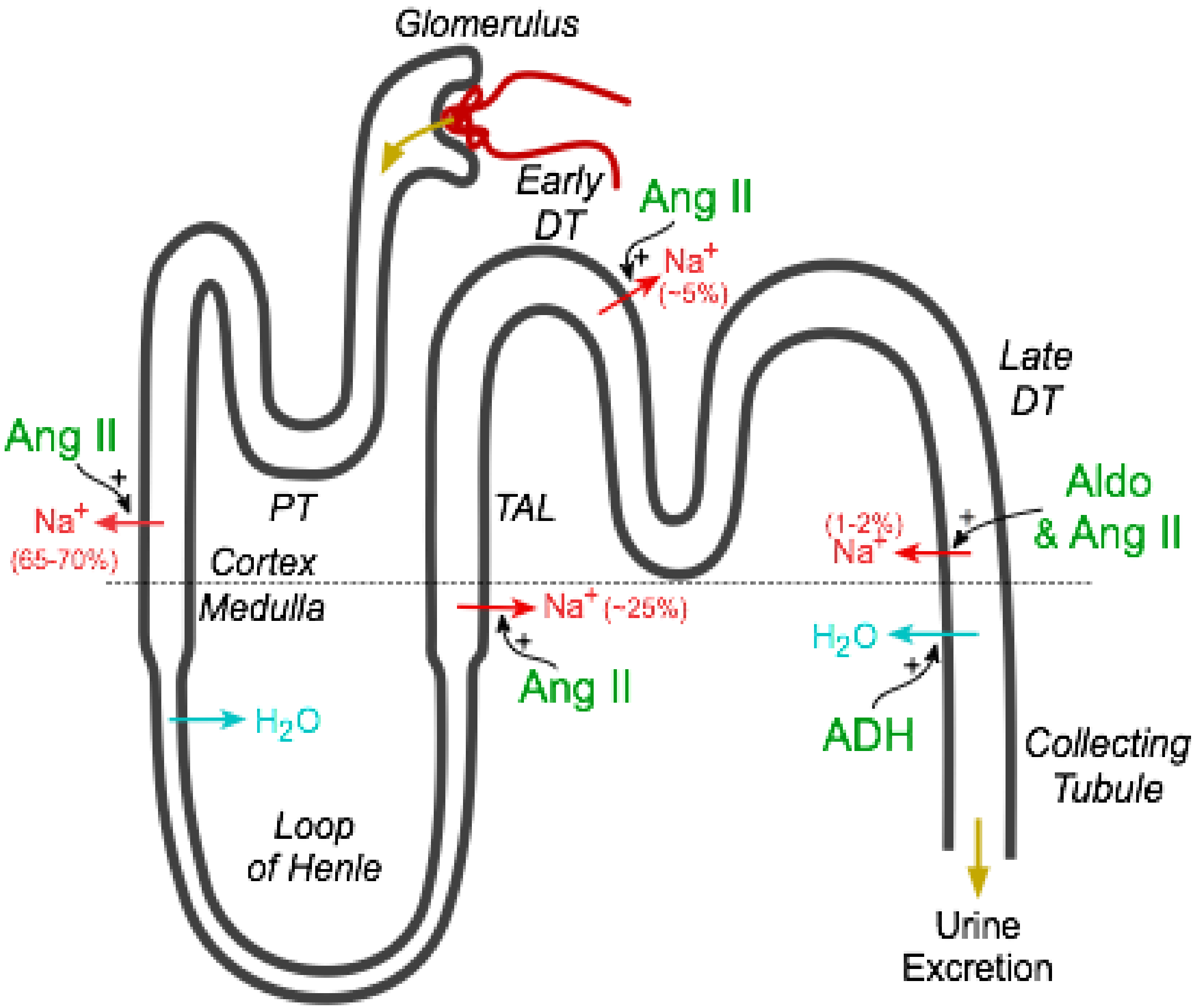
Sodium (Na+) is "*actively*" reabsorbed by the proximal and distal tubules.

"*Actively*" in biology means the use of ATP energy.

Chloride (Ca-) follows by opposite charges attract.

Water follows the reabsorption of Na+ and Cl- by osmosis.

Map of sodium (Na+) and water reabsorption in the nephrons



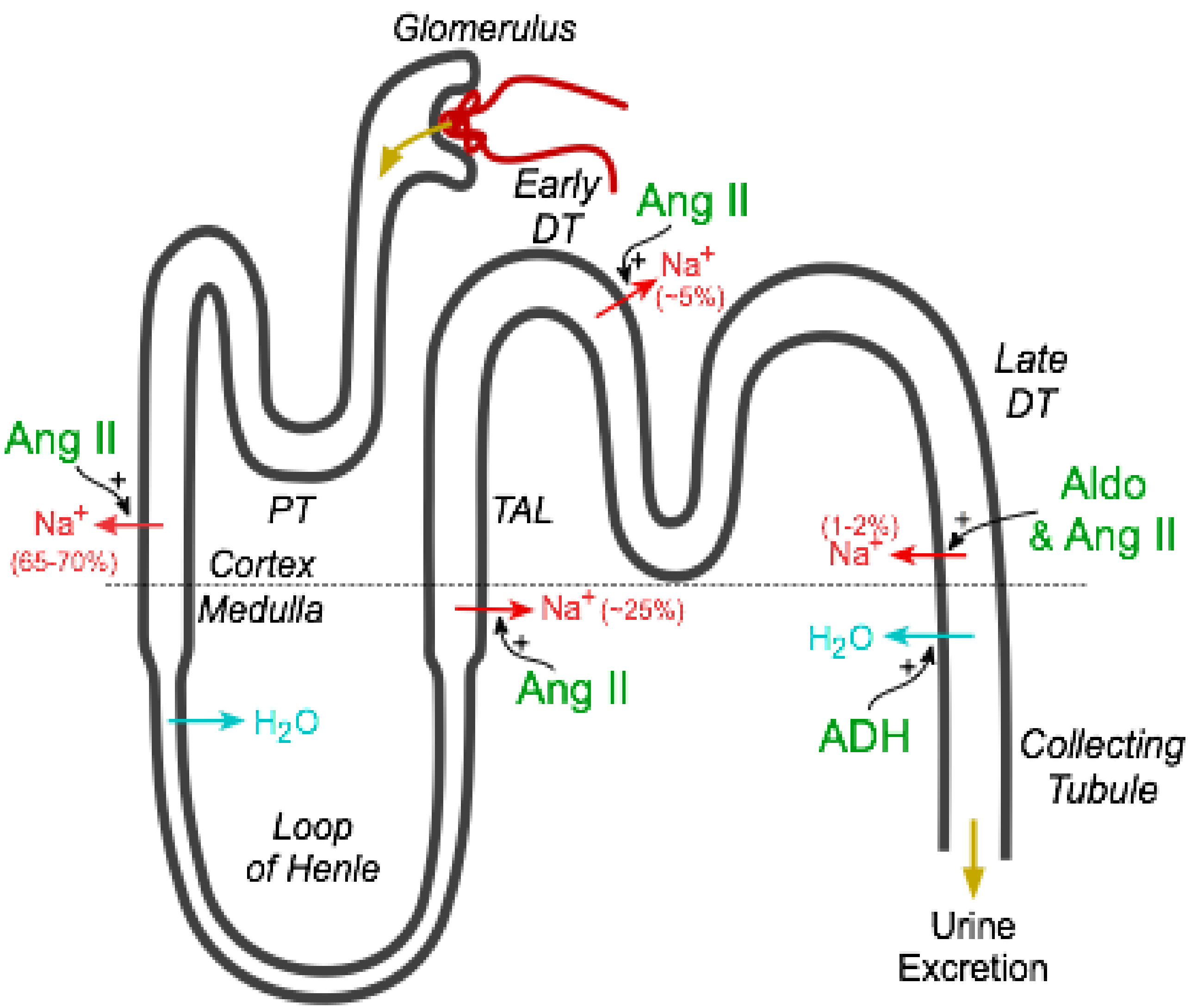
Abbreviations: PT, proximal tubule; TAL, thick ascending limb of loop of Henle; DT, distal tubule; Ang II, angiotensin II; Aldo, aldosterone

Ang II = angiotensin two (II)

Aldo = aldosterone

ADH = Antidiuretic hormone

Map of sodium (Na+) and water reabsorption in the nephrons

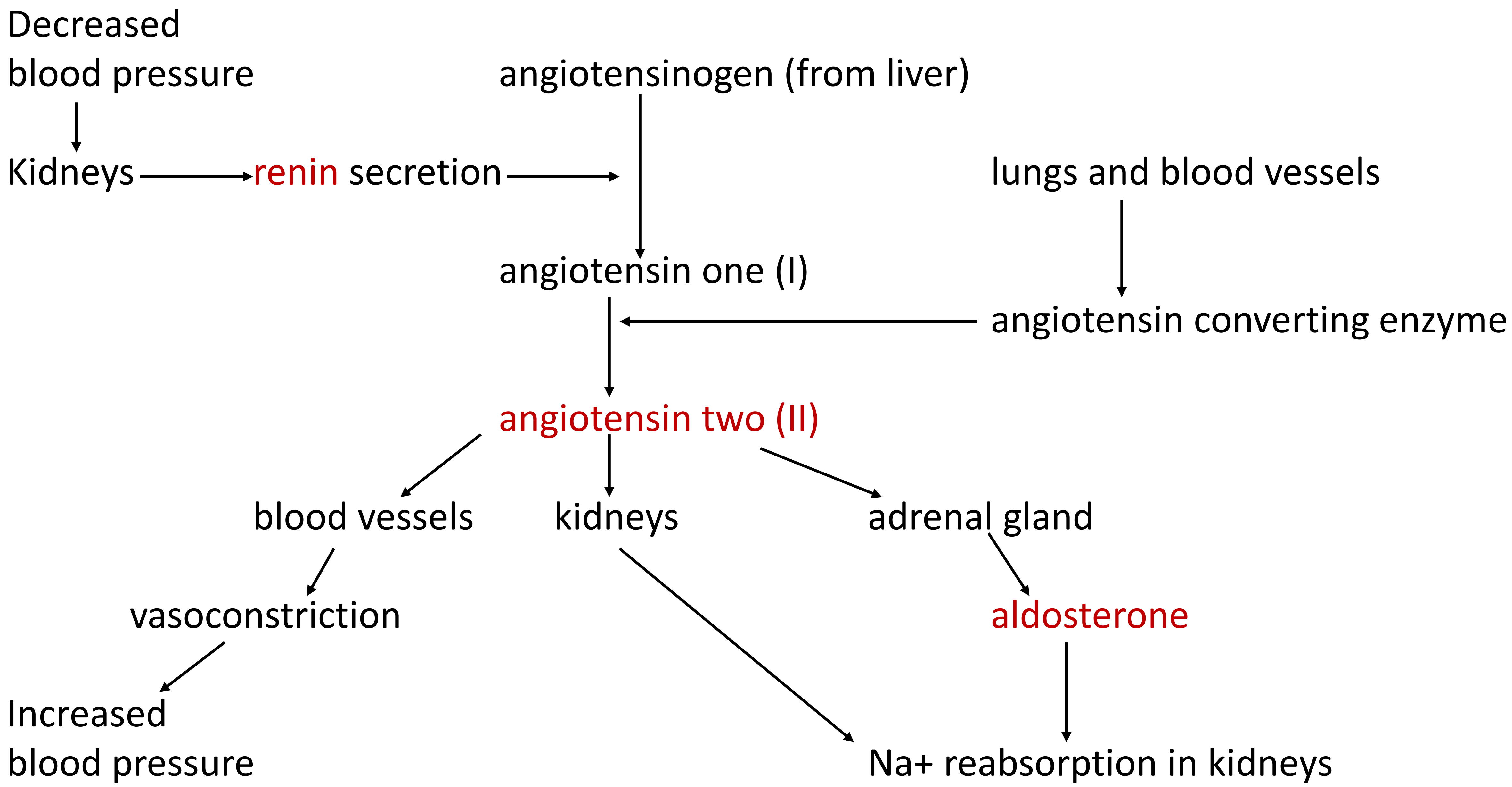


Abbreviations: PT, proximal tubule; TAL, thick ascending limb of loop of Henle; DT, distal tubule; Ang II, angiotensin II; Aldo, aldosterone

Ang II = angiotensin two (II)

Aldo = aldosterone

The Renin-Angiotensin-Aldosterone (RAS) system



Effects of age in the RAS system

In comparison of older (62 to 70 yr) to younger (20 to 30 yr) individuals Miller* found the older group to have:

Lower baseline levels of renin, angiotensin and aldosterone

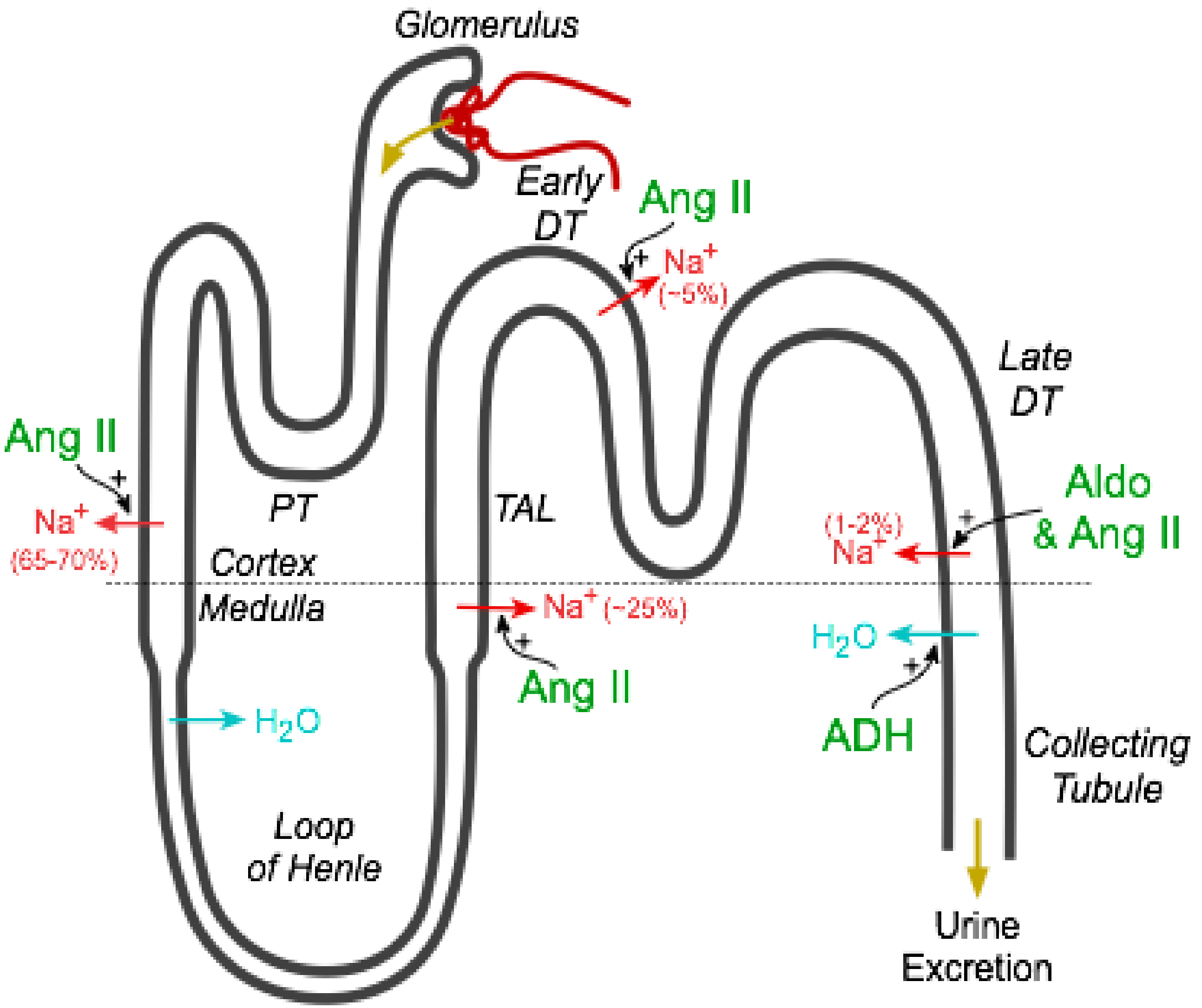
Reduced response to low blood pressure and low plasma sodium

may lead to bouts of hypotension resulting in dizziness, and

low plasma sodium (hyponatremia)

*American Society of Nephrology, Geriatric Nephrology Curriculum, Ch 17, 2009

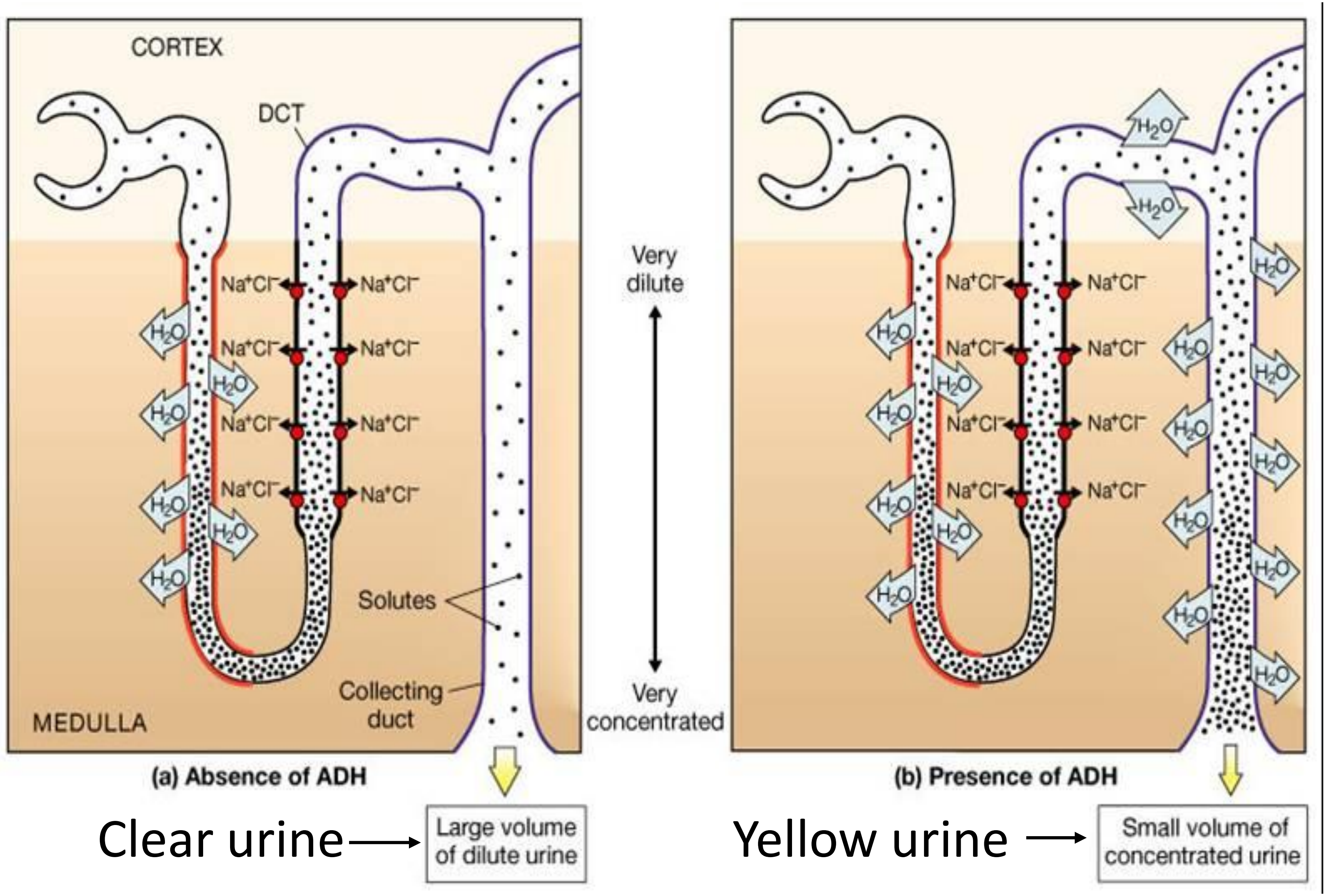
Map of sodium (Na+) and water reabsorption in the nephrons



Abbreviations: PT, proximal tubule; TAL, thick ascending limb of loop of Henle; DT, distal tubule; Ang II, angiotensin II; Aldo, aldosterone

ADH = Antidiuretic hormone

Role of antidiuretic hormone (ADH) in the renal reabsorption of water



Clear urine ⟶ Large volume of dilute urine

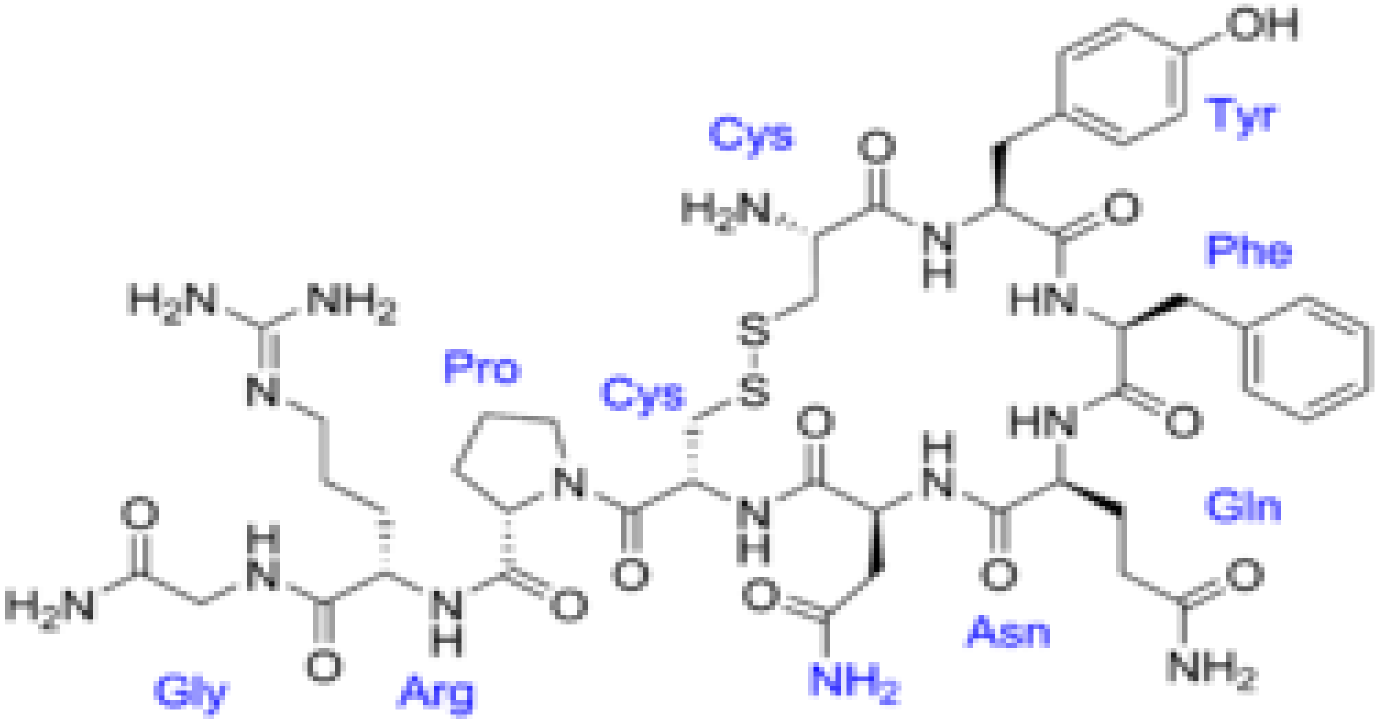
Yellow urine ⟶ Small volume of concentrated urine

Antidiuretic hormone (ADH)

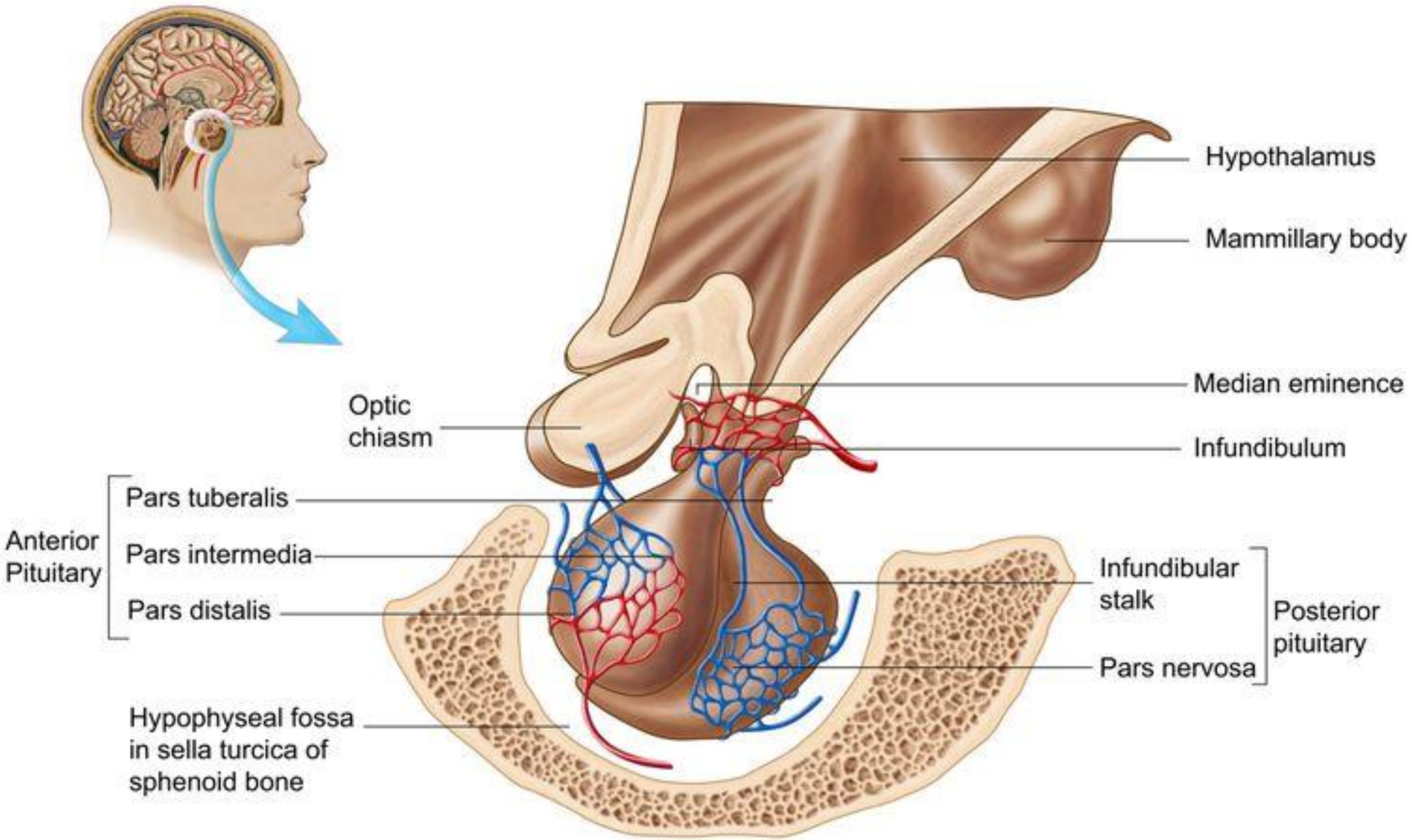
aka vasopressin, aka arginine vasopressin

THE hormone responsible for urine concentration

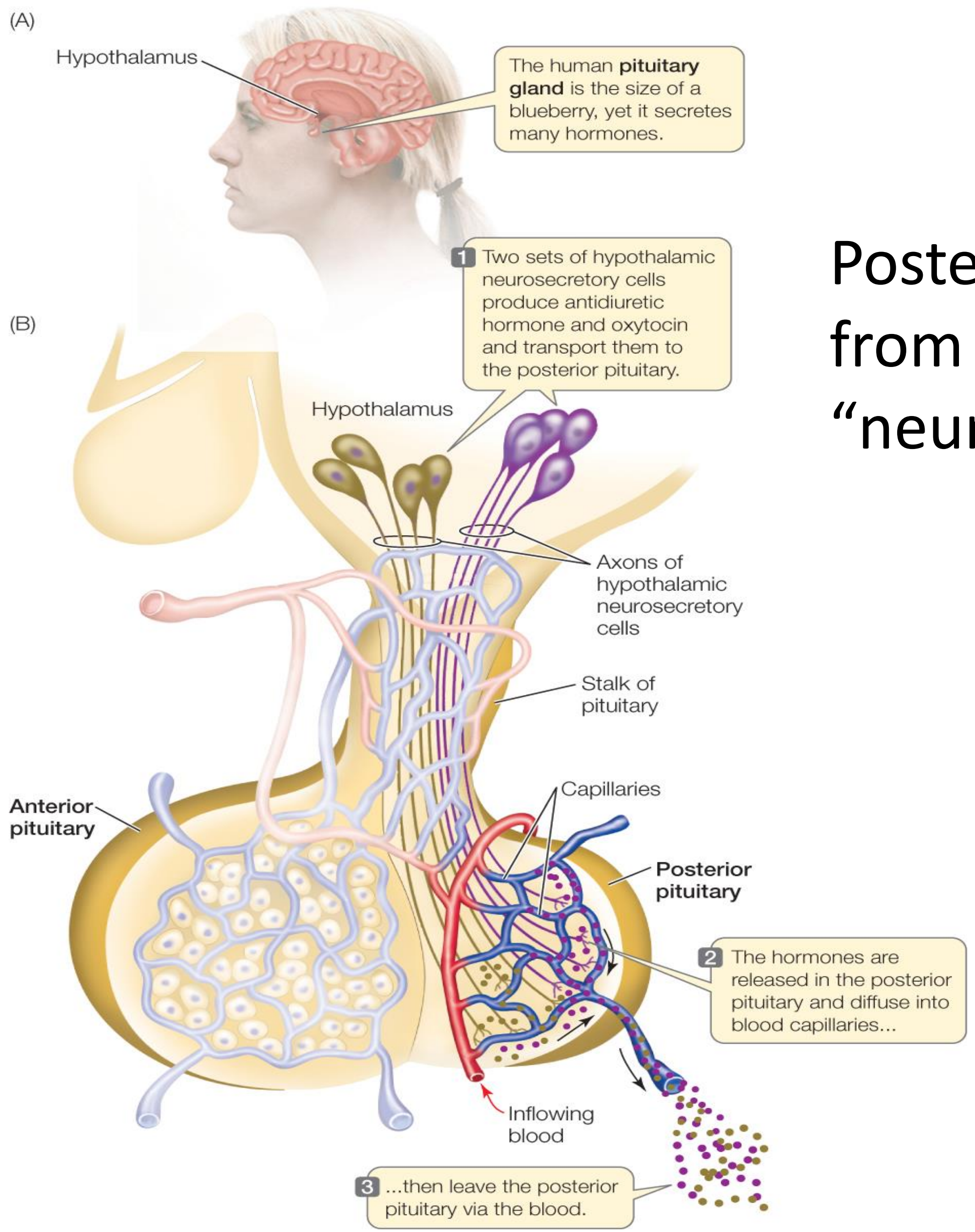
Secreted from the posterior pituitary gland



Arg = arginine, one of 11 non-essential amino acids

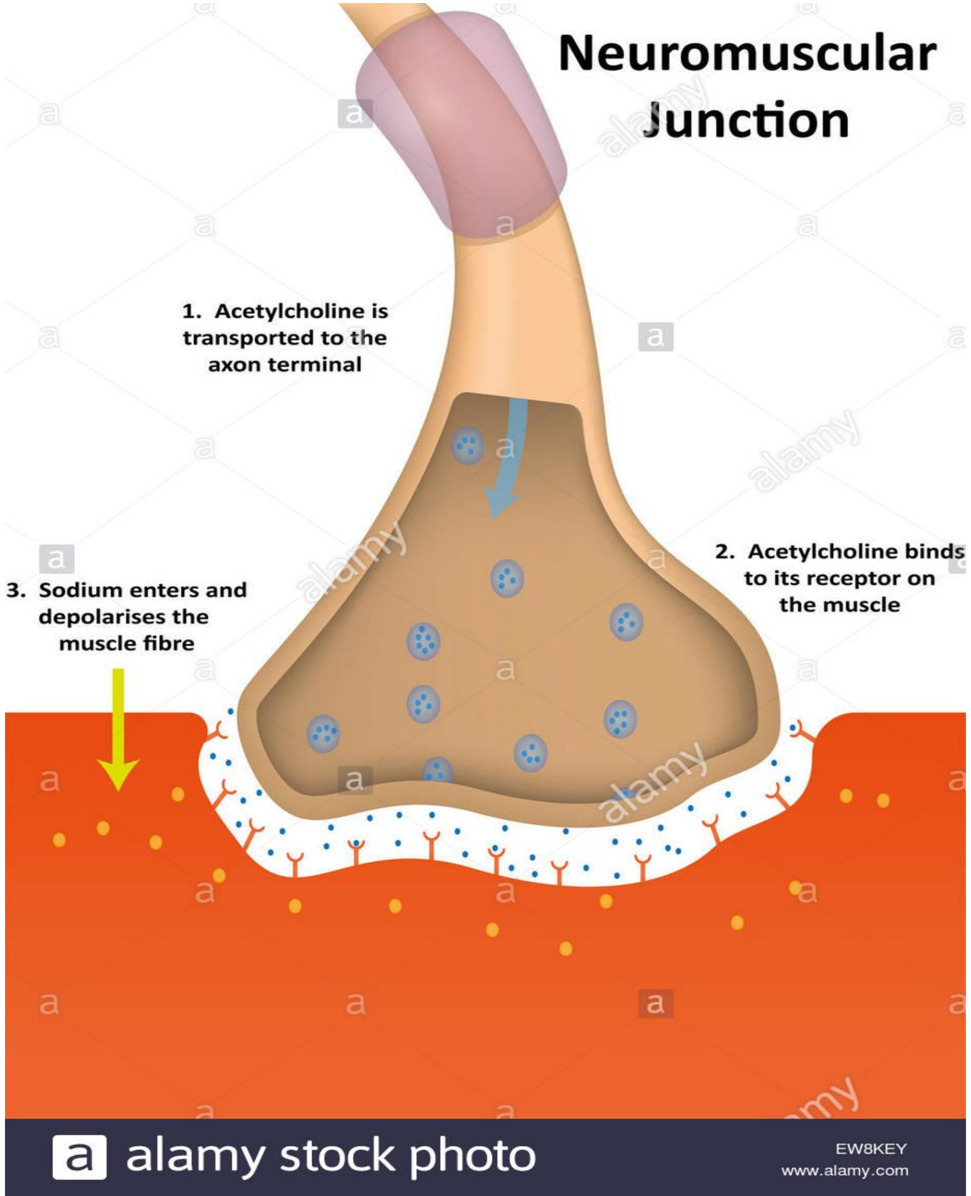


Hypothalamus
Mammillary body
Median eminence
Optic chiasm
Infundibulum
Anterior Pituitary
Pars tuberalis
Pars intermedia
Pars distalis
Infundibular stalk
Posterior pituitary
Pars nervosa
Hypophyseal fossa in sella turcica of sphenoid bone



Posterior pituitary secretes ADH and Oxytocin from neurons in the hypothalamus, called "neurosecretory neurons"

Regular neurons secrete transmitter substances close to tissues to be affected



Factors influencing the secretion of ADH

Stimulants:

- Decrease in blood volume in the thorax
  - dehydration
  - standing up (orthostasis)
- Increase in plasma sodium concentration
  - dehydration
  - excessive salt consumption
- Angiotensin II

Inhibitors:

- Increase in blood volume in the thorax
  - sitting or laying down
  - water submersion
    - shifts blood to the thorax (pee in the pool phenomenon)
- consumption of alcohol and caffeine
  - (one oz of Jack Daniels = several oz of pee)

Balance of stimulation and inhibition influenced by circadian rhythms (e.g. sleep-wake cycle)

Altered renal effects of ADH in aging*

An increase in ADH secretion which is offset by a more pronounced decrease in the renal effects of ADH.

leads to a decrease in ability of kidneys to concentrate urine.

Inhibits ability of elderly to conserve water

* Endocrinology Vol 156: pp 777-788, 2015

24 hr urine flow rates and volumes*

Young subjects (mean age 26 yr)

(day) 75 ml/hr X 16 hr = 1,200 ml
(night) 35 ml/hr X 8 hr = 280 ml
Total = 1,480 ml (1.03 ml/min)

Older subjects (mean age 52 yr)

(day) 50 ml/hr X 16 hr = 800 ml
(night) 70 ml/hr X 8 hr = 560 ml
Total = 1,360 ml (0.94 ml/min)

*American Society of Nephrology: Geriatric Nephrology Curriculum, Ch 17, 2009

Diuretics

If the conservation of body water is desirable,
then why are diuretics used to treat high blood pressure?

body water → blood volume → cardiac output → BP

Use of diuretics is a trade-off between lowering BP
and maintaining adequate body water for sweating.

Actions of frequently used diuretics

Hydrochlorothiazide

Inhibits distal tubular Na+ reabsorption
independent of Ang II

Angiotensin converting enzyme (ACE) inhibitors

Inhibits conversion of Ang I to Ang II
used as a vasodilator as well as a diuretic
diuretic action inhibits Na+ reabsorption

Conivaptan, a not so frequently used diuretic

Inhibits Antidiuretic Hormone (ADH)

Given iv under supervised clinical conditions

Elicits diuresis W/O loss of sodium

Summary

The most numerous weather related deaths in the US are due to heat

The incidence of heat related death increases with advancing age

A rise in heat related death for the general population since 2000

Correlates with the rise in global temperature

Heat Exhaustion shifts to heat stroke when sweating ceases

Body temperature rapidly rises

Summary: Continued

The body always produces heat

- Continually from metabolism
- Periodically from physical activity

For body temperature stability heat production must = heat loss

There are three general mechanisms of heat loss from the body

- Radiation, Convection, Evaporation (sweating)

Summary: Continued

Heat loss by evaporation is decreased with age:

- reduced number of sweat glands and their response to stimuli
- lower total body water
- lower blood volume

Heat loss by convection is increased with age:

- cutaneous blood vessels closer to surface of skin
  - due to thinning of epidermis

Summary: Continued

Lower total body water with age:

- Increased % body fat which holds less water
- Lower blood volume
- Altered kidney function
  - Reduced GFR and renal blood flow
  - Increase in nocturnal urine
  - Reduced response of Renin-Angiotensin-Aldosterone
  - Reduced effects of antidiuretic hormone (ADH)

Diuretics that work by inhibiting renal Na+ reabsorption

hydrochlorothiazide

angiotensin converting enzyme (ACE) inhibitors