The Holy Grail

Articular Cartilage
Objectives

- Describe the basic structure of articular cartilage and the importance of each component
- Apply concepts of senescence to articular cartilage changes with aging
- Translate these concepts into rehabilitation and prevention applications in a variety of populations
Roadmap

- Rationale
- Structure: Macro to micro
  - Cells (chondrocytes)
  - Chromosomes/DNA/telomeres and aging
- Articular cartilage mechanics
- Interventions: interplay of mechanics & exercise to optimize AC structure
The Holy Grail

- Why study articular cartilage?
- What is its structure?
  - What does the structure tell us about function?
- What are its mechanical properties?
  - What does this tell us about function?
- Rehab choices based upon basic science
Why study articular cartilage?

**BIG PICTURE**
- Individual & societal costs
- Third leading cause of hospital admissions
- Risk of disability due to knee OA > any other cause in elderly

**BASIC SCIENCE**
- Starts to answer the WHY question
Composition: Big Picture

- Chondrocytes
- Extracellular matrix
  - Ground substance
  - Collagen: primarily Type II
  - Proteoglycans:
    - Protein core with GAGs (glycosaminoglycans) attached
- Consider as a biphasic material
Proteoglycan

Aggrecan
Proteoglycan Aggregate in Collagen Meshwork

FIGURE 3. This representation of articular cartilage extracellular matrix shows how the collagen network traps the proteoglycan aggregate to form a fiber-reinforced composite.
TABLE 2-1
Approximate Biochemical Composition of
Adult Articular Cartilage

<table>
<thead>
<tr>
<th>Material</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>65–80</td>
</tr>
<tr>
<td>Solids</td>
<td></td>
</tr>
<tr>
<td>Inorganic (ash)</td>
<td>5–6</td>
</tr>
<tr>
<td>Organic</td>
<td></td>
</tr>
<tr>
<td>Collagen</td>
<td>48–62</td>
</tr>
<tr>
<td>Proteoglycan</td>
<td>30–38</td>
</tr>
<tr>
<td>Hyaluronate</td>
<td>1–2</td>
</tr>
<tr>
<td>Lipid</td>
<td>1–2</td>
</tr>
<tr>
<td>Chondronectin</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Anchoring</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Minor collagens</td>
<td>2–3</td>
</tr>
<tr>
<td>Matrix protein</td>
<td>715</td>
</tr>
</tbody>
</table>

FIGURE 2-3
Drawing of a glycosaminoglycan (GAG) subunit. The core protein has three zones: a G1 N-terminal that is the binding site to hyaluronate, which is protein rich and has no GAG chains; G2 in which short-chain keratan sulfate, oligosaccharide, and long-chain chondroitin sulfate (GAGs) are covalently bound at special binding sites; and a terminal G3 portion that represent the C-terminal portion of the molecule. (Reprinted with permission of the publisher from Mankin HJ: The articular cartilages, cartilage healing and osteoarthritis, in Adult Orthopaedics, edited by R. Cruess, WRJ Rennie, New York, Churchill-Livingstone, 1984, 163–270).

FIGURE 2-5
Diagram of the structure of the proteoglycan aggregate shows the proteoglycan subunits distributed along a long filament of hyaluronic acid. The aggrecan units are linked covalently and have as a cofactor in that linkage a glycoprotein molecule known as link protein (see text).
Big picture to small

Cell Replication

- Body is made of organs
- Organs are made of tissues
- Tissues are made of cells
- Cells made up of organelles/nucleus
Cell Replication

- Nucleus contains chromosomes
- Chromosomes contain genetic information
- DNA organizes into chromosomes during cell division
Chromosomes

- Are the carriers of DNA
- During cell replication, DNA compresses into chromosomes to allow quick and easy transfer to the new cell
- After cell division, chrom. disappear leaving a tangled heap of DNA, and reappear during next cell division
Telomeres on ends of chromosome ensure transfer of all genetic info
Like caps on the end of a shoestring
Telomeres

- During cell division, a small piece of telomere is consumed: a disposable buffer.
- Telomeres help protect the DNA strand from shortening during mitosis.
- If no telomeres, each time cell divides, it would lose DNA, losing vital genetic info.
Telomeres may be key to tissue aging of:

- Bone
- Intervertebral discs
- Tendons
- Muscle
- Articular Cartilage
- Fibrocartilage
- And much much more...
Telomeres are structures on the tips of all chromosomes which gradually get shorter with age. Short telomeres are linked with premature ageing and many diseases. By measuring telomere length, scientists can see how fast someone is ageing, and calculate their biological age. This data can then be used to predict life expectancy.
Telomeres

- When telomeres shorten to a critical level, the cell no longer divides
- This contributes to the changes we see in aging
Clinical Manifestations

- Aging connective tissues
  - Tendon: tendinosis
  - Fascia: plantar fasciosis
  - Muscle: sarcopenia
  - Bone: osteopenia/osteoporosis
  - Articular cartilage: osteoarthritis

- Requires healthy fibroblasts to produce healthy collagen
Mechanisms of age related chondrocyte dysfunction

- “Hayflick limit”: cells lose their ability to replicate after “x” number of cell divisions
  - Cell “senescence”
- Cell function may deteriorate before reaching Hayflick Limit
Cellular Senescence

- Phenomenon by which cells lose their ability to replicate
  - Fibroblasts: average of 50 population doublings
    - Galapagos tortoise: 110
    - Mice: 15

- Would you ever want cellular senescence?

Hayflick’s original work
Aging and AC degeneration

- Chondrocyte function deterioration (senescence)
  - Synthesize smaller more irregular aggrecans, less functional link proteins
- Severe decrease in GAG synthesis in people over 50 vs. < 35 years
Cell Senescence: Telomeres

- Length of DNA telomeres an important measure of the proliferative potential of tissues
- Telomere erosion occurs with aging
Cell Senescence: Telomere Erosion

- Intense joint loading or joint trauma +
- Cell aging +
- Other factors affecting telomeres?
  - Intrinsic and extrinsic
Chondrocytes that survive acute injury may have decreased ability to maintain and repair tissue.

Repetitive abnormally high joint surface loading causes chondrocytes to lose ability to maintain tissue.
Aging

**Telomere Length Declines in Dividing Cells as We Age**

- Telomere length in base pairs (human blood cells)
  - 8,000
  - 3,000
  - 1,500

- **Age (years):**
  - 0
  - 35
  - 65
Telomeres and Aging

- Shorter telomeres associated with shorter lives
- Those 60+ with shorter telomeres were:
  - 3x more likely to die from heart disease
  - 8x more likely to die from infectious disease
Telomeres & Aging

- Telomere length, gender, chronological age accounted for 37% of variation in risk of dying over age 60
- What causes the other 63%?
Telomeres and OA

- Hand OA associated with shorter telomeres
- Telomeres shortest nearer OA joint
- Appears to be a shared mechanism between OA and ageing
- Implies oxidative stress and low level chronic inflammation in both conditions

Zhai; Ann Rheum Med 2006
So now that I have your attention

- How do we maintain telomere length so that our chondrocytes produce healthy AC into old age??

Dolly
Telomere length and lifestyle

- Longer telomeres associated with:
  - Healthy lifestyle factors
    - Diets high in fruits and vegetables
    - Tobacco abstinence
    - Lower BMI
    - More exercise

Mirabello; Aging Cell 2009
Leukocyte telomere length is positively associated with increasing physical activity in leisure time:
- More physical activity = longer telomeres
- Controlled for smoking, BMI, SES

Not true of work-related physical activity.

Cherkas; Ann Int Med 2008
Leukocyte TL shorter in:
- the older vs. young
- sedentary vs. those involved in habitual exercise
- TL of **endurance trained adults** not significantly different from **young exercise – trained adults**
- Positively related to maximal aerobic capacity

LaRocca et al. 2010
Telomeres and exercise

+ Dose-response relationship between movement based behaviors & telomere length
  - Longer telomeres with more activity
  - Particularly robust for those aged 40-64
    - N = 6503 in NHANES

Loprinzi; MSSE 2015
Kadi et al. 2010
Strength training and telomere length

- Tested power lifters & compared with controls
  - TL in power lifters longer than control
  - TL inversely correlated with individual records in squat & deadlift
- Also, athletes with exercise-associated fatigue have abnormally short telomeres
  - May be an “optimal load” for telomere length

Kadi et al. 2008
Collins et al. 2003
Other factors in aging

OXIDATIVE STRESS

- Excessive reactive oxygen species (ROS) damage DNA
- Oxidants produced from:
  - Normal breathing
  - Inflammation
  - Infection
  - Alcohol and nicotine consumption

GLYCATION

- Glucose from food binds to some of our DNA, rendering them unable to do their jobs
- Worsens with age
- May be reason why studies of caloric restriction show increased lifespan

ROS are essential & beneficial, but cause damage in excess
GAG production and ROS

![Graph showing GAG production over time](image)

- Control
- Anti-oxidative agent only (Ascorbic acid: 100 μM)
- Oxidative stress only (H₂O₂: 0.1 μM)

Yudoh; Arthritis Res Ther; 2005
ROS and Joint Health

- Oxidative stress impacts
  - chondrocyte telomere DNA
  - Cellular replicative lifespan
  - Chondrocyte function
  - Cartilage matrix proteoglycan structure & function

- In OA:
  - Mechanical and chemical stresses affect cell’s ability to handle hypoxia
  - Leads to oxidative damage, changes in cell microenvironment
  - Downregulation of chondrocyte synthesis

Yudoh, 2005
ROS and Joint Health

- Oxygen free radicals directly damage DNA
  - Causes telomere erosion
  - Telomere shortening during DNA replication
- Chondrocytes under oxidative stress
  - Lower replicative lifespan & PG production
- Treatment with ascorbic acid maintained GAG content
So why does this matter to me?

BIG PICTURE: PT FOCUS

NEED TO SEE SMALL ALSO

Our interventions address the big picture while considering all factors associated with the small picture.
Potential Interventions

DIET & EXERCISE
Exercise induces the expansion of the satellite cell pool in human muscles of young and elderly.

Kadi et al. 2010
Potential Interventions

- Antioxidant enzyme activity is increased following long-term exercise training
- Oxidative stress = shorter telomeres

Fraile-Bermudez; Exp Gerontol 2015
Physical exercise can decrease oxidative stress in joints with OA.

Rats with OA who trained on a treadmill for 8 weeks had higher preservation of proteoglycans than nonexercisers.

Cifuentes et al. 2010
But.... Overtraining is associated with shorter telomeres and excessive fatigue

- Frequent bouts of satellite cell proliferation in response to injury

Collins MSSE 2003
Potential Interventions

- **Exercise!!**
  - Increases telomere length which is associated with health of all connective tissues
- **Diet: foods high in resveratrol**

Seems like this isn’t a new message.....
So we know that we should exercise...

- But HOW?
- And how MUCH?

Start with biomechanics of AC loading
Requirements for a Healthy Joint

- Freedom of motion
- Stability
- Equitable load distribution
- Neuromuscular control
Articular cartilage mechanics

- Functions
  - Allows nearly frictionless motion at joint
  - Distributes loads over a large area
  - Minimizes contact stresses
  - Dissipates energy
AC in compression

- Compression has different properties from shear
  - Compressive resistance due to biphasic prop
  - Shear resistance due to solid phase
- Loaded most in compression
AC in compression

- Forces applied at different rates have different responses
  - Slowly applied: give cartilage time to deform
    - Response is via viscoelastic properties (biomechanical)
  - Rapidly applied: no time for deformation
    - Response is via collagen & solids (structural)
Joint motion enhances fluid film lubrication across joint surfaces
Best in unloaded positions
- This avoids shear
Low load movements
AC nutrition by diffusion of synovial fluid
  - Solutes pass between AC and synovial fluid via....

Loading and unloading
  - Loading and unloading
    - Loading and unloading
      - Loading and unloading
        - Loading and unloading
          - Loading and unloading

You get the picture.....
What’s next?

- We have set the stage with fundamentals of AC structure and function; now...
- The scientific basis of interventions to promote healthy articular cartilage
What do we know from research?

Aquatic Based Interventions
Big Picture

Basic science of articular cartilage structure and function: DNA

Exercise Interventions: mobility and loading/unloading

Application of aquatic interventions: impairments, activity limitations, participation restrictions

Intervention Research & Evidence

Applications in case studies
What we know....

- Impaired strength negatively impacts activity level
- LE muscle strength associated with mobility, morbidity & mortality
- LE muscle strength associated with telomere length
- Quadriceps strength 22% greater in women w/o radiographic OA than those with
Roadmap

- Research in basic science
  - Buoyancy & Surface area
- Research addressing impairments
  - Range of motion, muscle performance, pain
- Research addressing activity limitations
  - Gait, timed up and go
- Exercise dosage
Aquatic rehabilitation

- Immersion to ASIS results in LE loading of 50-75% WB and to C7 to 0-25% WB
  - In static standing, depending upon body comp
- Viscosity & buoyancy used to strengthen
- Cardiovascular training with minimal weight bearing or non-WB
- Pain modulation
- HP to control swelling
Osteoarthritis Research Society International

Appropriate treatment modalities:

- Exercise (land and water based)
- Intra-articular corticosteroid injections
- Strength training
- Weight management
- Self-management and education
- Biomechanical interventions

McAlidon, TE et al. 2014
Cost Effectiveness

- RCT of 312 patients with hip or knee OA
  - Water: aquatic exercise x 1 year + 6 mo. Follow up
  - Control: usual care; quarterly structured phone call
- + cost-benefit ratio as measured by pain and WOMAC scores

Cochrane: *Health Technol Assess; 2005*
98 patients with LBP & N Root compression

Loaded walking x 15 m

Followed by:
- 15 min supine land tx
- Or
- 15 min aquatic vertical tx

Spinal ht change using stadiometer, pain
Impairments: Spinal ht & pain

- Both interventions resulted in significant increases in spinal ht
  - No signif diff. btwn land and aquatic
- Decreased pain after aquatic was signif greater than land
- Signif correlation between ht change and both pain reduction and centralization seen for aquatic only
Backwards walking in a pool elicited significantly more paraspinal EMG than backwards walking on land.

Even higher EMG with walking against a current.

Masumoto 2005
Backwards Walking: Speed

- Backwards walking showed significant greater EMG of paraspinal muscles, vastus medialis, and anterior tibialis compared with forward walking
  - With and without a current

- HR responses greater with backwards walking vs. forward, but significant only at faster speeds

Matsumoto 2007
Resistive walking with plow
Effect of Buoyancy on weight bearing

Fig 6: Partial weight-bearing walking at different levels of immersion

What’s wrong with this picture??
What are the assumptions?
Loading during SW running

- 11 females (20-25% bf), 11 males (12-16% bf)
- Ran on an 8.0’ immersed walkway w/ force platform
- Water adjusted to umbilicus or chest
- Self-selected speed

Haupenthal 2010
Loading during SW running

- **Vertical forces:**
  - 0.8 x body weight in chest deep water
  - 0.98 x bw at hip level water

- **AP forces**
  - 0.26 x bw at chest
  - 0.31 x bw at hip

- No differences for force values between immersion levels: due to self selected speed
  - Ran faster in more shallow water
Use of hydrotone bells in UE exercise produces an exponential (not linear) increase in force generated.

Law L, Smidt G; underwater forces produced by the Hydrotone bell; JOSPT 1996;23(4):267-71
18 healthy individuals performing knee flexion/extension w/ and w/o Hydrotone boot
- EMG and dynamometer, drag via math
- Speed not controlled; instructed to perform submaximal flexion/extension

Poyhonen T, Keskinen KL et al; Neuromuscular function during therapeutic knee exercise under water and on dry land; Arch Phys Med Rehabil; 2001;82:1446
Forces on dry land were higher except flexion w/ boot which was similar to isokinetic on land

Underwater EMG:
- Early decrease in concentric of agonists w/ temporal activation of antagonists
- Similar EMG between conditions but boot produced higher drag than barefoot
  - Why?

<table>
<thead>
<tr>
<th>Muscles</th>
<th>30/sec</th>
<th>45/sec</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supra Land</td>
<td>17</td>
<td>17</td>
<td>23</td>
</tr>
<tr>
<td>Water</td>
<td>4</td>
<td>6</td>
<td>27</td>
</tr>
<tr>
<td>Infra Land</td>
<td>11</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>Subscp Land</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>
Recent study reproduced same findings & suggested:

- Start exercise in water at 30 deg/sec
- Progress to 45 deg/sec on land OR water
- Progress to 90 deg/sec on land followed by
  - 90 deg/sec in water

This based on % sEMG & ms. performance; not other impairments

Muscle activation patterns of the tested muscles different on land vs. pool

- **Land**: greater muscle activation to execute the movement
  - Anterior deltoid and upper trap initiate movement
- **Water**: greater muscle activation to stabilize
  - Middle deltoid, pectoralis and anterior deltoid
  - Coupled work with eccentric of pectoral to counterbalance superior translation of deltoid

- No rotator cuff muscles tested
Important Issues

- Assumptions about exercise on land do not apply in water
- Buoyancy is relative
- Speed & equipment matter
Important Issues

Not “Can I do this exercise?” but rather **HOW** the exercise is done

- Speed
- Surface area
- ROM
- Stabilization
- Viscosity/buoyancy
- Etc, etc....
n = 46 patients with knee OA
Aquatic vs. land exercise
No difference in
  - Knee ROM
  - Thigh girth
  - 1 mile walk time
Pain levels significantly lower in aquatic group
Either mode sufficient for improvement
## Mobility Examples

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Additional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive knee extension with noodle under mid-calf</td>
<td>Noodle under ankle</td>
<td>Foot on rigid object</td>
<td>Provide downward pressure on knee</td>
</tr>
<tr>
<td>Passive knee flexion noodle under mid-shin</td>
<td>Noodle under ankle</td>
<td>Foot on rigid objects</td>
<td>Overpressure into flexion</td>
</tr>
<tr>
<td>March in place</td>
<td>March across pools</td>
<td>Emphasize gait components: knee flexion, ext</td>
<td>Add stop to provide balance challenge</td>
</tr>
<tr>
<td>Standing knee flex/ext with support</td>
<td>Increase ROM</td>
<td>Add buoyant equipment</td>
<td>Remove support</td>
</tr>
</tbody>
</table>
# Mobility Examples

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Additional Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle in stable, supported position</td>
<td>Bicycle on noodle or w/ vest</td>
<td>Increase ROM, speed</td>
<td>Vary activity to emphasize specific movements</td>
</tr>
<tr>
<td>Squats with support</td>
<td>Increase depth of squat</td>
<td>Hip &amp; knee flexion on ladder or step to increase ROM</td>
<td>Flex further as tolerated</td>
</tr>
<tr>
<td>Standing knee flex/ext with support</td>
<td>Increase ROM</td>
<td>Add buoyant equipment</td>
<td>Remove support</td>
</tr>
<tr>
<td>Stationary lunges</td>
<td>Increase stride length</td>
<td>Increase lunge depth</td>
<td>forward/backward moving lunges</td>
</tr>
</tbody>
</table>
Increasing Ms Performance: Level 1

- AROM, open chain, straight or multi-plane
  - Hip: flex/ext, ab/ad, IR/ER, circles, fig. 8’s, letter writing, etc.; Knee flex/ext
- Combination movements
  - PNF/diagonal patterns, kicking motions
- Focus on **strength** rather than **motion**
  - Note that these are primarily long lever arm activities
  - Less range, more speed, more repetitions
Increasing Ms. Performance: Level 1

- Wall sits
- Squats
- In place lunges
- Deep water
  - XC ski legs
  - Cycling
  - running
Increasing Ms. Performance: Level 2

- Added resistance through a ROM
- **Viscosity** resisted:
  - Increase surface area: aqua fins, flippers, etc.
  - Increase speed
- **Buoyancy** resisted:
  - Buoyant equipment under foot/around ankle
- **Other**
  - Add resistive bands at knees
Increasing Ms. Performance: Level 2

- Viscosity vs. buoyancy vs. bands
- What’s the difference?
- Let’s look at hip flexion/extension....
Need another example?

- Viscosity vs. buoyancy vs. bands
- Hip ab/ad
- You determine the working muscle groups and contraction types....
Increasing Ms. Performance: Level 2

- Wall sits
  - Progress to a single leg
- Squats
  - Progress to a single leg
- Lunges
  - Progress to dynamic
- DW exercise
  - Add resistive equipment
Increasing Ms. Performance: Level 3

- Resistive bands
  - Move to ankles
- Viscosity resisted
  - Increase speed
- Buoyancy resisted
  - Increase buoyancy
- “stack” exercises with decreased rest in between

- Wall sit
  - Add arm perturbation
- Squats
  - To more shallow water
- Lunges
  - Add resistive bands
- DW exercise
  - Add interval training
Lower limb muscle power, QOL, ADL and pain were all improved immediately and 6 wks after completion of program

- 29 adults age 50+ with symptomatic knee OA
- 45 min aquatic power training BIW x 6 wks
- 400 m walk time & lower limb function unchanged
  - May need a longer intervention time

Segal; Arthritis 2012
Evidence: HIT Aquatic Treadmill

- 6 week high intensity (HIT) aquatic treadmill training on 18 patients with knee OA
  - Pain, balance, function, mobility measures
- Included HIT and balance training using jets to destabilize
- Post: decreased pain; increased balance, function and mobility
  - Compared with non-exercising controls

Bressel J Strength Cond Res 2014
Improving Balance

- Same philosophy as land balance training
- Benefits
  - Limited weightbearing
  - Safety due to viscosity
  - Ability to use turbulence
- Start with static
- Progress to dynamic
Basic Static Stabilization

- Stationary, static standing
- Any form of turbulence
  - Provided externally by others in pool
  - Self-generated: decreased surface area to start
    - Sagittal plane
    - Frontal plane
    - Transverse plane
- Using arms and/or legs
Basic Static Stabilization

- UE movements
  - B shoulder flex/ext
    - Elbow curls
  - Reciprocal shoulder flex/ext
  - Horizontal ab/adduction
  - Shoulder IR/ER
  - Reciprocal shoulder ab/adduction
Progression options for basic stabilization exercises:

- Starting BOS,
- Narrow BOS,
- Single foot,
- Unstable surface,
- Eyes closed,
- Head movement

Note that these are all stationary
Progression of static balance

- Leg movements
  - Use arms for support/stability
  - Arms by side or across chest
  - Arms overhead (if possible)
  - Unstable surface
  - Eyes closed
  - Head movements
Dynamic balance activities

- **Step and hold**: progressively larger step
  - Forward, backward, side
  - 3 step stop and hold
- **Tandem walk**
- **Hop and stick**
  - Forward, backward, sideways, diagonal
  - Progress to arms across chest
  - Eyes closed
  - On and off a box or step
Activity Limitations

- Walking
  - Many improve gait simply by decreasing WB
  - Can use additional buoyant support
  - Progress by moving to more shallow water
  - Strengthen by increasing speed: fartlek
    - This also increases % weight bearing
  - Forward, back, side, march, grapevine,
8 weeks of aquatic exercise improved gait stability in elderly (n=11; x̄ age = 77 ± 5 yrs)

- 3-D motion analysis and force plate

Acute aquatic treadmill training improved joint angular velocity and arthritis-related joint pain in patients with knee OA

- Compared with land treadmill
- No difference in step rate or length

Roper; Arch PMR 2013
HS Lim; J Phys Ther Sci 2013
Activity Limitations

- Stairs: limited WB up & down using box or step
  - Step up and over repeatedly
- Hop/jump: progress deeper to shallow
- Jogging, running: deep to shallow
- Squats/transfers: readily performed in pool
- Getting up and down from floor
Dosage – Intensity, Duration, Frequency, Sequence

- **Intensity** – Perform exercise to substitution of form fatigue
- **Duration** – Vary rest intervals dependent upon volume (total repetitions) and rest intervals.
- **Frequency** – Depends on rehab goals.
- **Sequence** – Affects the development of strength. Rehab generally specific isolation training and graduate to multi-joint exercises, small-large movements.
Must assess discrepancy between current performance and
- Desired performance OR
- Capacity
Determine what constitutes the gap
What activities at what dosage will close the gap between current & desired performance?
Exercise challenges

- Increase task complexity
- Change muscle contraction type
- Change exercise speed
- Change exercise mode
- Decrease stability of BOS
- Reduce feedback
- Alter the environment
- Alter exercise sequence
- Vary start and end position
- Reduce cognitive control

Add more exercises
Increase repetitions
Add more sets
Increase frequency

Decrease rest interval
Change exercise speed
Change exercise mode
Decrease stability of BOS
Reduce feedback
Alter the environment
Alter exercise sequence
Vary start and end position
Reduce cognitive control

Continually Expanding Exercise Volume
Exercise progression

- Theory is continually expanding exercise volume until goal is reached.
- How gap is closed varies from one patient to the next.
- Some need to change/progress therapy within current volume.
- Others need to increase dosage.
Exercise progression

- Increasing dosage/volume
  - F, I, D
- Progressing within current volume . . .
Within current volume

- Muscle contraction type
- Speed
- Mode
- Base of support
- Feedback

- Change environment
- Sequence
- ROM
- Cognitive control
- Task complexity

Followed by...
Exercise Progression

- When ready, increase total volume
- In general, modify within, then increase volume, repeat
- As always, sounds easier than it probably is...
Applying these concepts in patient cases...
References

References

22.
IMPACT OF AQUATIC AND LAND EXERCISE UPON CARTILAGE: THE EVIDENCE

PAULA RICHLEY GEIGLE PT PHD
UNIVERSITY MARYLAND REHABILITATION RESEARCH CENTER
BALTIMORE, MD
WHAT DO WE KNOW ABOUT SPECIFIC EXERCISES AND ARTICULAR CARTILAGE?

• Mode
• Frequency
• Intensity
• Duration
• Muscle contraction type
• Range of motion

Emerging mechanistic information—requisite for optimum exercise prescription
WHAT ARE POSITIVE OUTCOMES: HIP OA WITH LAND EXERCISE?

• Pain: ES=0.32-0.52

• Function: ES=0.32-0.46

No clear consensus on how to prescribe strengthening and aerobic training for land exercise.
WHAT ARE POSITIVE OUTCOMES WITH AQUATIC EXERCISE?

Bartel <2006/Batterham<2010 Waller et al>2013

• Pain: 0.19 0.26
• Function: 0.26 self=0.30, standard=0.22
• Ambulation: 0.18 0.22
• QOL: 0.32 0.24
• ROM: 0.56
• Muscle Strength: 0.00

No clear consensus on aquatic exercise prescription.
EXERCISE FOR HIP OSTEOARTHRITIS: RCT/SYSTEMATIC REVIEWS/META-ANALYSIS

- Roddy et al, SR 2005 Walking or Strengthening, Hip/knee
- Hinman et al 2007 Hip/knee
- Fransen, 2009, 2014 Exercise, Cochrane Review Hip
- Zhang, Meta-Analysis, Pain, 2010
EXERCISE FOR HIP OSTEOARTHRITIS:
RCT/SYSTEMATIC REVIEWS/META-ANALYSIS

• Waller et al
**EXERCISE FOR HIP OSTEOARTHRITIS: RCT/SYSTEMATIC REVIEWS/META-ANALYSIS**

<table>
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<th>Study</th>
<th>Year</th>
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<td>Hale et al</td>
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<td>Arnold/Faulkner</td>
<td>2010</td>
<td>Hip</td>
<td>6</td>
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<td>Fukomoto</td>
<td>2014</td>
<td>Hip</td>
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</tbody>
</table>
EXERCISE FOR HIP OSTEOARTHRITIS: RCT/SYSTEMATIC REVIEWS/META-ANALYSIS

• Iversen, Rehabilitation interventions for pain and disability in osteoarthritis: a review of interventions including exercise, manual techniques, and assistive devices, 2012 American Journal Nursing

• Kloek, Effectiveness and cost-effectiveness of a blended exercise intervention for patients with hip and/or knee osteoarthritis: study protocol of a randomized controlled trial, 2014 BMC Musculoskeletal Disorders

• Larmer, Hydrotherapy outcome measures for people with arthritis: A systematic review, 2014 New Zealand Journal Physiotherapy

• Roper, Acute Aquatic Treadmill Exercise Improves Gait and Pain in People With Knee Osteoarthritis, 2013 Archives Physical Medicine (knee OA)
EXERCISE FOR HIP OSTEOARTHRITIS: RCT/SYSTEMATIC REVIEWS/META-ANALYSIS

- Schencking, A comparison of Kneipp hydrotherapy with conventional physiotherapy in the treatment of osteoarthritis of the hip or knee: protocol of a prospective randomised controlled clinical trial, 2009 BMC Musculoskeletal Disorders

- Schencking, A comparison of Kneipp hydrotherapy with conventional physiotherapy in the treatment of osteoarthritis: a pilot trial

- 2013 Journal Integrative Medicine

- Uthman, Exercise for lower limb osteoarthritis: systematic review incorporating trial sequential analysis and network meta-analysis

- 2013 BMJ
AQUATIC AND LAND EXERCISE + CARTILAGE = IMPROVED FUNCTION: WHAT ARE THE ‘MAGIC BLACK BOX’ MECHANISTIC COMPONENTS??

Exercise + Cartilage → Improved Function
CURRENT METHODS TO ASSESS CARTILAGE INTEGRITY

  • delayed Gadolinium Enhanced MRI of Cartilage (dGEMRIC) technique detects early reduction of glycosaminoglycan (GAG) as a surrogate measure of cartilage degeneration/regeneration via a paramagnetic contrast agent gadolinium (Gd-DTPA2-).

  • T2 relaxation time determined by tissue collagen degeneration and fiber orientation in extracellular matrix, helps to detect early degeneration or senescent changes of cartilage.
CURRENT METHODS TO ASSESS CARTILAGE INTEGRITY


Physical function, perceived pain, knee stiffness, and self-rated physical functioning. The exercise group improved their isometric leg extension force by 11% (p=0.009), dynamic balance by 3% (p=0.022), and cardiorespiratory fitness by 4% (p=0.027) compared to control group with no intergroup differences in knee pain, stiffness, or self-rated physical functioning.
RELATIONSHIP LOWER LIMB NEUROMUSCULAR PERFORMANCE AND BONE STRENGTH IN POSTMENOPAUSAL WOMEN WITH MILD KNEE OSTEOARTHRITIS

Neuromuscular performance in postmenopausal women with mild knee OA predicted lower limb bone strength in every measured skeletal site.
WALLER ET AL RCT CARTILAGE AND AQUATIC EXERCISE, 2015
EXERCISE EFFECT UPON ARTICULAR CARTILAGE

• Orthopedic Clinics of North America
  Volume 43, Issue 2, April 2012, Pages 187–199
  Gahunia HK, Pritzker KPH

EXERCISE & TRAINING PRINCIPLES

• Exercise can be + or -
  • Depends on dosage and other factors

• Intermittent rather than constant mechanical stress produces positive changes

• Need both load and motion

• Rate of program initiation:
  • Use a conditioning period
EXERCISE SPECIFICS

Must know... 

• Composition and biomechanics of AC at that joint 
• Location, size, nature of lesion 
• Any surgical procedure performed 
• Joint stability, motion, load distribution 

And must speculate....or request imaging to better understand: 

• Cell/telomere quality and its ability to effect repair
EXERCISE & TRAINING PRINCIPLES

• Nutrition enhanced with exercise
  • Use movements that produce fluid film across joint with minimal wear
    • Pendular movements
    • Low load, high velocity movement
  • Use traction with passive motion
AQUATIC BASED INTERVENTION FOR HIP AND KNEE OSTEOARTHRITIS

- Mode
- Frequency
- Intensity
- Duration
- Muscle contraction type
- Range of Motion
KEY PRINCIPLES: LOADING

Type of loading is important
• Static loads should be **brief**
• Shear most detrimental

• Potential for wear increases as load goes from static to high

• Repetitive impulsive loading is detrimental to AC and subchondral bone
• Jumping, running

Rehab implications
MODE: UNLOADING

- Loading more important than motion?
- Rehab implications
  - Graduated WB
  - Graduated activity
  - Use of reduced load environments
- Pool and land appear to be equally effective
  - Likely patient specific
  - Pain scores better with pool
- Group based water exercises over a year yield significant improvements in reported lower extremity joint pain
MODE: UNLOADING

• Alternate periods of loading & unloading

• Early phase: unloaded period should exceed loaded

• When static loads are started, follow w/ periods of unloading that exceed loaded
FREQUENCY
MOTION: ROM

• Minimize shear
  • PROM or AAROM initially

• May need to restrict AROM activities if joint forces are unhealthy to cartilage

• Avoid compression during ROM: how is this possible?
CASE 1: OSTEOARTHRITIS MULTIPLE JOINTS

HX: 71 yo female, OA hip and knee B, R>L involvement; over the counter pain medication, with current R knee pain level 6 to 8 (0-10 scale)

DATA: ROM: L hip/knee/ankle WFL; R: hip: -15 hip extension; knee: -10 to 85; ankle: WFL. Strength: LLE—4 to 4+ throughout; R: hip 4-; knee 3-; ankle 4 to 4+. Sensation: knee diffuse tenderness, LT and proprioception grossly intact throughout BLE. Ambulates SP cane L hand for 2 block maximum, requires railing for all stairs (to unload body weight), unable to complete housework, grocery shop, drive independently.

GOALS: 1) ambulate 12 blocks wo assistive device; 2) carry bag groceries to car and into home; 3) negotiate full flight steps carrying small laundry basket; 4) increase R knee ROM 0-125

DESIGN AN AQUATIC THERAPY PROGRAM ADDRESSING CLIENT GOALS/PRESENTATION AND HEALTHY CARTILAGE PRINCIPLES

Adapted from Aquatic Exercise for Rehabilitation and Training. Thein Brody and Richley Geigle, 2010.