General Notes on Therapeutic Modalities

- **There are Too Few <u>Controlled Randomize Clinical Trials</u> Which Address the Effectiveness of Therapeutic Modalities**
  - (Denegar et al., Therapeutic Modalaties for Musculoskeletal Injuries, 2006: page 96)

- **Most of the Evidence for Efficacy of Treatment is Through:**
  - **Retrospective Studies**
    - **Looking Back on What was Observed**
    - **Single Case Study Observation**
  - **Studies on animals**

- All this taken into consideration, there are as many "correct" and "most effective" ways of doing things as there are therapists (which form their treatment and rehab paradigms through their own experience)

Stretching & Mobilization

- **Definitions:**
  - **Elasticity** - ability to return to resting length after a passive stretch
    - related to elastic elements of musculotendinous tissue
  - **Plasticity** - ability to assume a greater length after a passive stretch
    - related to viscous elements of musculotendinous tissue
    - 103^0 - 104^0 F ➞ destabilization of collagen hydrogen bonds ➞ ↑ plasticity
  - **Stress** - force applied to tissue per unit of area
    - tension stress - tensile (pulling) force applied perpendicular to cross section
    - compression stress - compression applied perpendicular to cross section
    - shear stress - force applied parallel to cross section
  - **Strain** - amount of deformation resulting from stress
  - **Stiffness** - amount of strain per unit of stress
  - **Creep** - amount of tissue elongation resulting from stress application
    - heat applied to tissue will increase the rate of creep (similar to "Plasticity')
  - **Necking** - fiber tearing ➞ less stress required to achieve a given strain

Stretching & Mobilization

- **Definitions (continued):**
  - **Contractures** - shortening & "tightening" of a tissue crossing a joint
    - May be caused by: deformity, immobility, injury, chronic inflammation, stroke
    - usually results in a loss of range of motion
    - myostatic contractures - muscle tightness (no pathology)
    - scar contractures
    - fibrotic contractures - inflammation ➞ fibrotic changes in soft tissue
    - pseudomyostatic contractures - contracture cause by CNS lesion or pathology
  - **Adhesions** - scar tissue that binds 2 or more tissue together causing loss of tissue function (➞ ⬇ ability of tissues to move past one another)
    - Most common in the pelvic / abdominal area
    - May be caused by: abdominal surgery, endometriosis & c-section (women)
    - Can cause sever pain and small bowel obstruction
  - **Ankylosis** - stiffness or fixation of joint due to disease, injury, or surgery
  - **Laxity** - excessive looseness or freedom of movement in a joint

Stretching & Mobilization

- **<u>Indications for Stretching - Mobilization Therapy</u>**
  - **<u>Prolonged immobilization or restricted mobility</u>**
    - muscle immobilized in elongation ➞ ↑ # of sarcomeres
      - maintenance of optimal actin-myosin overlap
    - muscle immobilized in shortened position ➞ ↑ amount of connective tissue
      - protection of tissues when stress is applied
    - both adaptations are transient if muscle is allowed to resume normal length
    - prolonged immobilization ➞ ↓ amount of stress before tissue failure
    - <u>bed rest</u>:
      - ➞ ↓ size & quantity of muscle & collagen fibers ➞ ↑ tissue compliance
  - **<u>Contractures & adhesions</u>**
    - tissue disease or neuromuscular disease
    - pathology (trauma, hemorrhage, surgical adhesion, burns, etc.)
  - **Lack of Flexibility ????**

Stretching & Mobilization

- **Flexibility - the controversy**
  - Krivickas (1997) - lack of flexibility a predisposing factor to overuse injuries
  - Krivickas (1996) - lack of flexibility related to lower extremity injury in men but not women
  - Twellar et al. (1997) - flexibility not related to number of sports injuries
  - Gleim & Mchugh (1997 review) - “no conclusive statements can be made about the relationship of flexibility to athletic injury”
  - Cornwell et al. (2001) stretching reduces vertical jump performance
  - Fowles et al. (2000) stretching reduces strength in plantar flexor muscles
  - Craib et al. (1996) - muscle tightness improves running economy
  - Balaf & Salas (1983) - “excessive flexibility may destabilize joints”
  - Beighton et al. (1983) - joint laxity predisposes one to arthritis
  - Gomolk (1975) - “tight jointed individuals are ‘better protected’ from injury”

Stretching & Mobilization

- **<u>Flexibility - the controversy</u>…..now, the bottom line**
  - Thacker et al., The Impact of Stretching on Sports Injury Risk: A Systematic Review of the Literature. Medicine & Science in Sports and Exercise Vol 36, No. 3, pp 371-378, 2004)
  - 361 <u>experimental</u> research articles were reviewed
    - Stretching was the independent variable
    - Number of injuries was the dependent variable
    - Meta analysis used to analyze the data.
  - Relative risk for injury = .93 (average risk = 1)
  - <u>Conclusions</u>: stretching has no significant effect on injury risk
  - <u>Corollary</u>: flexibility, per se, should not be viewed as an indicator of physical fitness. However, the **<u>LACK OF FLEXIBILITY</u>** should be viewed as:
    - a sign of being **<u>UNFIT</u>**
    - a risk factor for low back pain
    - an indicator of fall risk and reduced life quality in the elderly

Stretching & Mobilization

- **Contraindications for Stretching - Mobilization Therapy**
  - Acute inflammatory arthritis (danger of exacerbating pain & inflammation)
  - Malignancy (danger of metastases)
  - Bone disease (osteoporosis ➞ weak bones ➞ ⬆ fracture risk)
  - Vascular disorders of the vertebral artery (danger of artery impingement)
  - Bony block joint limitation (floating bone spur may wedge in joint)
  - Acute inflammation or hematoma (danger of injury exacerbation)
  - Recent fracture

  - Contractures contributing to structural stability or functionality
    - allowing immobility to develop in the trunk and lower back of a thoracic or cervically injured paralysis patient
    - allowing immobility to develop in the finger flexors of a partially paralyzed person in order to facilitate a "grip"

Types of Stretching

- **Balistic Stretching (bouncing)**
  - creates 2 X as much tension as static stretches
  - ↑ flexibility (Wortman-Blanke 1982, Stamford 1984)
    - static stretches produce greater increases (Parsonius & Barstrom 1984)
  - does activates monosynaptic reflex

- **"Static" or "Passive" Stretching**
  - slow stress applied to musculotendinous muscle groupings
    - held for 6 to 60 seconds
    - one study suggested 15 sec stretch as effective as 2 minute stretch
  - usually repeated between 5 to 15 times per session
  - held to a point just below pain threshold
  - can be done with assist devices or manual assistance
    - common in martial arts

Types of Stretching

- **Proprioceptive Neuromuscular Facilitation (PNF)**
  - a group of techniques for stretching specific muscle groups that utilizes proprioceptive input to produce facilitation of the stretch

- **Examples of PNF (agonist: hamstrings antagonist: quads)**
  - **Contract - Relax:**
    - isometric or isotonic contraction of agonist then static stretch of the agonist
    - pre-stretch contraction relaxes agonist via autogenic inhibition
      - inverse myotatic reflex
        - GTO impulses inhibit α efferents from spindles ➞ stretch facilitated
        - Hip extension example
  - **Antagonist Contraction**:
    - contraction of antagonist relaxes agonist via reciprocal inhibition
    - example: contracting quads just prior to stretching hamstrings

Motion Therapy

- **Motion Therapy:** the use of both manual & active motion to:
  - combat spasms that develop following joint or soft tissue injury
  - prevent atrophy
  - prevent the development of contractures

- **Manual ROM Therapy:** manual manipulation of joints:
  - used in paralysis, coma, immobility, bed restriction, painful active motion
  - benefits for patient:
    - maintains existing joint & soft tissue mobility
    - minimizes contracture formation
    - assists circulation (venous return)
    - enhances diffusion of materials that nourish joint
    - helps to maintain kinesthetic awareness
    - to a small extent - helps in minimizing atrophy

Motion Therapy

- **Active ROM Therapy:** supervised patient manipulation of joints
  - used when patient is able to actively move body segment
  - progresses to resistance exercises
  - benefits for patient:
    - all benefits of manual ROM therapy
    - helps to maintain elasticity & contractility of muscle tissue
    - provides stimulus for maintenance of bone density & integrity
    - helps maintain motor skill coordination
    - helps prevent thrombus formation

Cold (Cryotherapy - Heat Abstraction)

- **Methods of Heat Transfer**
  - evaporation
  - radiation
  - convection
  - conduction
- **Heat Conduction Equation**

$$\text{RATE OF HEAT TRANSFER (cal / sec)} = \frac{SA \bullet k \bullet (T_1 - T_2)}{\text{TISSUE THICKNESS}}$$

SA = surface area to be treated

k = thermal conductivity constant of medium (cal / sec / $cm^2 \bullet {}^oC$ / cm)

T_1 = temperature of first medium (^oC)

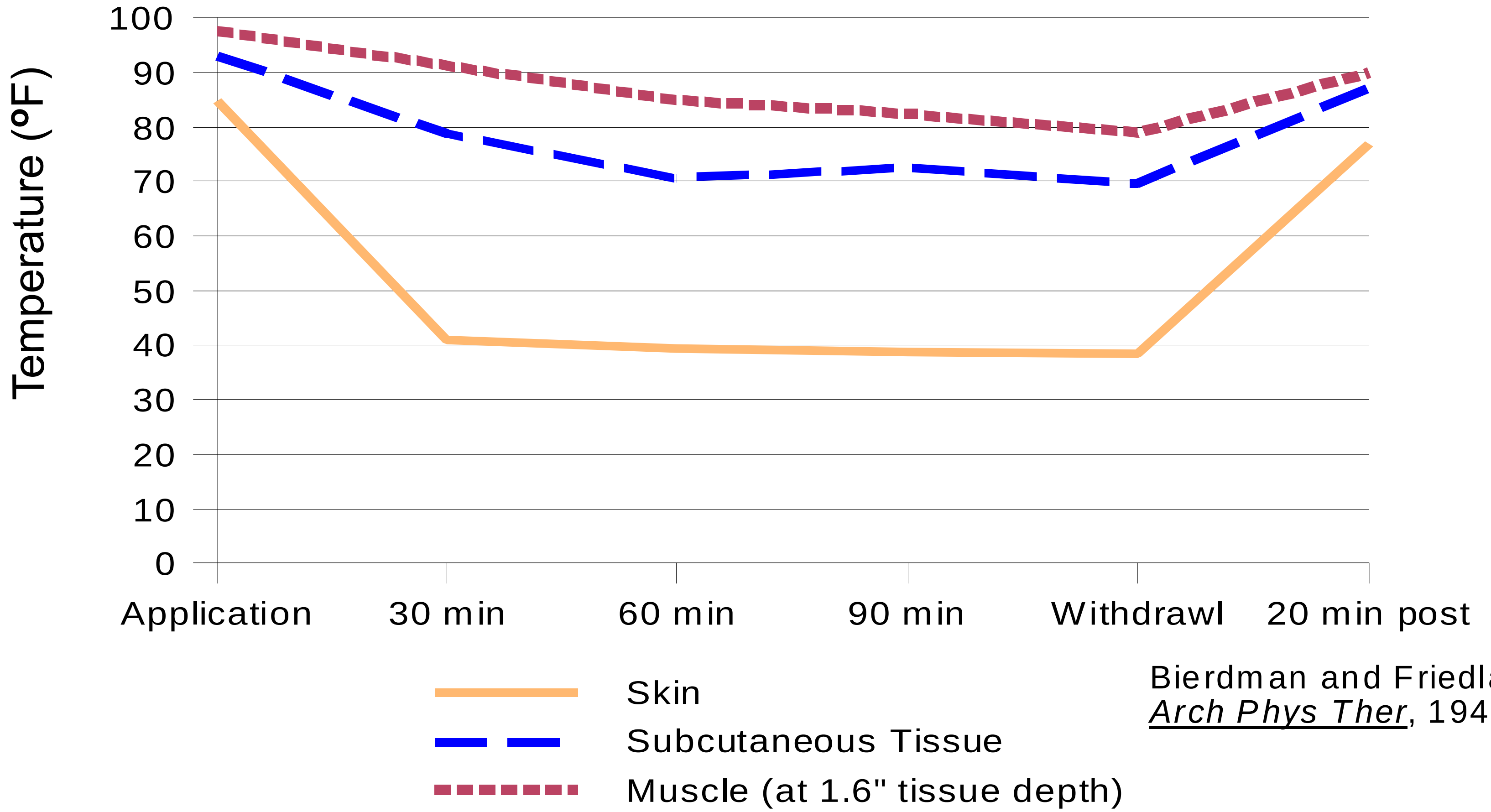
T_2 = temperature of second medium (^oC)

- **Thermal Conductivity Constants**
  - aluminum 1.01
  - water .0014
  - bone & muscle .0011
  - fat .0005
  - air .000057

Temperature Alterations in Cold Application

- Decreased skin temperature
- Decreased subcutaneous temperature
- Decreased intramuscular temperature
  - may continue up to 3 hours after modality is removed if application is sufficiently intense
- Decreased intra-articular temperature
  - may continue up to 2 hours after modality is removed if application is sufficiently intense

Tissue Temperature Changes with Ice Pack Application to the Calf



Bierdman and Friedlander, *Arch Phys Ther*, 1940

It takes 30 minutes to effect a 6.3 F temperature reduction in a muscle 1.6" deep using ice packs

Research suggests that INTRA-ARTICULAR cooling and rewarming patters are very similar to that of MUSCLE (Oosterveld 1992), but temperatur decrease may be greater than in muscle (Wakin 1951)

Physiological Responses to Cold Application

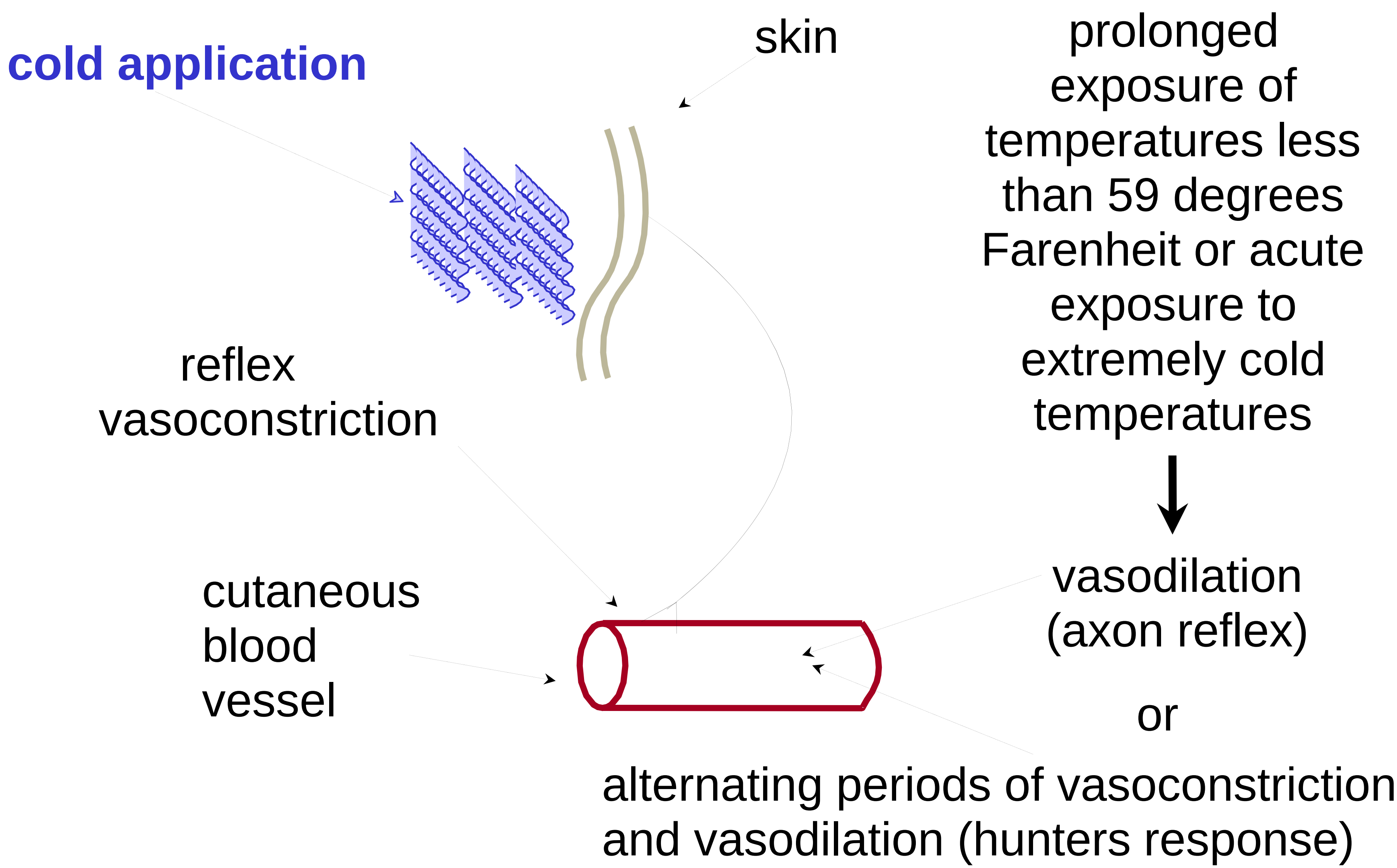
- Free nerve endings ➡ reflex vascular smooth muscle contraction ➡ vasoconstriction

- ⬆ affinity of α-adrenergic receptors for norepinephrine ➡ vasoconstriction
  - Vasoconstriction ➡ ⬇ blood flow to periphery ➡ ⬇ peripheral edema formation?
    - ? Cote (1988) - ankle immersion in ice water actually increased edema formation
  - Vasoconstriction ➡ ⬇ blood flow to periphery ➡ ⬇ delivery of nutrients & phagocytes

- Increased blood viscosity ➡ ⬆ resistance to flow ➡ ⬇ flow ➡ ⬇ edema in periphery
  - Trnavsky (1979) - cold pack application ⬆ blood flow ?
    - ? Baker & Bell (1991) - cold pack application did not reduce blood flow to calf muscle
      - ⬆ swelling & edema may be due to ⬆ in permeability of superficial lymph channels

- Maximum peripheral vasoconstriction reached at a skin temperature of 59^o F
  - During prolonged exposure to temperatures < 59^o F, vasodilation occurs due to:
    - Inhibition (⬇ conduction velocity) of constrictive nerve impulses
    - Axon reflex ➡ release of substance similar to histamine
    - Paralysis of contractile mechanisms
  - This is called reactive hyperemia and has been termed the "Hunter's Response"
    - Maximum vasodilation occurs at 32^o F
    - Continued exposure ➡ alternating periods of vasoconstriction & vasodilation
    - Temperature never drops to or below that of initial vasoconstriction (frostbite protection)

Reflexes Associated with Cold Application



Physiological Responses to Cold Application

- Cooled blood circulated → hypothalamus stimulated → ↑ peripheral vasoconstriction
  - Reflex vasoconstriction effect & hypothalamus mediated effect are multiplicative
    - Effective flow change = effect of local reflex mechanisms X effect of central mechanisms
  - If cooled body part is large enough:
    - Shivering will occur
    - Blood pressure will be increased
- Decreased cellular metabolic activity → ↓ O_2 requirement → ↓ ischemic damage
  - ↓ vasodilator metabolite activity (adenosine, histamine, etc.) → ↓ inflammation
  - ↓ ischemic damage → ↓ cell death
- Decreased conduction velocity in peripheral nerves
  - ↑ threshold of firing of pain receptors (free nerve endings)
  - ↓ size of action potential fired by pain receptors
  - ↓ synaptic transmission of pain signals (impaired at 59^0 F, blocked at 41^0 – 50^0 F)
    - Most sensitive: small diameter mylenated Aδ fibers
    - Least sensitive: small diameter unmyelinated C fibers
- Contralateral limb flow may be reduced
  - Not anywhere near the same extent as the area of direct application
- Counter - irritation (crowding out pain signals at spinal cord level)

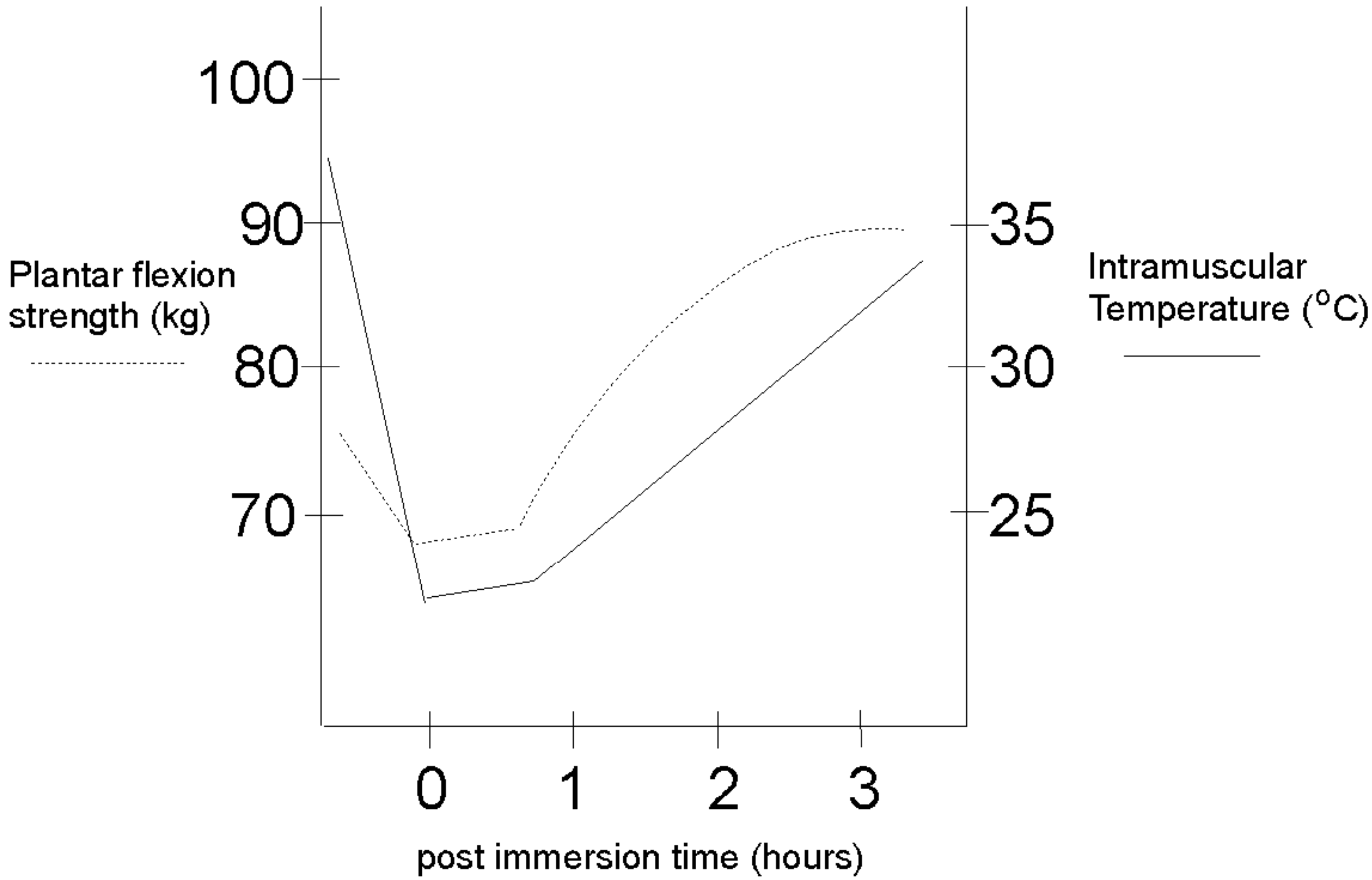
Physiological Responses to Cold Application

- Decreased inflammation via:
  - Inhibition of neutrophil activation
  - Inhibition of histamine release
  - Inhibition of collagenase enzyme activity
  - Inhibition of synovial leukocytes
- Decreased sensitivity of muscle spindles to stretch → ↓ muscle spasticity → ↓ pain
  - Helps breaks the pain → spasm → pain cycle
    - Due to inhibitory effect on ***Ia, II,*** and ***Ib*** afferent fibers and γ motor efferent fibers
  - GTO output also decreased (by as much as 50%)
- Increased joint "stiffness" mediated by ↑ viscosity of joint fluids and tissues
  - Intra-articular temperature is closely related to skin temperature
  - Intra-articular temp may ↓ from 2 - 7 ^{o}C depending on type & time of application
  - Loss of manual dexterity and joint range of motion

- **NOTE:** Cooling of tissues containing collagen during a stretch may help to stabilize collagen bonds in the lengthened position facilitating creep

Physiological Responses to Cold Application

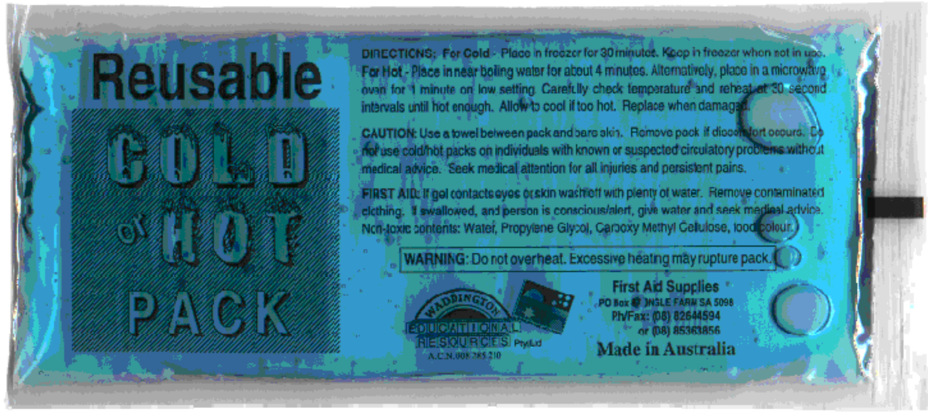
- Exposure to cold may ↑ muscle contraction strength possibly due to:
  - ↑ muscle blood flow
  - Facilitory effect on α - motor neurons



ApplicationTechniques for Cold

- Ice Packs - wet towel next to skin to minimize air interface, ice pack on top
  - Gel Packs - popular, possibly the most effective method of application
    - Jordan (1977) - 20 minute application ⬇ skin temperature by 30 ^{o}C
- Ice Massage - make cup “cicles”, rub ice over skin in overlapping circles
- Ice Baths-Whirlpools - ice water immersion
  - Disadvantages - initially more painful - difficult to incorporate elevation
  - Whirlpool allows water to be constantly circulated ➡ no “thermoplane” formation
    - Jordan (1977) - 20 minute application ⬇ skin temperature by 26.5 ^{o}C
- Vapocoolent Sprays - highly evaporative mixtures (ethyl chloride)
  - not used extensively in most settings
  - flouromethane banned by clean air act of 1991 - effective 1/1/96
  - sometimes used as local anesthetics for musculotendinous injections
- Cold Compression Units - cooled water pumped through inflatable sleeve
  - sleeve is activated periodically to “pump out” edematious fluid
  - pressure in sleeve should never exceed diastolic pressure
  - very popular as a treatment modality
  - Bauser (1976) “mean disability times” were ⬇ 5 days by adding compression
- Cryo-Kinetics - combining cold application with exercise (or stretching)

Cold / Hot Pack



Cold Compression Unit

General Principles of Cold Application

- Application duration of cold pack or ice pack
  - To acute injury : 15 – 30 minutes
    - Accompanied by compression and elevation
  - To decrease pain and swelling following exercise: 15 – 30 minutes
- Application duration of ice massage: 7 – 10 minutes
- Cold whirlpool – cryokinteics
  - Water temperature: 55^{o} - 64^{o} F

Indications for Cryotherapy

- Analgesia (pain relief):
  - Acute trauma
  - Post surgery
  - Analgesia usually achieved when temperature is ↓ 45 - 50 ^{o}F
  - Most well documented and currently popular use of cold application
- Reduce peripheral swelling & edema associated with acute trauma
  - Most effective with trauma to peripheral joints
    - Ankle, knee, elbow, shoulder, wrist, etc.
  - Less effective with deep muscle or deep joint trauma
    - Hip, thigh, etc.
- Reduce muscle spasms
- Reduce DOMS pain
- Reducing / preventing / treating inflammation in overuse injuries
  - Packing pitchers' arms in ice after a game
  - Putting ice packs on achilles tendons after a long run
  - Treating lateral epicondylitis with ice packs

Precautions for Cryotherapy

- Hypersensitivity reactions - cold urticaria
  - Histamine release → wheals (lesions with white center and red border)
- Systemic cardiovascular changes
  - ↑ heart rate ↑ blood pressure
    - Considerable variation among studies as to quantity of increase
      - One study showed a 50% ↑ in cardiac output
    - ↑ myocardial oxygen demand may adversely affect cardiac patients
- Cryoglobulinemia - the gelling (freezing) of blood proteins
  - Distension of interstitial spaces → tissue ischemia → gangrene
- Exacerbation of peripheral vascular disease
  - Ice application may ↓ blood flow to an already ischemic area
- Wound healing impairment
  - ↓ tensile strength of wound repair
- Raynaud’s Disease
  - Vasospastic activity from cold or anything that activates symp. outflow

Efficacy of Cryotherapy

- **A systematic review of the literature suggests that repeated applications of cryotherapy is better than superficial heating in acute ankle injuries but a single application was of no benefit.** (Bleakly 2004)

- **A systematic review of literature (only 4 clinical trial studies available) suggest that cryotherapy may have a positive effect on return to participation** (Hubbard 2004)

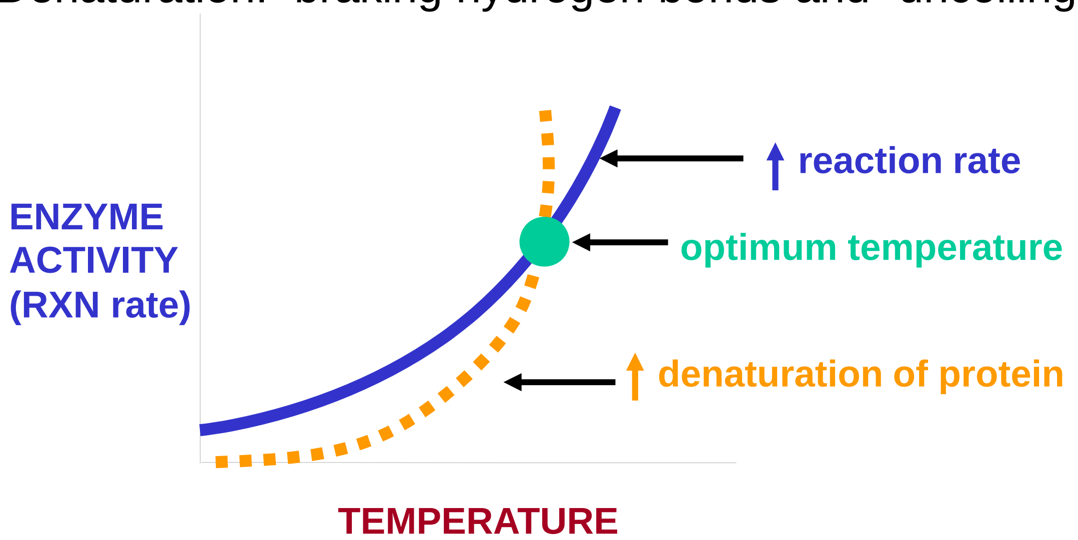
- **Cryotherapy was found to reduce pain and the need for pain medication in one study** (Levy 1993) **but not in another** (Leutz 1995)

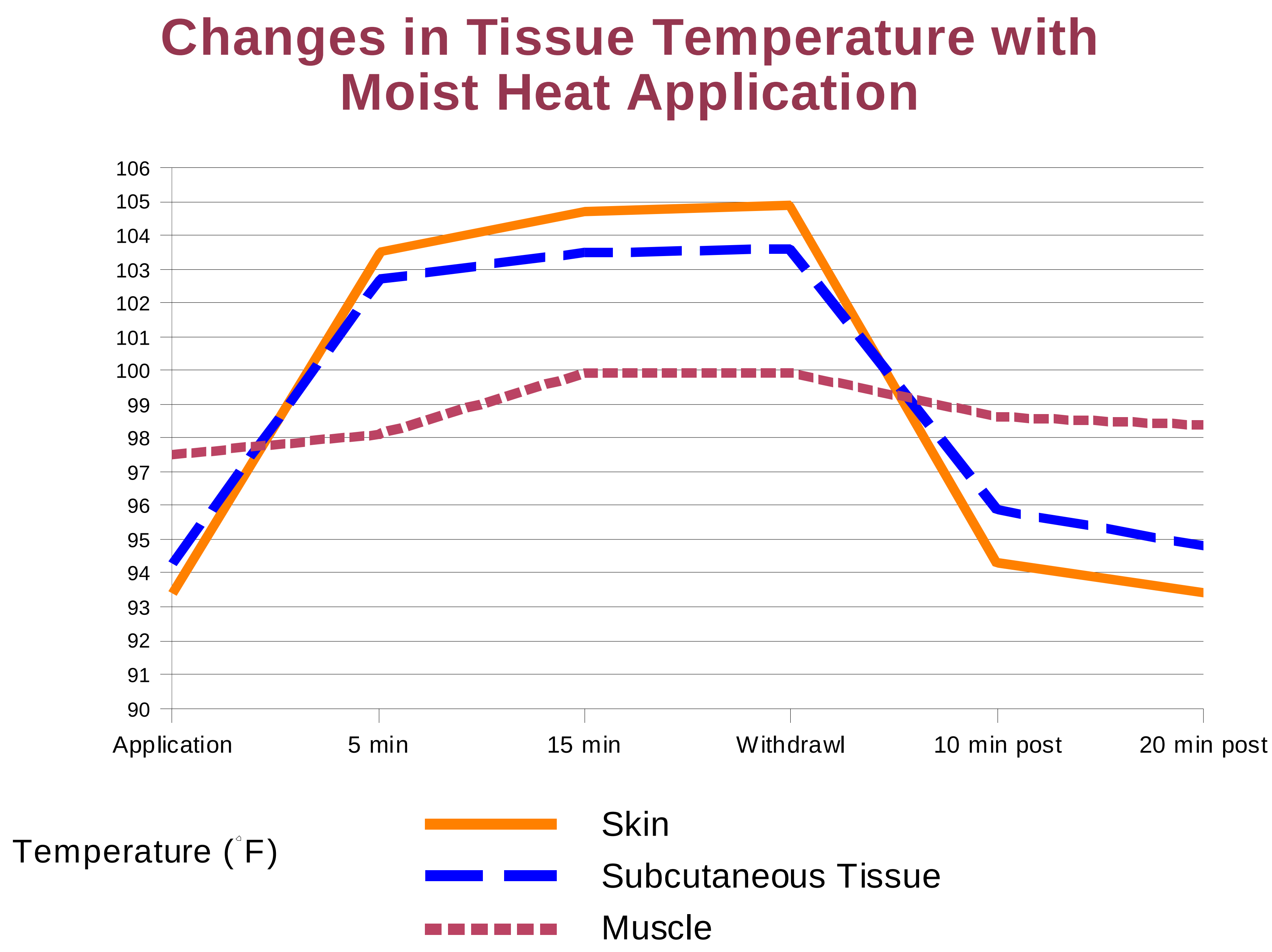
Heat Application

- **Two major categories of heat application**

  1. **superficial heat** (heat packs, paraffin,) 2. **deep heat** (ultrasound, diathermy)

- **General Principles of superficial heat application**
  - Heat is contraindicated for the first 48 – 72 hours following injury
  - Temperature increase greatest within .5 cm from surface
  - Maximal penetration depth: 1-2 cm - requires 15-30 minutes
  - Optimal tissue temperature is between 104 ^{o} F - 113 ^{o} F
    - Temperatures > 113 ^{o} F will denature protein in tissues
      - Denaturation: braking hydrogen bonds and “uncoiling” tertiary structure



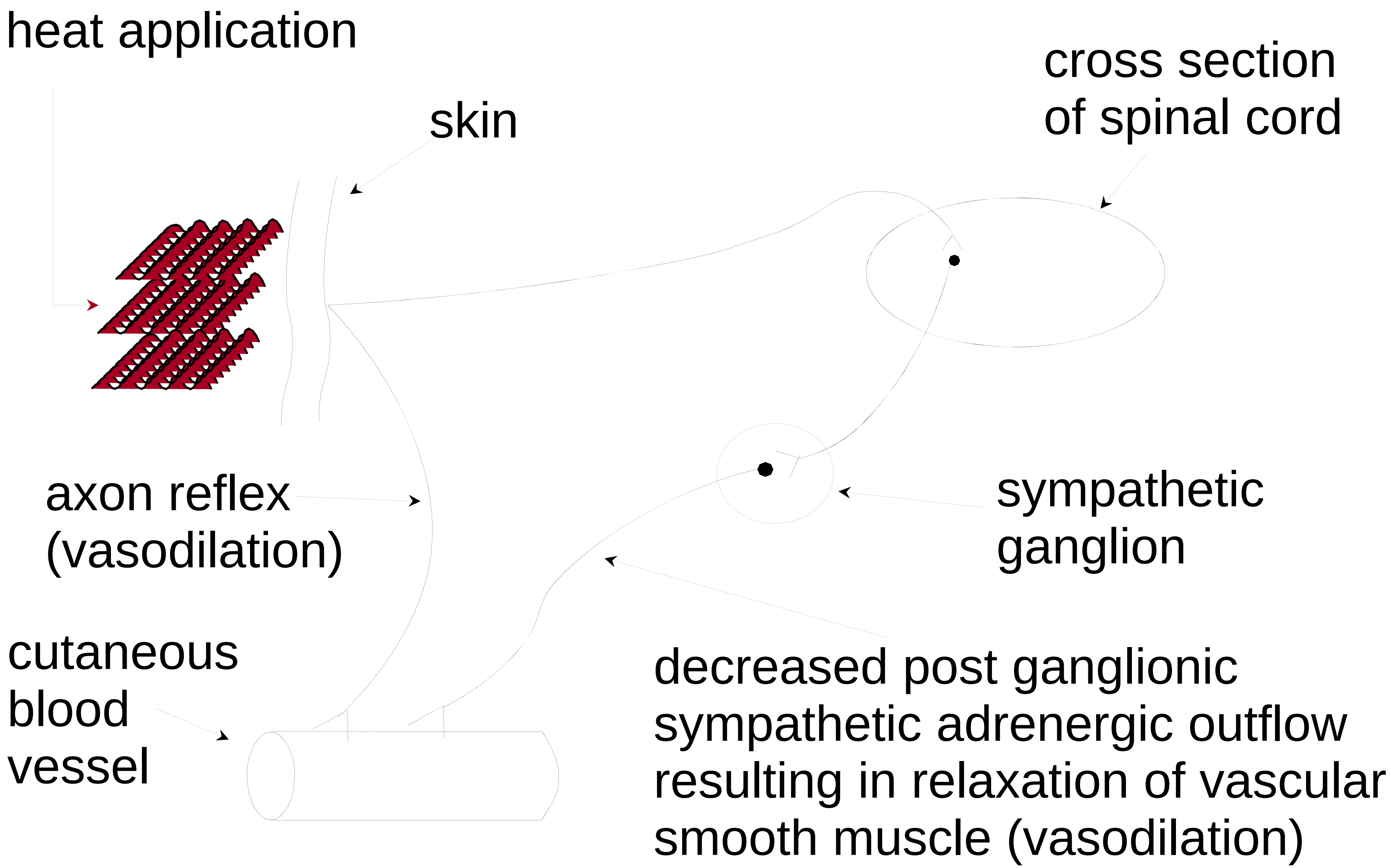


Changes in Tissue Temperature with Moist Heat Application
106
105
104
103
102
101
100
99
98
97
96
95
94
93
92
91
90
Application
5 min
15 min
Withdrawl
10 min post
20 min post
Temperature (°F)
Skin
Subcutaneous Tissue
Muscle

Physiological Responses to Superficial Heat Application

- Cutaneous vasodilation due to:
  - Axon reflex
    - Afferent skin thermoreceptor impulses cause relaxation of skin arteriole smooth muscle
  - Spinal cord reflex ➞ ⬇ post ganglionic sympathetic outflow
  - Direct activation of vasoactive mediators (histamine, prostaglandins, & bradykinin)
    - ⬆ capillary and venule permeability +⬆ in hydrostatic pressure ➞ mild edema ?
    - ⬆ blood flow ➞ ⬆ lymphatic drainage ➞ ⬇ edema ?
  - Reflex vasodilatory response of areas not in direct contact with heating modality
    - Heat applied to low back of PVD patients ➞ ⬆ cutaneous flow to feet
- ⬆ Metabolic activity (⬆ cellular VO2 - 13% for each 2° F rise in temperature)
  - May ⬆ hypoxic injury to tissues if applied to early
  - ⬆ Phagocytosis
  - ⬆ CO_2 production, ⬆ lactate production, ⬆ metabolite production
    - Pathogenic if venous circulation or lymphatic drainage is impaired
  - ⬇ pH
- ⬆ Sensory nerve velocity
  - Most pronounced changes coming in the first 3.5 ° F increase in temperature
- ⬇ Firing of muscle spindle ➞ ⬇ α-motor neuron activity ➞ ⬇ muscle tension & spasms
  - Facilitated by ⬇ firing of type II afferents and γ efferents

Reflexes Associated with Heat Application



Physiological Responses to Superficial Heat Application

- **Analgesia - thought to be due to:**
  - Counter-irritation
  - ↑ in circulation & lymphatic drainage → ↓ edema → ↓ pressure on free nerve endings
  - ↑ circulation → removal of inflammatory pain mediators ? (in contrast with direct activation)
  - Elevation of pain threshold on and distal from the point of application
    - May be useful in facilitating therapeutic stretching and mobilization exercises
- **Acute reduction in muscle strength**
  - ↓ Availability of ATP (used up by ↑ metabolism)
- **Increased tissue extensibility**
  - Facilitated by ↓ in the viscosity of tissue fluids

- **Notes:**
  - Maximal & constant heat application for > 20 minutes → rebound vasoconstriction
    - body's attempt to save underlying tissue by sacrificing the outermost layer
    - modalities such as hot packs ↓ this problem because heat dissipates over time

  - Skeletal muscle blood flow is primarily under metabolic regulation
    - Best way to ↑ skeletal muscle blood flow is via exercise

Indications for Superficial Heat Modalities

- Analgesia (most frequent use)
  - some therapists argue that this should be the only use
- Treatment of acute or chronic muscle spasm
- ↑ ROM – ↓ caused by joint contractures & stiffness
- ↓ subcutaneous hematoma in post-acute injuries
- ↑ skin pliability over burn or skin graft areas
- ↑ pliability of connective tissue close to surface

General Principles of Application

- ↑ tissue temperature to 104 ^{o}F - 113 ^{o}F
- Application duration: 20 - 30 minutes

Application Techniques for Superficial Heat

- **Hot Packs (Hydrocollator packs, gel packs)**
  - Hot packs placed on top of wet towel layers (minimize air - body interface)
  - Do not lie on top of heat packs - check after 5 minutes for skin molting
    - water squeezed from pack will accelerate heat transfer → ↑ danger of skin damage
- **Paraffin**
  - Melting point of paraffin is 130 ^{o} F but remains liquid at 118 ^{o} F when mixed with mineral oil
  - Mineral oil / paraffin combination has a low specific heat
    - It is not perceived as "hot" as water at that same temperature
    - Heat is conducted slowly → tissue heats up slowly → ↓ risk of heat damage
  - Dip & wrap method of application
    - Extremity is dipped in paraffin mix 9 - 10 times to form a glove
    - Extremity is then covered with a plastic bag & towel
  - Dip & re-immerse method of application
    - Extremity is dipped in paraffin mix 9 - 10 times to form a glove
    - Extremity is then re-immersed in mixture
    - This method increases temperature to a greater degree than the dip & wrap method
  - Method of choice for increasing skin pliability (plasticity)
    - Paraffin is "painted on" areas than cannot be immersed
    - Treatment is usually done daily for 2 - 3 weeks

Paraffin Bath

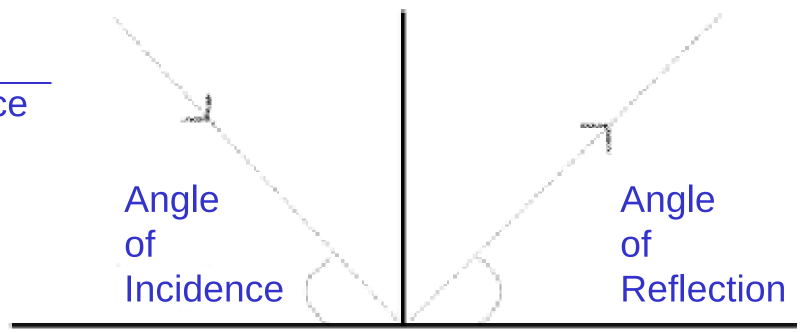
Hydrocollator hot pack heater

ApplicationTechniques for Superficial Heat

- **Fluidotherapy - convection via circulation of warm air using cellulose particles**
  - Circulating air suspends cellulose particles ➞ low viscosity mixture that transfers heat
  - Limbs easily exercised in the particle suspension - open wounds can be covered & inserted
  - Higher treatment temperatures can be tolerated
  - Temperatures: 110 º F - 120 º F penetration depth: 1 - 2 centimeters
- **Radiant Heat - heat energy emitted from a high temperature substance**
  - Not used very often today
  - Types of infrared heat
    - Far infrared - invisible - λ = 1500 - 12,500 nanometers - penetration depth = 2 mm
      - absorption & wavelength: the higher the λ ➞ ↓ penetration depth and ↑ skin temperature
    - Near infrared - visible - λ = 770 - 1500 nanometers - penetration depth = 5 -10 mm
      - absorption & wavelength: the lower the λ ➞ ↑ penetration depth and ↓ skin temperature
  - Heat intensity is proportional to
    - Wattage input
    - Distance of the lamp from the point of application on the skin
    - Angle at which the light strikes the point of application on the skin (optimal angle 90º)

$$E_T = \frac{E_S}{D^2 \times \text{cos of the angle of incidence}}$$

E_T = heat energy imparted to the tissues
E_S = heat energy given off by the source
D = distance of heat source from the tissues



Radiant Infrared Heat lamp

ApplicationTechniques for Superficial Heat

- **Contrast Baths**
  - Uses: subacute and chronic injuries
    - May be used as a transition between cold and heat
  - Hot:Cold = 3:1 or 4:1 Hot water
    - (Whirlpool) 105-110° F   Cold water 45-60° F
  - Alternating vasoconstriction and vasodilation
    - ↓ Edema and ↑ removal of necrotic cells and waste ???
      - Previously thought to create pumping action …now that theory has been disproven

Contraindications for Superficial Heat Application

- Malignancy in area treated
- Ischemia in area treated
  - ↑ metabolism → ↑ need for O_2 → ↑ in circulation cannot keep pace
- Loss of sensation in area treated
  - ↑ risk for tissue burns & associated damage
- Acute hematoma or hematoma of unknown etiology
- Phlebitis
- Predisposition to bleeding & coagulation disorders

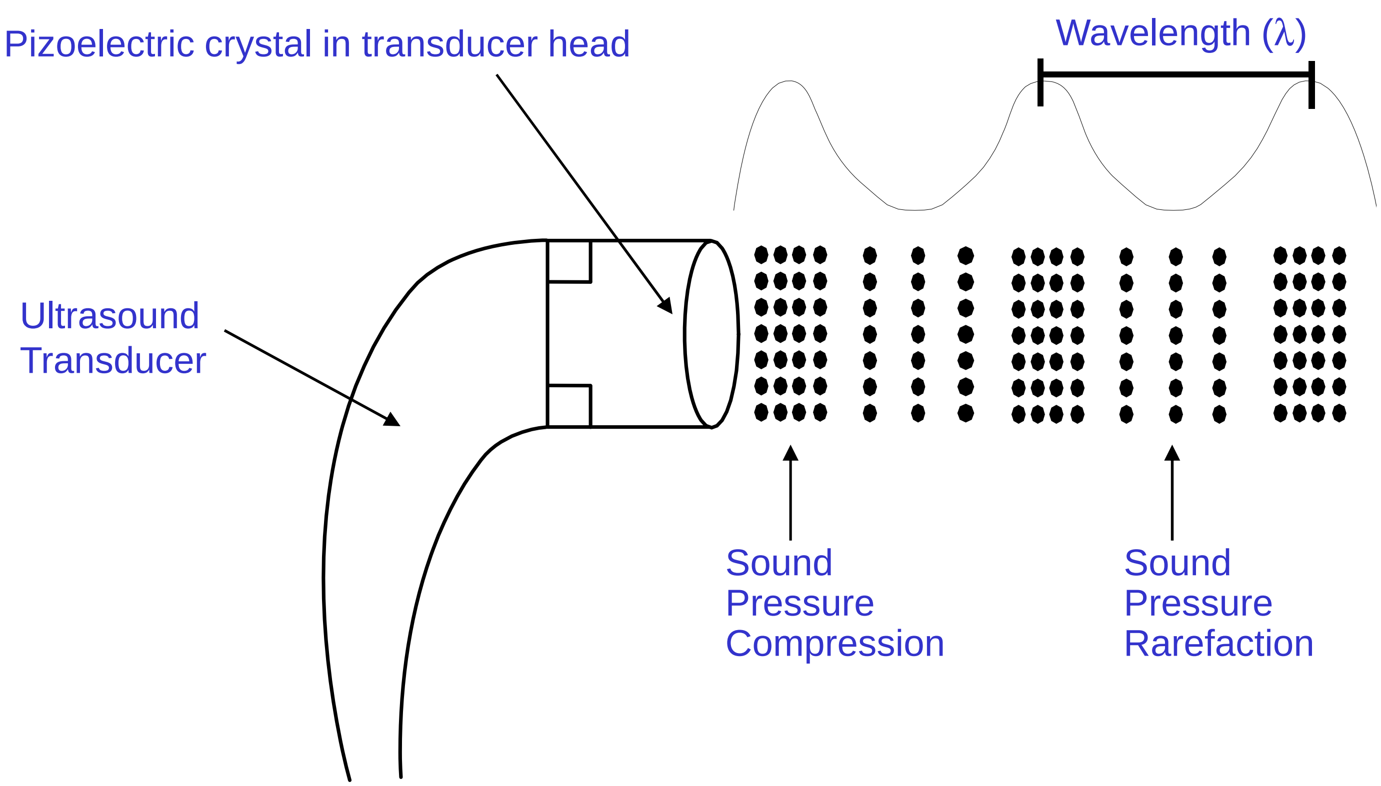
Deep Heat - Ultrasound

- **Sound - propagation of vibratory motion**
  - Chemical bonds hold molecules together
  - One molecule vibrates ➞ vibration transmitted to neighbor molecule
- **Sound (ultrasound) properties**
  - Frequency (F) - number of vibratory oscillations (cycles) / sec (Hertz -Hz)
    - Human ear hearing range: 16 Hz - 20,000 Hz
    - Therapeutic ultrasound: 750,000 Hz - 3,000,000 Hz (.75 MHz - 3 MHz)
  - Wavelength (l) - distance between 2 successive peaks in pressure wave
    - Time passes before vibration in one molecule is transmitted to the next
    - Vibration in second molecule always lags behind first
      - Asynchronous oscillation - being out of phase
      - Phase delay ➞ areas of sound pressure compression and pressure rarefaction
      - Areas of pressure compression & rarefaction form pressure waves
  - Velocity = Frequency X Wavelength
    - Average soft tissue velocity = 1540 m / sec ➞ at F of 1 Mhz λ = 1.5 cm
  - Intensity - rate at which sound energy is delivered / cm^2 of surface area
    - measured in Watts / cm^2

Ultrasound Machine & Coupling Agent Dispensers

Generation of Ultrasound

- **Pizoelectric effect - generated by pizoelectric crystals**
  - Crystals produce + & - charges when they expand or contract
  - Reverse pizoelectric effect
    - Occurs when an electric current is passed through the crystal
    - Crystal expands & contracts at frequencies that produce ultrasound



Generation of Ultrasound

- **Properties of ultrasound**
  - The higher the sound frequency, the less the propagation wave diverges
    - Ultrasound beams are well collimated (travel in a straight line)
  - Like electromagnetic energy, ultrasound energy can be:
    - Transmitted through a medium
    - Totally reflected back toward the point of generation
    - Refracted (bent)
    - Absorbed or attenuated (loose energy)
  - In tissues, ultrasound is transmitted, absorbed, reflected, or refracted
    - Absorption of ultrasound energy generates heat
    - At higher F's, more tissue friction must be overcome to propagate beam
      - The more friction that must be overcome, the more heat is generated
        - The more friction that must be overcome, less energy left for propagation
        - Higher frequencies of ultrasound penetrate less deep before being absorbed
        - 3 MHz frequency used to treat tissues at depths of 1 cm to 2 cm
        - 1 MHz frequency used to treat tissues > 2 cm from the surface

Reflection of Ultrasound & Sonography

- Ultrasound is reflected at the interface of different tissues
  - reflection amount & time until reflection returns to transducer can be charted
    - image construction: sonogram (depth, density, & position of tissue structures)

Amount of Ultrasonic Reflection (Acoustic Impedance)

Interface	Energy Reflected
water-soft tissue	.2%
soft tissue - fat	1%
soft tissue - bone	15-40%
soft tissue - air	99.9%

highly reflective surfaces include:

1) muscle tendon junctions
2) intermuscular interfaces
3) soft tissue-bone

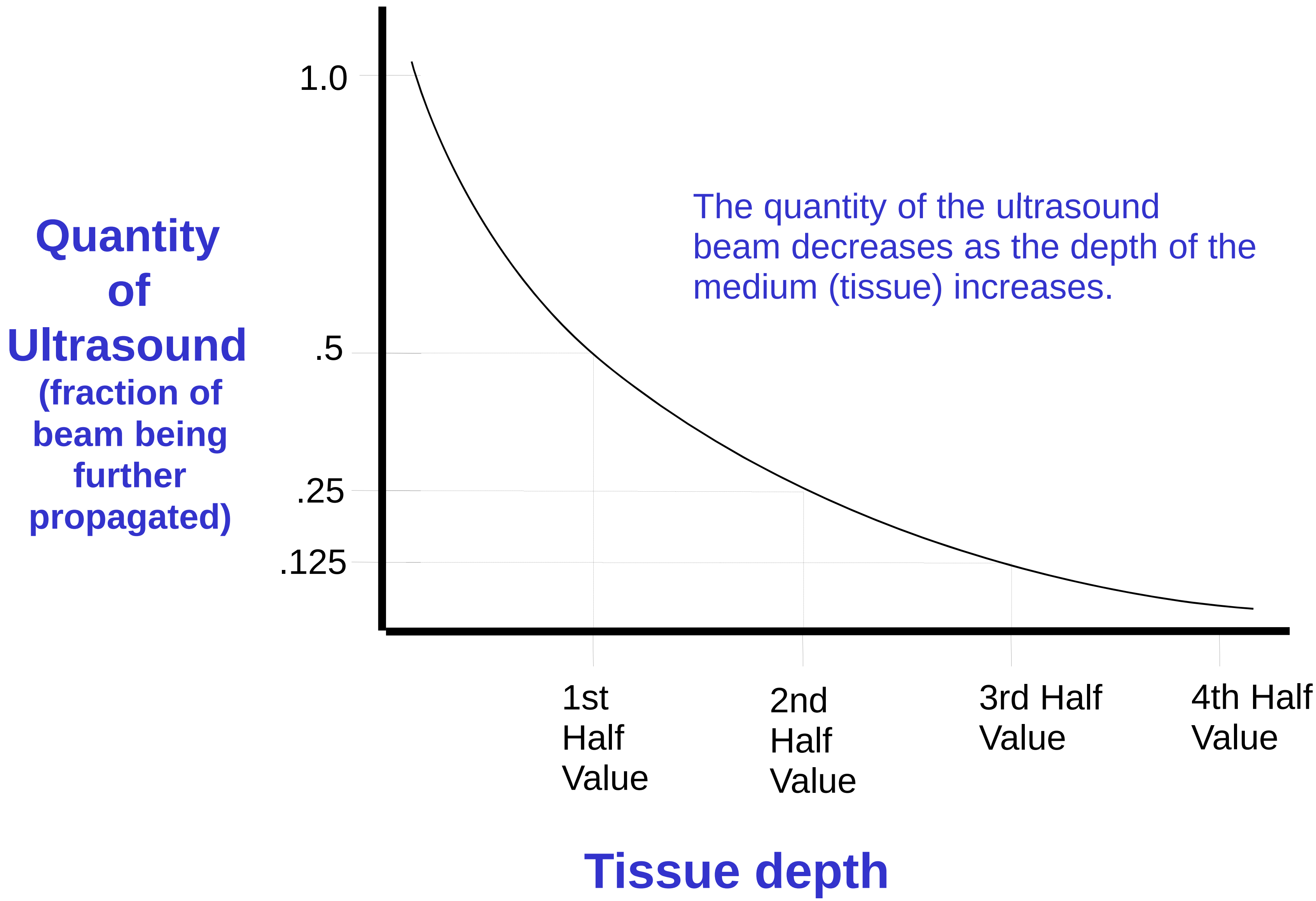
Attenuation of Ultrasound

- The higher the tissue H_2O content, the less the attenuation
- The higher the tissue protein content, the more the attenuation

<u>attenuation of 1 MHz beam</u>

- Blood 3% / cm
- Fat 13% / cm
- Muscle 24% / cm
- Skin 39% / cm
- Tendon 59% / cm
- Cartilage 68% / cm
- Bone 96% / cm

Exponential Attenuation



Attenuation of Ultrasound

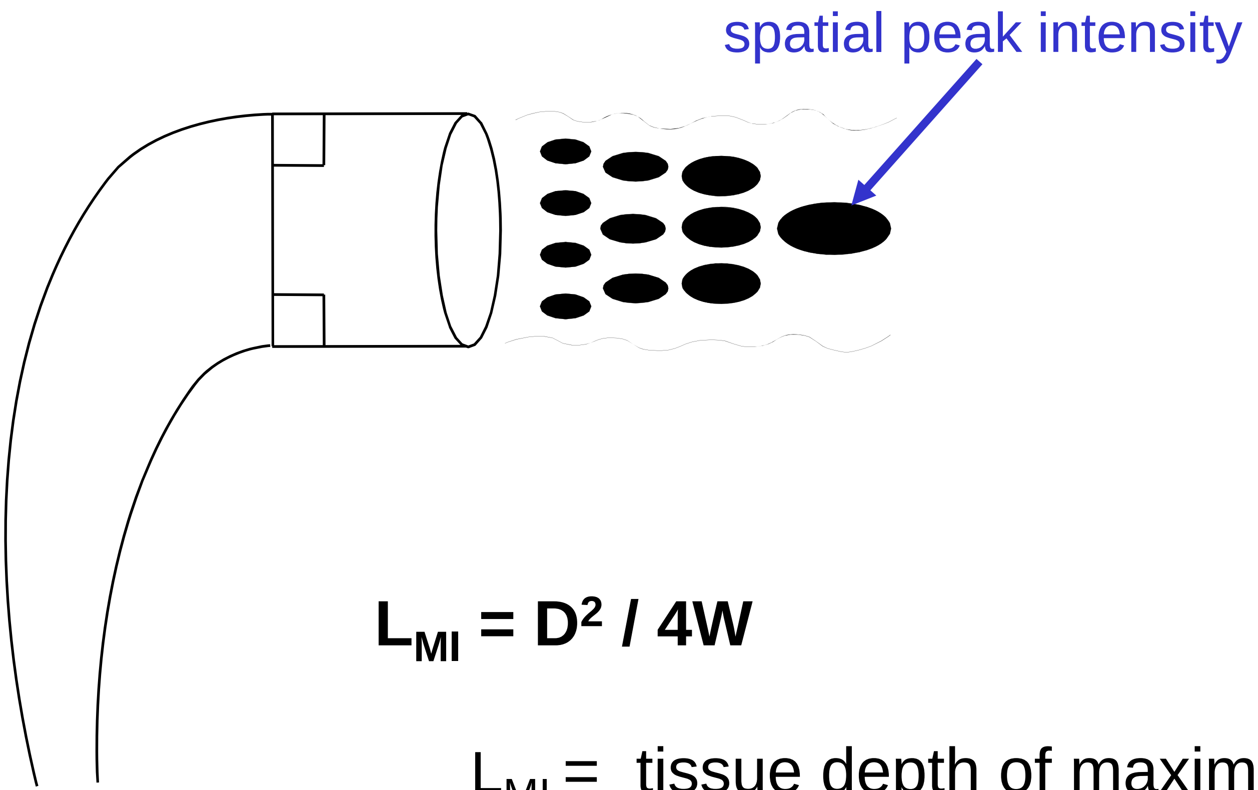
- **Half value thickness (centimeters)**
  - tissue depth at which 1/2 of the sound beam of a given frequency is attenuated

	Fat	Muscle	Bone
@ 1 MHz	15.28	2.78	.04
@ 2 MHz	5.14	1.25	.01
@ 3 MHz	2.64	.76	.004

Ultrasound Intensity (Sound Pressure)

- Ultrasound Intensity - “pressure” of the beam
  - rate at which sound energy is delivered (watts / cm^2)
- Spatial Average Intensity (SAI) - related to each machine
  - watts of US energy / area (cm^2) of transducer head
  - normal SAI = .25 - 2 watts / cm^2
  - maximal SAI = 3 watts / cm^2
  - intensities > 10 watts / cm^2 used to destroy tissues
    - lithotrypsy - destruction of kidney stones
  - intensitites < .1 watts / cm^2 used for diagnostic imaging
- Spatial Peak Intensity (SPI) - highest intensity within beam
- Beam Non-uniformity Ratio - can be thought of as “SPI/SAI”
  - the lower the BNR the more even the distribution of sound energy
  - BNR should always be between 2 and 6

Ultrasound Intensity Calculation



$$L_{MI} = D^2 / 4W$$

L_{MI} = tissue depth of maximum intensity
D = diameter of transducer head
W = ultrasound wavelength

Types of Ultrasound Beams

- **Continuous Wave** - no interruption of beam
  - best for maximum heat buildup
- **Pulsed Wave** - intermittent "on-off" beam modulation
  - used for non-thermal effects
  - builds up less heat in tissues ➞ used for post acute injuries
  - duty cycle - (pulse length) / (pulse length + pulse interval)
  - temporal peak intensity (TPI)
    - peak intensity during the "on" period
  - temporal average intensity (TAI)
    - mean intensity of both the "on" and "off" periods
    - duty cycle (%) X TPI
    - example:
      - duty cycle: 20%, TPI = 2 watts/cm ^{2} ➞ TAI = .4 watts/cm ^{2}

Physiological Effects of Ultrasound

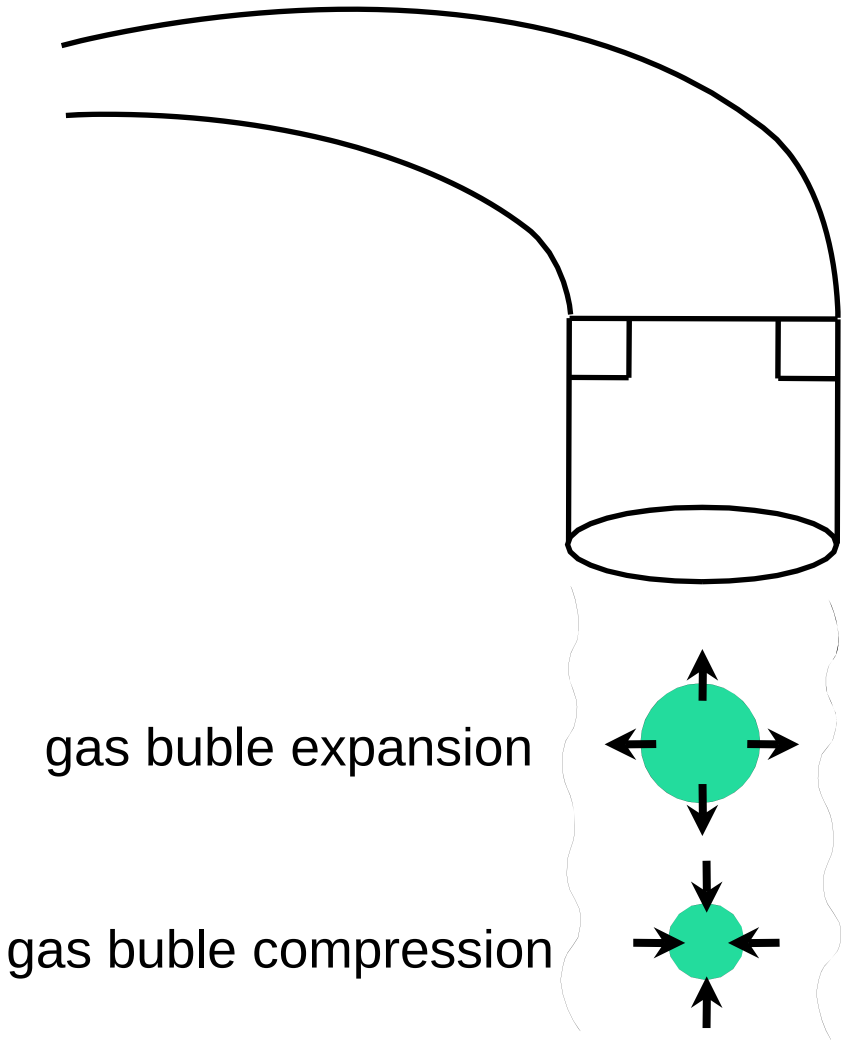
- **<u>Thermal effects</u>** (minimum 10 min - 2.0 watts - 1 Mhz)
  - ↑ blood flow
    - ↓ inflammation and ↓ hematoma (remains controversial)
  - ↑ enzyme activity
  - ↑ sensory and motor nerve conduction velocity
  - ↓ muscle spasm
  - ↓ pain
  - ↑ extensibility of connective tissue & possibly scar tissue
  - ↓ joint stiffness

Physiological Effects of Ultrasound

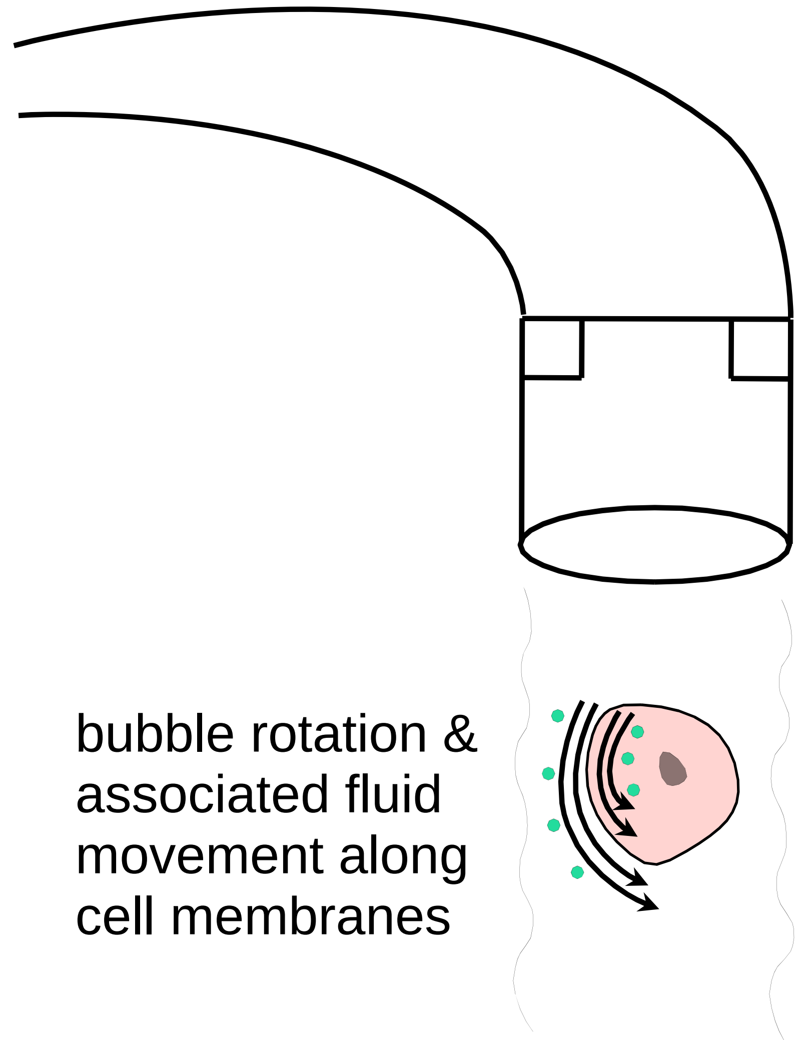
- **Non-thermal effects**
  - cavitation
    - alternating expansion & compression of small gas bubbles
    - may cause ↑ cell membrane & vascular wall permeability
    - unstable cavitation may cause tissue damage
      - unstable cavitation - violent changes in bubble volume
  - microstreaming
    - bubble rotation → fluid movement along cell walls
    - changes in cell permeability & ion flux → ↓ healing time
      - May enhance entry of Ca^{++} into fibroblasts and endothelial cells
- **Possible therapeutic benefits of non-thermal effects**
    - difficult to make distinction from thermal benefits
  - ↑ capillary density & ↑ cell permeability
  - ↑ fibroblastic activity and associated collagen production
  - ↑ cortisol production around nerve bundles → ↓ inflammation

Non-thermal Effects of Ultrasound

Cavitation



Microstreaming



Ultrasound Adverse Effects & Contraindications

- **Adverse effects associated with ultrasound**
  - potassium leakage from red blood cells
  - ↑ platelet aggregation → ↓ microscopic blood flow
  - damage to tissue endothelium
- **Contraindications to ultrasound**
  - throbophlebitis or other blood clot conditions
  - fractures ? (studies exist suggesting ultrasound may help)
  - epiphyseal injuries in children
  - vascular diseases (embolus formation - plaque rupture)
  - spinal column injuries (treat low back pain with caution)
  - cancer (danger of metastases)
  - do not apply directly over heart (pacemaker concerns)
  - do not apply to reproductive organs (pregnancy)

Ultrasound Coupling Agents

- **Coupling Agent** - substance used to transmit sound to tissues
  - must be viscous enough to fill cavities between transducer & skin
    - air interface must be minimized
  - must not be readily absorbed by the skin
  - must have acoustic impedance similar to human tissue
    - necessary to prevent undue reflection & absorption

- **Examples of coupling agents**
  - ultrasound gel
  - gel pack
  - water submersion
    - best when treating areas with irregular surface (ankle, hand, etc)
    - ceramic container is best because it reflect the sound waves

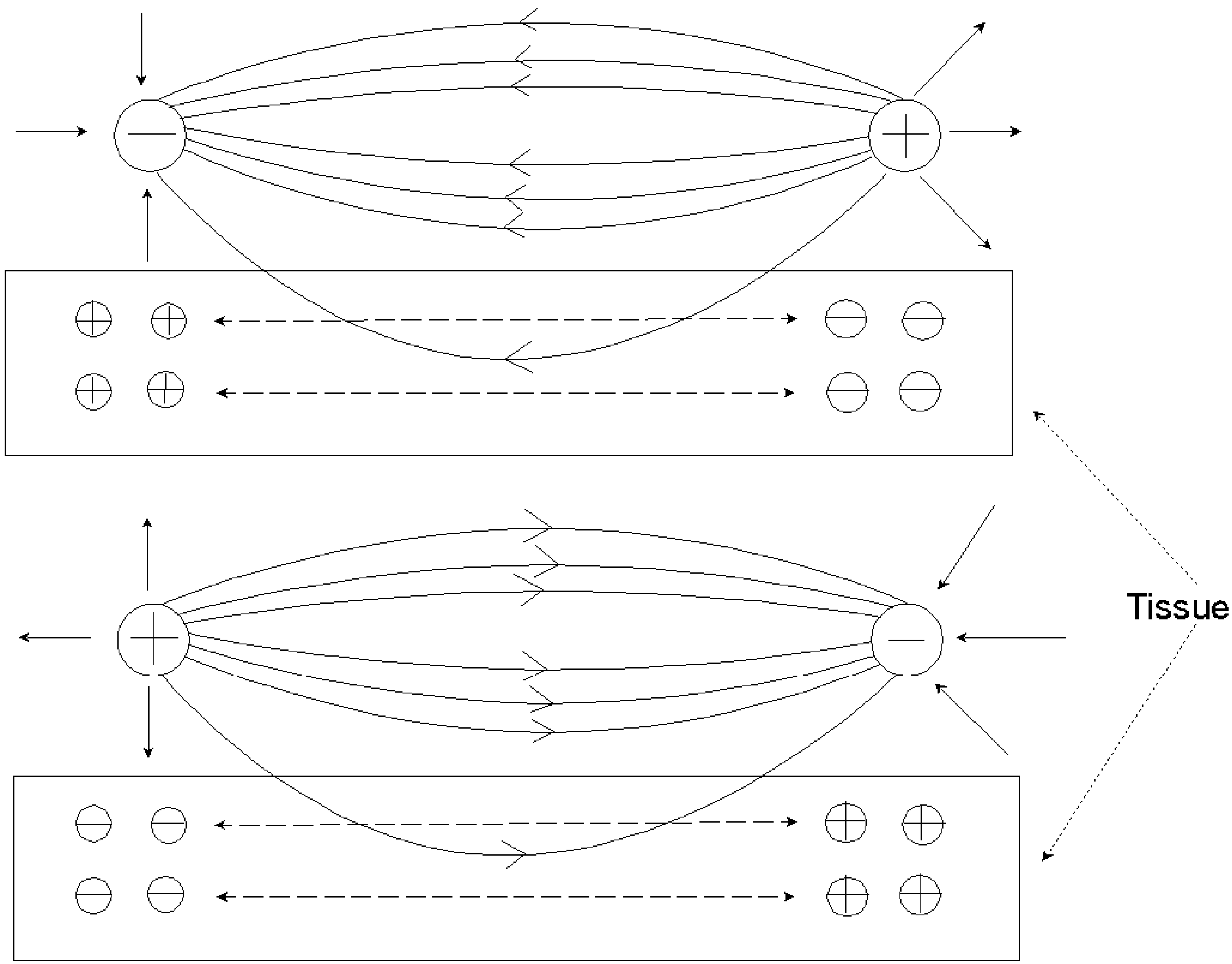
General Principles of Ultrasound Application

1) clean affected area to be treated
2) spread coupling agent over area with transducer (machine is off)
3) reduce intensity to 0 & turn power on (keep transducer on skin)
4) set timer to proper duration
5) start the treatment
6) ↑ intensity while moving transducer in circular motion of about 4 cm/sec
7) treatment area should be 2-3 X transducer head area per 5 minutes
8) if periosteal pain is experienced, move the transducer at a faster pace
9) if more gel is needed, press “PAUSE”, apply gel, then resume treatment
10) treatment can be given once a day for 10 - 14 days

Diathermy - "to heat through"

- **<u>Shortwave diathermy</u>** - non-ionizing electromagnetic radiation
  - non-ionizing - insufficient energy to dislodge orbiting electrons
    - electrons dislodged ➞ tissue destruction
      - example: DNA uncoupling of cancer tissue with radiation treatments
  - 27.12 Mhz - 11 meter wavelength - 80 watts power (most common)
    - more than 300 million times too weak to produce ionization
  - Mechanism
    - alternating current EM radiation causes tissue ions to move within tissues
    - in order for ions to move, resistance must be overcome ➞ friction ➞ heat
  - Contraindications
    - Ischemic areas, metal implants, cancer

Diathermy Mechanism

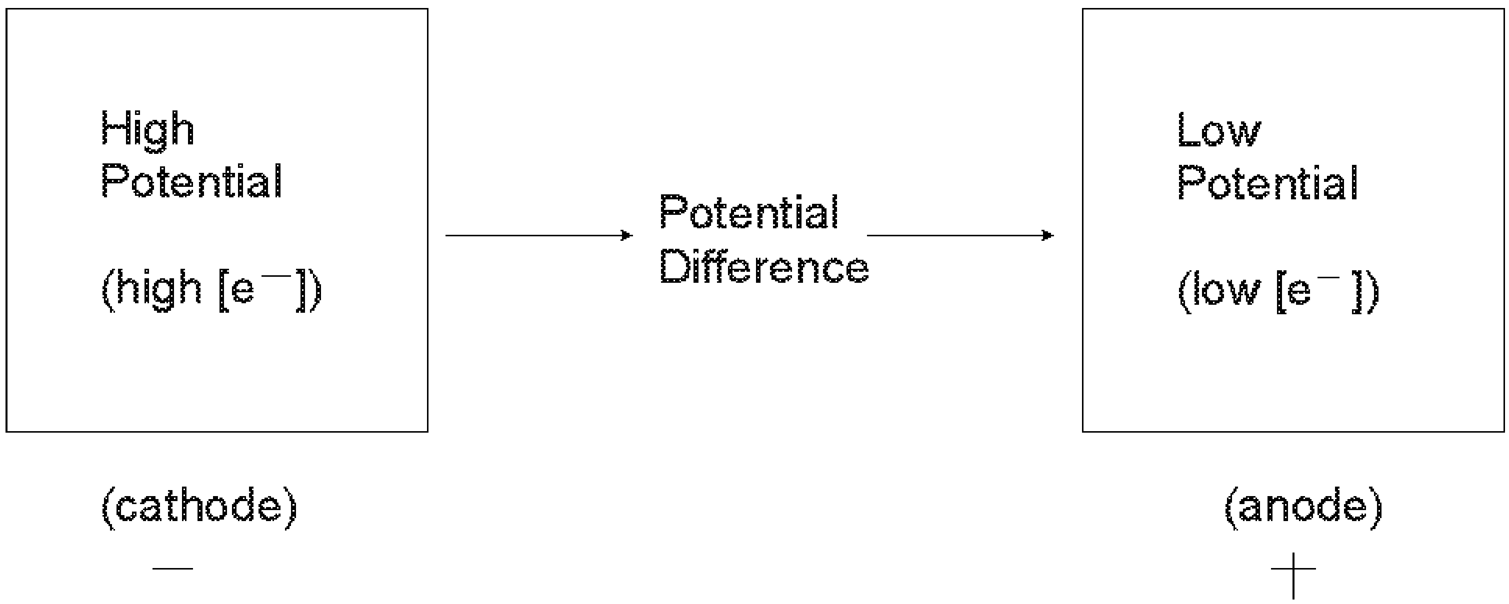


Electricity

- **Electricity** - flow of e^- from higher to lower concentration
  - cathode (-): point of high e^- concentration
  - anode (+): point of low e^- concentration
- **Voltage** - difference in e^- population between two points
  - voltage is a potential difference (electromotive force - electrical pressure)
  - higher voltages ➡ deeper penetration (depolarization of deeper tissues)
  - commercial current: 115 volts or 120 volts
  - devices using < 150 v termed "low voltage" - > 150 v "high voltage"
- **Amperage** - the intensity of an electric current
  - rate of e^- flow from cathode to anode: 1 amp = 6.25×10^{18} e^-'s / sec
  - intensity perception of electron flow to humans
    - 0-1 milliamps (mamps) — imperceptible
    - 1-15 mamps — tingling sensation and muscle contraction
    - 15-100 mamps — painful shock
    - 100-200 mamps — can cause cardiac and respiratory arrest
    - > 200 mamps — will cause instant tissue burning and destruction

Electrical Stimulation Machine

The Concept of Voltage in Electricity



Electricity

- **Resistance** - quantitative degree of impedance to e^- flow
  - resistance measured in Ohms
  - 1 Ohm - resistance developing .24 cal of heat when 1 amp flows for 1 sec.
  - resistance is inversely proportional to the diameter of the conduction medium
  - resistance is directly proportional to the length of the conducting medium
  - Ohms Law - relationship among intensity, voltage, and resistance

$$\text{Amperage (current } \textbf{flow}\text{)} = \frac{\text{Volts (electromotive } \textbf{pressure}\text{)}}{\text{Ohms (electrical } \textbf{resistance}\text{)}}$$

- **Wattage** - the power of an electric current
  - 1 Watt = 1 amp of current flowing with a pressure of 1 volt
  - Wattage = Volts X Amps

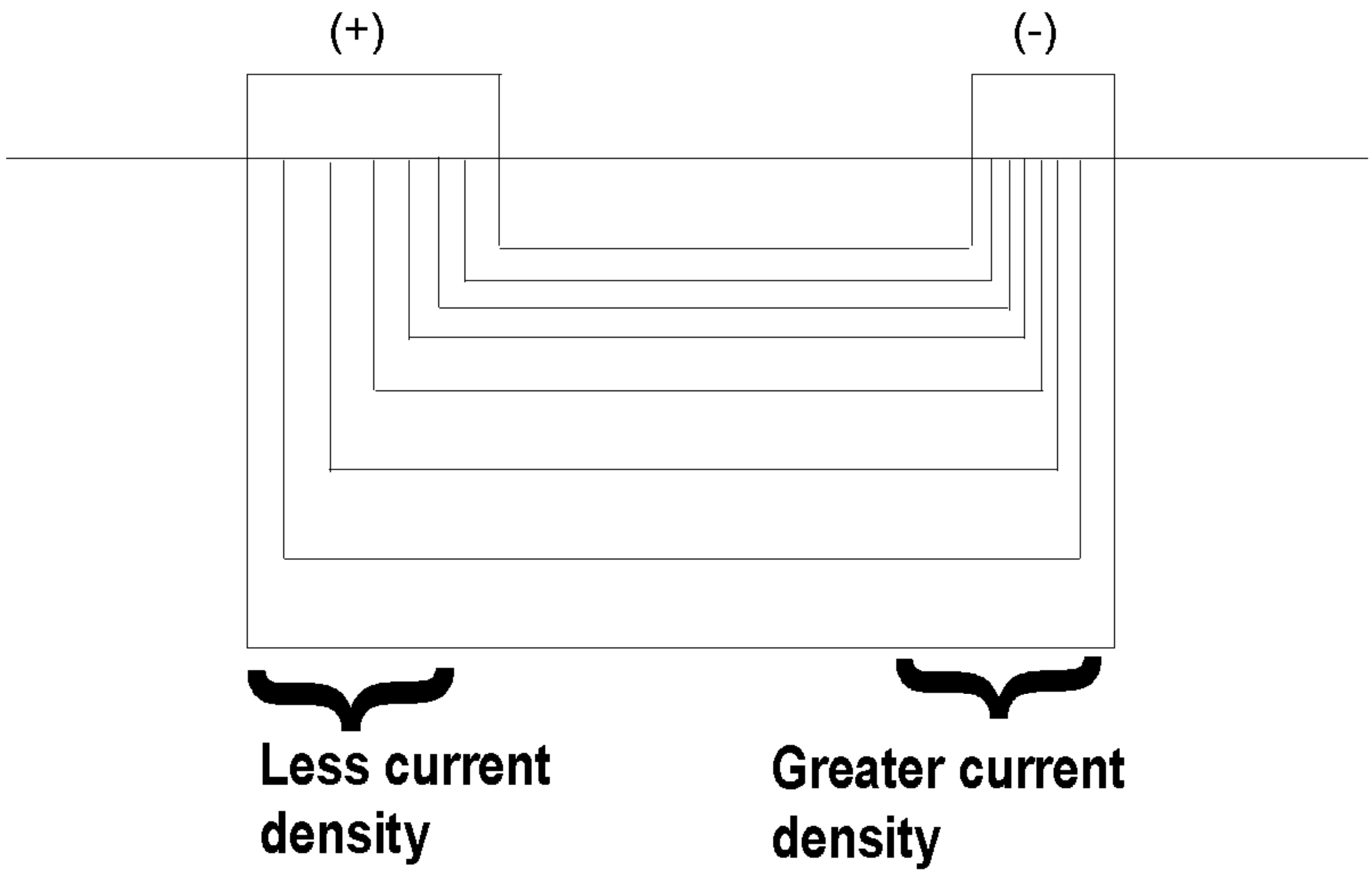
Electricity

- **Conductance** - the ease at which e^-'s flow through a medium
  - high conductance materials have high numbers of free e^-'s
    - silver, copper, electrolyte solutions
    - the greater the percentage of H_2O in tissues, the better the conductance
      - blood: highest ionic & H_20 concentration of any tissue ➡ best conductor
      - bone has the lowest H_2O percentage ➡ poorest conductor
  - low conductance materials have few free e^-'s
    - air, wood, glass, rubber
    - skin has keratinized epethleium (little H_20) ➡ insulator
      - necessitates skin preparation procedures for electrodiagnostic devices

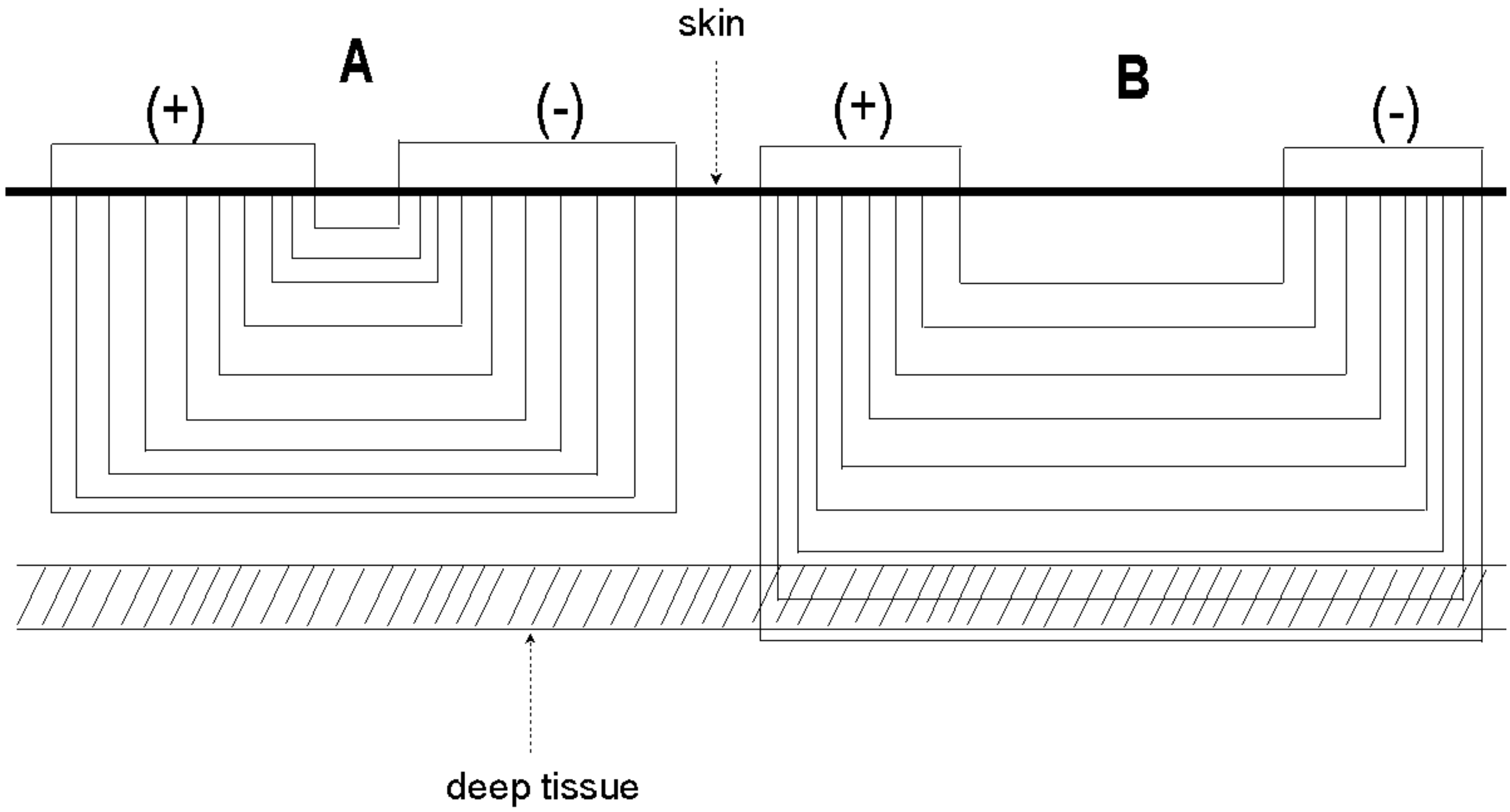
Electricity

- **Types of Electric Current**
  - Direct Current (DC) continuous flow of e^-'s in one direction
    - also called galvanic current
  - Alternating Current (AC) - e- flow in alternating directions
    - household current is AC current
    - a device powered by AC current can output DC current
    - AC current frequency: number of "direction changes" in AC current
      - usually 60 cycles / sec or 60 Hz
- **Electricity Waveforms**
  - Graphic representation of current direction, magnitude, & duration
  - "Modulation" - alteration of current magnitude and duration
  - Pulsatile current - interrupted current flow ("on" - "off" periods)
    - < 15 pulses / sec, the induced contractions are individual
    - between 15 & 25 pulses / sec, summation occurs → ↑ muscle tone
    - > 50 pulses / sec induces tetany
  - Current density (amps / cm2) - inversely related to electrode size

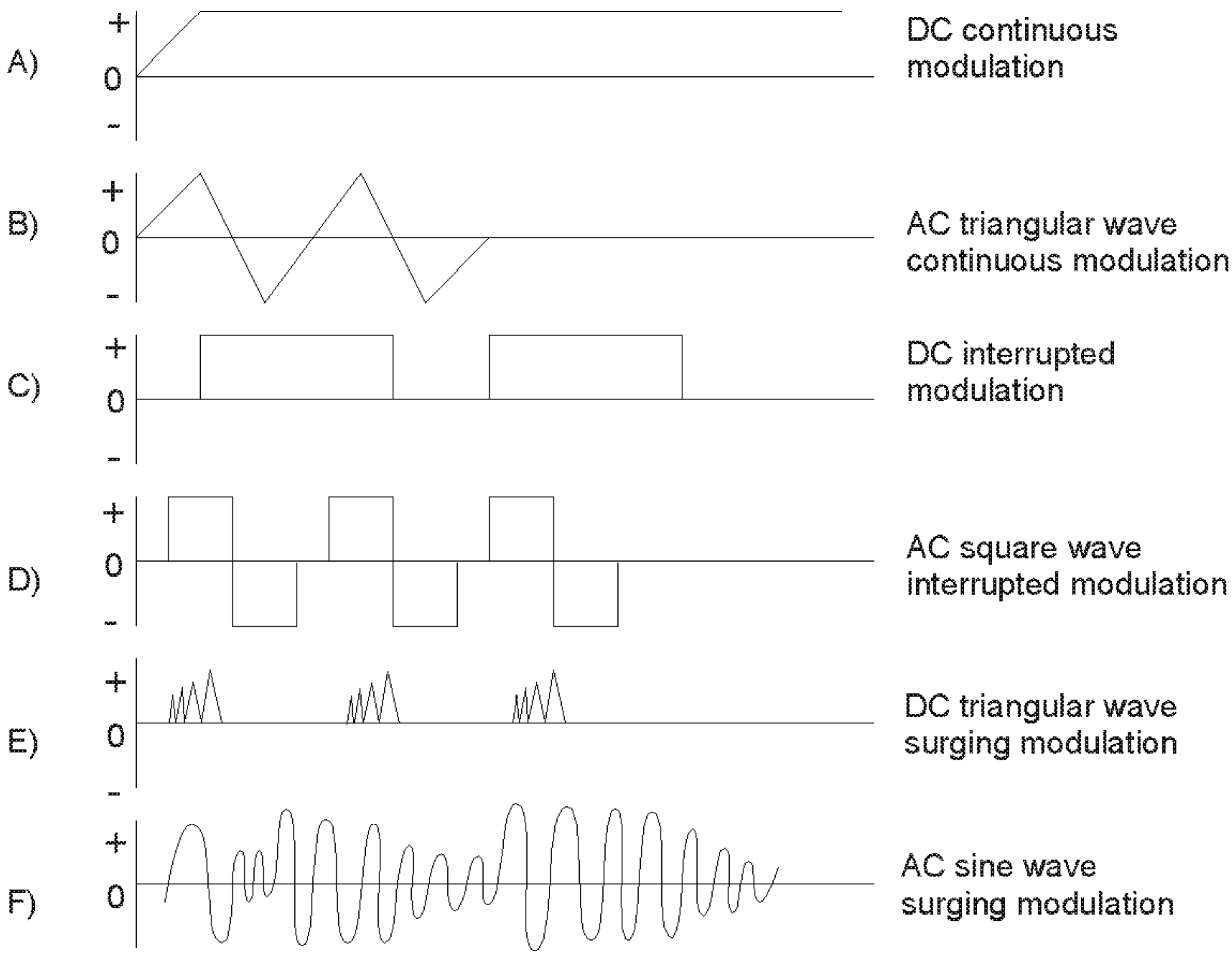
Electrode Size and the Density of an Electric Current



Penetration Depths of an Electric Current



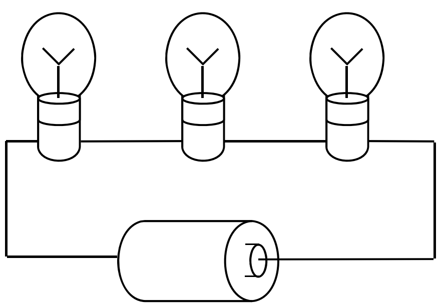
Electric Current Waveforms and Modulations



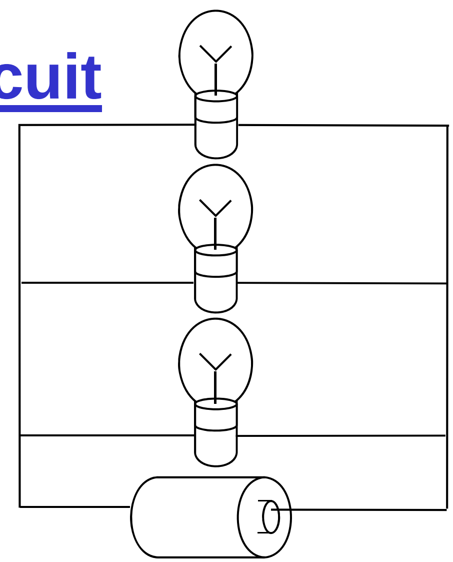
Electric Circuits

- **Series Circuit**
  - Only one pathway for flow of electrons to follow
  - Total resistance = sum of the resistances in each resistance element
    - $R_{total} = R_1 + R_2 + R_3$
    - voltage will decrease at each resistance component
- **Parallel Circuit**
  - More than one pathway exists for flow of electrons
    - $1 / R_{total} = 1 / R_1 + 1 / R_2 + 1 / R_3$
  - Voltage will not decrease at each resistance component

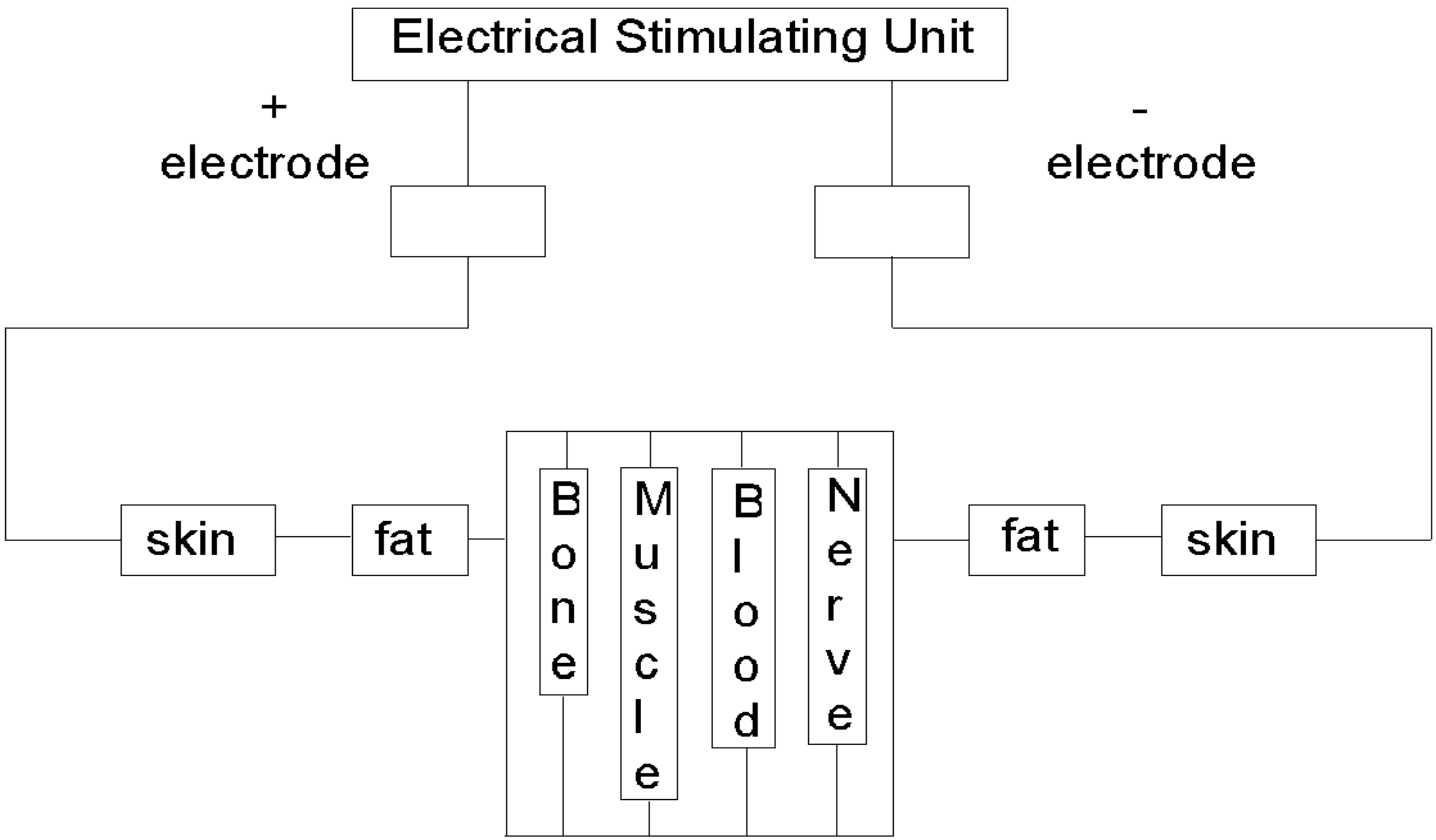
Series Circuit



Parallel Circuit



Electrical Circuits in the Body



Physiological Responses to Electricity

- Depends on frequency, modulation, & current density
- Muscle excitation → contraction → ↑ blood flow
- ↑ in capillary permeability (animal study)
- ↑ in quantity of aerobic enzymes in stimulated muscle
- ↓ quantity of anaerobic enzymes
- Muscle fiber hypertrophy
  - both type I and type II fibers
- Possible increase in proportion of type I fibers
- Stimulation of fibroblasts and osteoblasts
- Attenuation of the decrease in ATP-ase that is usually seen in immobilization

Physiological Responses to Electricity

- **As electricity enters the body…..**
  - e^- flow is replaced by ion movement toward opposite poles
- **At the negative pole…..**
  - the + ions cause an alkaline rxn ➞ protein breakdown
    - tissue softening
  - alkaline rxn kills bacteria
- **At the positive pole….**
  - the - ions cause an acidic rxn ➞ protein coagulation
    - tissue hardening
  - skin cell migration toward the pole
    - used in healing decubitis ulcers (bed sores)
- **Pulsing the current minimizes these effects**

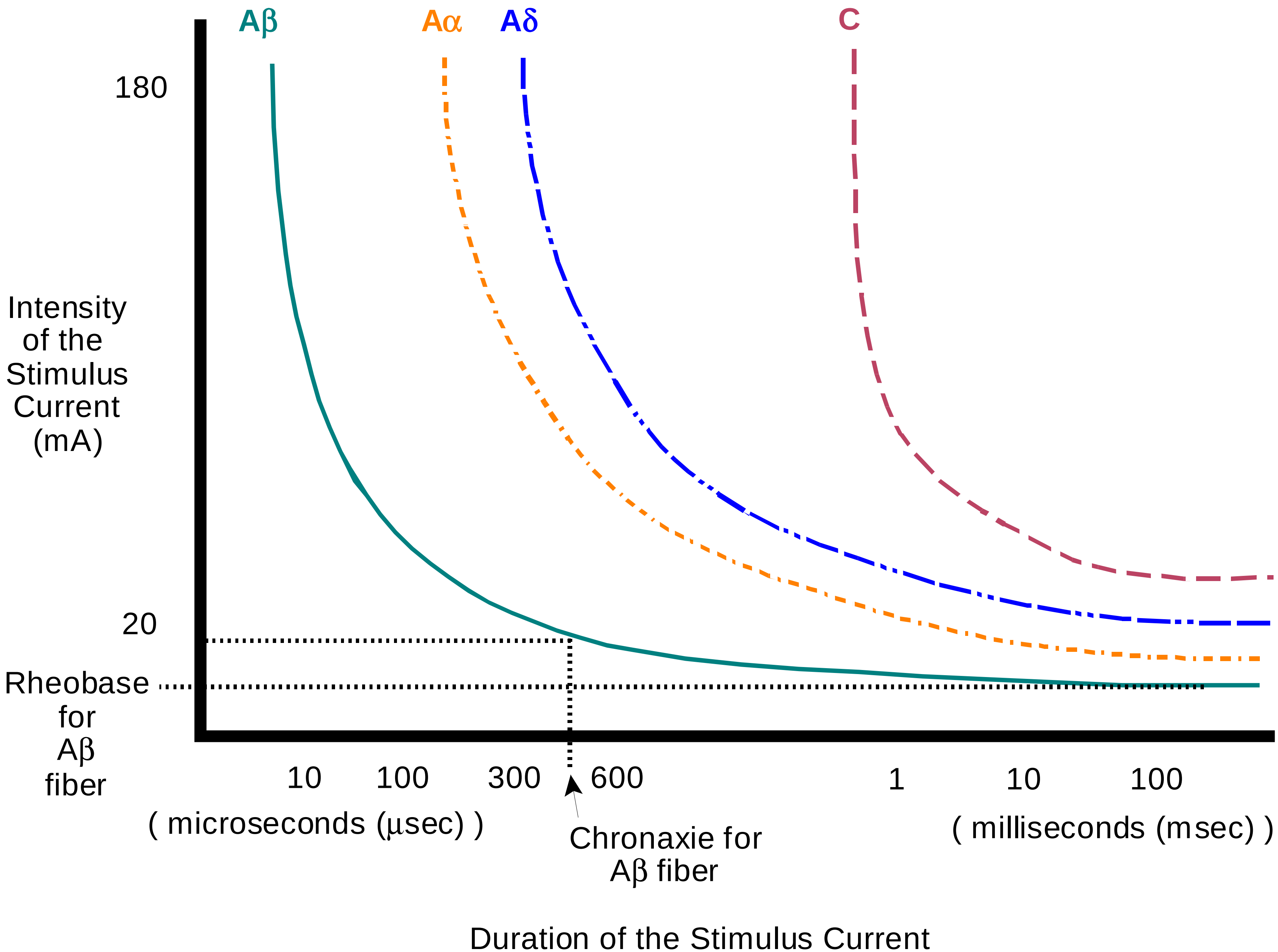
Clinical Uses of Electricity

- Low voltage uninterupted DC Current
  - **Wound healing** - bacteriocide & enhanced cell migration
  - **Fracture Healing** (non-union only)
    - cathode of DC current invasively placed near fracture site
    - produces electromagnetic field normally produced by bone ends
      - attracts osteoblasts (which have found to be electropositive)
  - **Pain Control**
    - high frequency, low amperage, currents induce counter-irritation
  - **Iontophoresis**
    - using electricity to “push” ion charged drugs into the epidermis
      - Dexamethasone
      - Lidocaine

Clinical Uses of Electricity

- **High Voltage Pulsed DC Current**
  - **Wound healing** - bacteriocide & enhanced cell migration
  - **Edema Reduction**
    - induced muscle contractions ↑ venous and lymphatic return ??
  - **Pain Control**
    - low frequency, high amperage → activation of desc. analges. system
  - **Muscle re-education - Atrophy Prevention**
    - forcing a muscle to contract creates sensory input from the muscle
  - **Treatment of bladder & bowel incontinence**
    - vaginal or anal plugs used to stimulate pelvic floor musculature
      - not widely used because of poor patient tolerance
  - **Prevention of post operative deep vein thrombosis**
    - muscle contraction → ↑ blood flow → ↓ blood “pooling” → ↓ thrombi
    - electric current thought to ↑ fibrinolytic activity
  - **Maintenance of ROM (contracture prevention / therapy)**

Duration-Intensity Relationship for Excitation Threshold in Nerve Tissue



Contraindications to Electricity Therapy

- Pacemakers
- Skin Lesions
- Skin Hypersensitivities
- Thrombophlebitis
- Malignancy