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Ultrasound and Phonophoresis

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Content

• Ultrasound physics
• Physiological response
  – Thermal
  – Non-Thermal
• Phonophoresis
• Evidence
• Clinical applications
Physics of US

• Reverse piezoelectric effect
• US waves generated and transmitted
  – Doesn’t travel through air
• Collimation
• Attenuation in tissues

Collimation depth and energy

• Depends on frequency
  – 1 MHz – 4 cm deep
  – 3 MHz – 2-3 cm deep
• Note that 3 MHz delivers 3X the energy for a given period of time
Absorption of US energy

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

Other nerd stuff

- Ultrasound calibration
- Beam non-uniformity ratio
- Refraction of energy
- Continuous vs pulsed US
- ERA
Calibration

• Underwater balance system
• Calibrates actual output to displayed output
• Should be done every 6-12 months
• Patient injury scenario

Beam nonuniformity ratio

• BNR
• Gives ratio of peak intensity/average intensity
• 6:1 or less
Refraction of energy

- US energy can bend like light
- Need to apply perpendicular to skin

Continuous vs. pulsed US

- Continuous US
  - Thermal and non-thermal effect
- Pulsed US
  - Non-thermal effect
  - Literature is very poor
Physiological effects

• Thermal
  – Increased molecular kinetic energy
  – 1 °C – increase metabolic rate
  – 2-3 °C – reduce muscle spasm and increase blood flow
  – 4 °C – increase tissue extensibility


Physiological effects

• Non-thermal
  – Microstreaming
  – Cavitation
  – Mast cell degranulation
Physiological effects

- Non-thermal
  - Microstreaming
  - Cavitation
  - Mast cell degranulation
Cavitation

- Formation of gas bubbles
- Oscillation of these bubbles
- Opens spaces in cell membrane

Overall non-thermal effects

- Increase permeability of cell membranes
  - Oxygen, good ions in
  - Waste products out

\[ \text{O}_2 \]
US is applied

Cell is happy

Effects on muscle

• Draper 1995 – JOSPT 22:142-150
• Thermistors inserted into triceps of healthy individuals
• Measured at depths of 0.8 cm and 1.6 cm
• Temperature increase the same at both depths
• Treatment area kept to 2 x ERA
• * = temperature increase 0.5 degrees
• ** = painful
**Effects on muscle**

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**Connective tissue effects**

- Higher collagen content = more heat absorbed
- Relative avascularity
- Chan et al 1998, J Athl Training 33:130-135
- Healthy patellar tendons
- 3 MHz at 1.0 W/cm²
- 4 minute treatment
Connective tissue effects

- Average temperature increase 8°C
- Return to baseline after 20 minutes
  - However 4°C increase (necessary for increased collagen extensibility) was lost after 4 minutes post treatment
- When 4 x ERA
  - Average temperature increase 5°C
  - Lasted 15 minutes
  - However 4°C increase (necessary for increased collagen extensibility) was lost after 2 minutes post treatment
  - “window of post US treatment”

Joint pain

- Double blind placebo-controlled
- Continuous US at 1 MHz, 1.0 W/cm2 x 5 minutes
- Measured pain scale
- Real US superior to sham US
Circulatory effects

- Theory is that the body wants to “ship away” the new heat and maintain homeostasis – thus vasodilation
- Not supported by the literature at all
- Small changes in circulation if small area treated
- Perhaps non-thermal mediated as well
  - Histamine release from mast cells

Wound healing

- Byl et al – Archives PMR1992
- Pig model for wound
- 20% duty cycle, 1 MHz, 0.5 watts/cm²
- 5 minute treatment time
- Intensity increased at day 4 and 5 to 1.5 watts/cm²
Wound healing continued

- US treated wounds were smaller, higher breaking strength
- Greater collagen deposition
- Lower dose more effective

Neurologic effects

- Sensory NCV shown to increase with therapeutic thermal doses of US
- Currier et al APMR 59:181-85, 1978
- Lehmann et al APMR 39:560, 1958 showed increased pain thresholds
Rationale for using US in different phases of healing

• Inflammatory phase
  – Stimulate release of growth factors
  – Promote angiogenesis
  – Use an anti-inflammatory medication with phonophoresis

Rationale continued

• Proliferative phase
  – Angiogenesis promoted
  – Increased activity of fibroblasts
Rationale continued

• Remodeling phase
  – Elevate tissue temperature
  – Increase tissue extensibility

In vitro research

• Increased activity of fibroblasts
  – Harvey et al Rheum Rhabil 14:237, 1975
• Increased collagen synthesis
• Increased calcium uptake in cultured fibroblasts
In vitro muscle

  – Injured rat gastrocnemius
  – 3 days post injury, US at 20% duty cycle, 3 MHz, 1.5 W/cm² for 6 minutes
  – Treated for 2 days
  – 10 days post injury, significant increase in myogenic precursor cells and fibroblasts

More in vitro muscle

• Karnes et al APMR 83:1-4, 2002
  – Contraction induced muscle injury in rat model
  – 1 MHz US underwater at 0.5 W/cm² for 5 minutes daily
  – Significantly increased force production compared to controls
In vitro nerve healing

  - Rat model sciatic nerve injury
  - Increased quantity of nerve fibers regenerating, increased myelinization, increased diameter of nerve fibers, increased Schwann cell activity
  - US at 1.5 MHz, 16mW/cm²

In Vitro tendon/ligament

  - Achilles tendon rupture in rats
  - Treated for 3 weeks with US at 1.5 W/cm²
  - Greater tensile strength, more parallel, dense collagen fibers
  - Not seen with just 2 weeks of treatment
  - US every other day for 3 minutes
  - Another study showed no effect if 1 week went by before treatment began
In Vitro tendon/ligament

  - Rat MCL model
  - Pulsed US at 1.5 MHz daily for 12 days
  - Superior tensile strength compared to controls

Bone healing with US

- Parameters
  - 20% duty cycle
  - 1.5 MHz
  - 30 mW/cm²
  - 20 minutes
Bone healing

- Kristiansen 1997, JBJS
- 60 patients with distal radius fracture
- Treatment started within 7 days of fracture
- 20 minutes daily for 10 weeks
- Time to union
  - 61 days (US)
  - 98 days (placebo)

Other conducting media

- Underwater
  - 40-60% less heating than gel
- Balloon
  - 50% energy loss in transmission
- Gel pads
  - Equivalent to US gel
Apply these to humans

- Sadly, few well done controlled trials
- It is prudent to approximate the treatment protocols from animal studies
- Low intensity or pulsed US soon after injury
- Frequent treatments

Contraindications

- Eyes/testes – fluid
- Cardiac pacemaker – ion flux
- Pregnancy – WIDC (when in doubt…)
- Active bleeding or infection
- Tumor/ malignancy
- DVT
- Epiphyseal plate of growing bone (???)
Precautions

• Plastic implants
• Metal – reflects US energy

Appropriate use of US

• Heating of the tissues prior to soft tissue mobilization or stretching
• Perform stretching/tissue mobilization or exercise within the “stretching window”
• Introduction of medication through Phonophoresis
Appropriate use of US

- Research has shown that at least 4-6 treatments are needed for full effect
- If no effect by 6 treatments, try something else
- If patient is improving and US appears to be part of this (used properly), continued use of US is prudent

Application nuggets of wisdom

- Treatment area = 1.5 to 2 times ERA
- Keep applicator moving 4 cm/sec
- Don’t fret short removal of applicator from skin – you won’t break the crystal
- Applicator perpendicular
- Patient should feel gentle warmth
QUIZ

- 20 applications of US with patient not improving
- 8 applications of US with ROM of shoulder increasing by 45°, resulting in increased functional use of UE to perform overhead ADLs
- 6 applications of US and patient has not shown measurable functional gains – should document that it’s time to try something else

Phonophoresis

- Medication delivery through the skin
- Changes permeability of the skin and cells
- Passive diffusion
Optimize your phono

• Good transmission medium
  – Cortisone impregnated gels – POOR
  – Salicylate preparations – POOR
  – Lidex (corticosteroid) – GOOD
  – Theragesic cream – GOOD
  – Betamethasone in US gel - GOOD

Optimize your phono 2

• The skin should be pretreated with heat, US, moistening, shaving
  – Hydration
  – Denude stratum corneum
  – Dilate hair follicles
  – Thin skin
Optimize your phono 3

• Position your patient to maximize circulation during the treatment
  – Max local absorption in 2-4 hours
  – Max systemic absorption in 12 hours
  – Maintain hydration of tissues
Optimize your phono 4

- An occlusive dressing that seals the area should be applied after treatment
  - Medication is still in the tissues after the treatment
  - Evaporation
  - Passive diffusion
  - Hair follicles dilated up to 2-4 hours after treatment

Optimize your phono 5

- Intensity of 1.5 W/cm² to capture thermal and non-thermal effects of US
  - Oscillates particles .018um
  - Following the research
Optimize your phono 6

- Low intensity US for acute injuries
  - 0.5 W/cm² instead of pulsed US
  - Seems to oscillate particles better

Case study 1

- 70 y.o. patient with knee OA and lacking 15 degrees of extension
- US could be used in posterior knee to decrease stiffness and increase tissue extensibility
- Parameters:
Case study #2

- Patient with right shoulder calcific tendonitis
- US can increase tissue extensibility and increase resorption of the calcium deposits
- Parameters:

US evidence

- Systematic review in 2001
  - 35 RCT’s
  - 10 used acceptable methods, measures
  - Only 2 of 10 showed positive results compared to placebo
  - Poor methodology of US studies
US evidence

• Grade I evidence for positive effects in
  – CTS – Ebenbichler 1998
  – Shoulder pain – Munting 1978
  – Calcific tendonitis - Ebenbichler 1999
  – Elbow epicndylitis – Binder 1985
  – Wounds – multiple

• Seems to be stuck still at the animal model stage of research

Grade II and III evidence for

• Osteoarthritis
• Myofascial pain
• CTS
• Adhesive capsulitis
• Shoulder pain
• Subacromial bursitis
• Calcific tendonitis
• RSD pain

• Biceps tendonitis
• Plantar warts
• Plantar fascitis
• Elbow epicndylitis
PHTH 523 – EBP2

Therapeutic Ultrasound – Effectiveness

studies from

**Physical Therapy** 2001; 81:1339-1350

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**Background**

- US is one of the most frequently used physical modalities (Nussbaum 1992)
- Early reviews
- Lack of blinding, control groups, info on parameters
Inclusion criteria

- Adequate controls
  - Placebo treatments
  - Randomized group allocation
- Adequate blinding
  - Observers
  - Subjects
  - Treating therapists

Inclusion criteria

- Adequate description of treatment variables
  - Output
  - Time
  - Calibration of US machine
- Meaningful outcome measures
- Adequate sample size
- Acceptable statistical analysis of results
Methods

• Examined only RCTs
• Search strategy
  – 1975-1999
  – Clinical databases (no PEDRO, PubMed)
  – 35 RCTs (seems low to me)
  – Only used studies on real impairments
  – Didn’t use studies with multiple interventions
  – Didn’t use duplicated results
  – Finally 27 RCTs

Filter #1 - controls

• Subjects randomly allocated to groups
• High alleged placebo effect (gate??)
• Rejected Callam et al (1987)
  – Chronic leg ulcers
  – 56 subjects standard care
  – 52 subjects standard care + weekly pulsed US
  – 20% faster healing in US group
Wait a minizzle

Is it fair to reject this study??

Filter #2 - Blinding

- Assessor, subjects, users
- Difficult to blind subjects
- Rejected Bradnock et al (1990)
  - Used .45MHz and 1 MHz US on in vitro solution
  - Showed increase in fibroblast and osteoblast proliferation
  - Showed increase in collagen production
- Even though it was in vitro, another positive study bites the dust
Filter #2

• Even though it was in vitro, another positive study bites the dust

Filter #3 – Treatment Variables

• Should provide information on all treatment parameters, calibration
• Rejected a number of studies due to lack of calibration of the device
• Rejected Creates 1987 (didn’t even find Creates 1991) “inadequate details”
  – Perineal pain post childbirth – positive outcomes
• Rejected Haker 1991 – lateral epicondylitis
Haker et al 1991

- “The output of the machines were controlled every day on a simple underwater radiation balance”
- 10 treatments total, followed up in 3 months and 12 months, no significant difference between groups
- **Weak – evaluated too late**
- Weak #2 – should not have been rejected

**Force balance**

US force causes motion in a carefully calibrated teeter-totter, the amount of motion is correlated with the power of the US
Filter #4 - Outcome measures

- All measures had at least face validity
- Measures such as area tracings, pain scale, grip strength were all OK

Filter #5 – Sample size

- Power analysis – based on effect size ($d$)
  - $d = (\text{Mean1} - \text{Mean2})/(\text{std dev})$
  - Use this $d$ in a table based on alpha (accepted error) and probability of detecting difference (usually 80%)
  - Estimated $d$ at 0.80, this is a very big effect
Rejected by filter #5

- Downing 1986 – sub acromial bursitis – 20 total subjects – no effects
- Gam 1998 – myofascial pain and trigger points – 20 or 18 per group
  - One group US, ex, massage
  - One group sham US, ex, massage
  - One control group, no intervention
  - First 2 groups improved
- McDiamid 1985 – pressure ulcers, improvement in healing (#s not found)

Filter #6 – Data analysis

- Rejected study if they thought wrong stats were used
- Dyson 1976 – Venous ulcers – too large of variance at start of treatment – should have normalized start data
  - Final size/start size
Venous ulcer

Rejected by filter #6

- Roche et al 1984 – venous ulcers –
  - Didn’t show equality of groups before treatment – it probably was there however
  - Significant effects of US
- Binder 1985 – lateral epicondylitis
  - Randomly allocated
  - Positive effects
Overall

• 10 studies left, only 2 showed positive effects
• Newer RCTs (PEDRO)
  – Ebenbichler 1999 – CTS – positive – 45 subjects
  – Ebenbichler 1999 – shoulder calcific tendonitis – 54 subjects - improvements
• Cochrane review 2002 – beneficial for RA

Further studies

• Power analysis for numbers (30 per group is good ballpark)
• Calibrate the durned machine and report it
• Report every parameter
• Include a sham US group
• Blind at least the assessor
• Use a sensitive outcomes measure (i.e. quality of life scales, etc.)
Questions?

• Thank you!

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