Osteoarthritis

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The Three Destroyers of Articular Cartilage

• High Magnitude Contact Pressures
  CP = CF/CA. The “job function” of AC is to protect subchondral bone from high pressures
• Impact Loading
• Frictional Abrasion

Articular Cartilage Composition

• Aneural and avascular
• 60-80% H₂O
• 20-40% solid matrix
  – type II collagen 60%
  – ground substance 40%
  – chondrocytes <2%

Articular Cartilage Structural Organization
**High Contact Pressures**  
Upper Extremity Joints

- Protect Joint from High Contact Forces
  - Stretch tight soft tissues with heating first
    - Muscles- stretches of relatively brief duration (Bandy JOSPT, 1998)
    - Ligaments/Capsular tissue- either creep (Dynamic splints) or stress relaxation (serial splinting)
  - Keep muscles as “quiet” as possible. Therapeutic exercise? Really? Show Shoulder Example.
  - Try to have joints function in mid-range to avoid excessive stretching of soft tissues that cross joint. Discuss the Bristow and Putti-Platt Procedures.

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**Dynasplint Application for the Knee Joint**

Stress Relaxation

Joint Active System
• Similar to serial casting
• Stretch to strain level and maintain position for approximately 30 minutes
• Use 3 times per day


Non-Anatomic Repairs
Bristow Procedure- Lombardo et al, JBJS, 1976

Distal coracoid process cut with the attachments of the short head of the biceps and the coracobrachialis.
Non-Anatomic Repairs
Bristow Procedure - Lombardo et al, JBJS, 1976

- Creates a bony block as well as a protective soft tissue sling.

Non-Anatomic Repairs
Bristow Procedure - Issues Gill and Zarins, 2003

- Recurrence rates 2%-33%
- Decreases external rotation as much as 23 degrees
- Decreased internal rotation
- Migration of hardware
- Articular cartilage damage
- Posterior instability
- Issues with scar tissue if revision necessary

Non-Anatomic Repairs
Putti-Platt Procedure

- The subscapularis tendon is divided, the distal stump (B) is attached to the glenoid rim, followed by attachment of the proximal stump to the lesser tubercle.

Non-Anatomic Repairs
Putti-Platt Procedure - Issues Gill and Zarins, 2003

- Limitation of external rotation
- Degenerative arthritis
- Adverse influence on throwing mechanics secondary to the loss of external rotation
- Recurrence rates of 1.2-19%
**High Contact Pressures**

**Upper Extremity Joints**

- Protect Joint from Reduced Contact Area
  - Try to have joints function as much as possible in mid-range where contact area may be larger
  - Encourage repair of labral tissues (SLAP lesions) and meniscal tissues (TMJ, knee, and wrist)
- Be very, very concerned about the long-term health of articular cartilage in patients who have lost fibrocartilage.

**High Contact Pressures**

**Lower Extremity Joints**

- Mass & The Ground Reaction Force
  
  \[ \text{Force} = \text{mass} \times \frac{\Delta v}{\Delta t} \]

- Protect the Joint from High Magnitude Contact Forces
  - Obesity and heavy labor are among greatest risk factors for OA. Exercise to burn calories and referral to an RD.
  - The multiplicative effect of weight loss- do a space diagram of knee flexion.
  - Carrying heavy loads is to be avoided- roller bags or rolling carts
  - Keep the muscles “quiet”
    - Rising from a chair if the patient has OA at knee or patellofemoral joints
    - Rising from a chair if the patient has OA at the hip joint
    - Climbing stairs with knee OA
    - Descending stairs with knee OA
    - Stretch tight soft tissues- e.g., tight patellofemoral retinacular tissues
High Contact Pressures
Lower Extremity Joints
Changes in Downward & Forward Velocity

\[ \text{Force} = \text{mass} \times \frac{\Delta v}{\Delta t} \]

- Does the patient fall through space too much?
  - Bouncer versus glider
  - Walking downhill - zig-zag strategy
  - Step aerobics - there's a step!
  - Limb length inequality

Medial/Lateral Glide

- Magee (1987)

High Contact Pressures
Lower Extremity Joints
Changes in Downward & Forward Velocity

- The effect of changes in forward velocity as it influences braking forces. Show a space diagram of the knee joint
  - Walking more slowly
  - Greater treadmill walking braking forces (van Caekenberghe et al, 2013)

High Contact Pressures
Lower Extremity Joints
Prolonging Time for Velocity Changes

\[ \text{Force} = \text{mass} \times \frac{\Delta v}{\Delta t} \]

- Landing strategy from a jump using joint motion to prolong \( \Delta t \)
- Selecting appropriate ground surfaces that deform
- Selecting foot wear with appropriate density of the sole materials
The Second Destroyer of Articular Cartilage
Impact Loading

• Articular cartilage and subchondral bone like to be loaded slowly
• Impact loading involves high magnitude loading rates which have been associated with stress fracture and AC destruction
  – Upper extremity air compressive driven tools-padded gloves and tool grips
  – Lower extremity impacts with walking and heel strike running- see next slides

VERTICAL GROUND REACTION FORCE

% Stance Phase

Negative Effects of Malalignment

The Double Whammy!
• Increased Contact Force
• Decreased Contact Area
Knee Varus/Valgus

It Can Get Worse going from Bilateral to Unilateral Stance!

\[ \sum M = 0 = -(GRF \cdot d_{GRF}) + (W \cdot d_W) + (STF \cdot d_{STF}) = 0 \]

Malalignment in the Skeletally Immature Child

- Epiphyseal plates are still open
- Influence of malalignment on these growth plates can result in a feed-forward-negative scenario that worsens the malalignment
Properties of Bone

Epiphyseal Plate Structure

- Four zones of transition as bone is added to the metaphysis
- Interface between the last zone and metaphyseal bone is weakest structurally
- Suspect epiphyseal plate injury if excessive tension placed on tendon or ligament that might injure epiphyseal plate (e.g., MCL sprain in skeletally immature individual).

Properties of Epiphyseal Plate

- Compressive stress is the stimulus for activity that adds bone length
- Too little or too much pressure through the epiphyseal plate attenuates growth
- Skeletal malignment, therefore, can be a major “feed forward” patient problem

Effect of Deformity on Growth Plate Function

Excessive pressures may inhibit endochondral ossification at growth plate and produce a feed forward scenario that may worsen the deformity, thereby increasing medial growth plate pressures.
Effect of Deformity on Growth Plate Function

Excessive pressures may inhibit endochondral ossification on the medial sides of the growth plates at the distal femur and proximal tibia and produce a feed forward scenario that may worsen the deformity, thereby increasing medial growth plate pressures.


Articular Cartilage Function

- Dense fluid filled sponge with normal degree of relatively low permeability
- Most pathologies act to increase permeability, resulting in ↓Δt or loading across the joint
- Normal deformation, though, serves to prolong Δt and attenuate contact forces that cross the joint
- ↓ frictional abrasive wear 2° low μ: 0.001-0.05 with synovial fluid

Articular Cartilage Function

- Deformation Increases Contact Area
- Decrease Articular Cartilage Contact Pressure
- Decrease Stress Transmitted to Subchondral Bone

Articular Cartilage Mechanical Behavior

- Constant low level loading—temporary creep as fluid is continually displaced to other unloaded areas of AC and into the intra-articular space
  - gradual increase in stress of subchondral bone (e.g., “movie theater sign”)
- Speed of Loading—Stiffer and less hysteresis with higher speeds of loading: implications …..
  - stiffness may lead to OA
  - unload creep-compressed AC prior to ↑ loading
Articular Cartilage
Repetitive or Constant Loading Scenarios

- Recovery time for full reformation of the articular cartilage following repetitive loading or a period of constant loading may be fairly long.

Articular Cartilage
Mechanical Behavior
Joint Lubrication Methods

1. Boundary Lubrication- hyaluronic acid-glycoprotein molecule complex layer on each articulating surface.
2. Fluid Film Lubrication- larger volume of synovial fluid trapped between the two joint surfaces.

$\mu$ for Boundary Lubrication typically is 2 orders of magnitude > than $\mu$ for Fluid Film Lubrication

Articular Cartilage
Healing

Depth of Defect

- Injury/drill hole to subchondral bone
- communication with vascularized bone tissue & migration of cells that end up producing fibrocartilage in the injured articular cartilage
- inferior shock absorber 2” less H2O and dense matrix that acts as barrier to diffusion that is required for nutrition of articular cartilage
Articular Cartilage Healing

Volume and Surface Area
• chondrocytes are metabolically “slow” and usually no blood supply is available
• injury to large volumes and surface areas do not have good potential for healing
• protected weight-bearing may help matters

Location of the Injury
• healing is poorer if the defect is subjected to weight-bearing that elicits high contact pressures
• need to “listen” to what the joint has to say and try to limit weight-bearing in positions in the ROM for which the joint “talks”

Articular Cartilage Repair
Osteochondral Autograft Transfer System (OATS)
Autologous Osteochondral Transplantation (AOT)

Donor Site
Recipient Site

System of hollow chisels are used to take healthy grafts from non-weight bearing sites and prepare damaged weight bearing areas.
Articular Cartilage Repair
Osteochondral Autograft Transfer System (OATS)
Autologous Osteochondral Transplantation (AOT)

Chow JCY et al. Femoral condyle repairs in 33 adults with 87% reporting normal knee function an average of 45.1 months post procedure. Arthroscopy 2004; 20: 681-690


Oats Procedure vs Microfracture

Gudas et al (2005)- 60 high level athletes younger than 40 with defects on femoral condyles
Same surgeon, NWB 4 wks then PWB 4 wks
93% OAT group returned to sport 4-6 months later, only 53% microfracture
Biopsy from some of the patients in each group showed more AC formation in the OAT group and fibrocartilage and fibrillation in MF group.

Autologous Chondrocyte Implantation (ACI)

Chondrocytes are harvested from healthy AC, grown in vitro, and then implanted at the site of the AC defect underneath a protective flap of periosteum that covers the protective pouch at the site.
Autologous Chondrocyte Implantation (ACI)

- Brittberg et al (1994)- Good to excellent results or 14/16 femoral & 2/7 patellar ACI procedures. Saw normal AC in 11/15 femoral and 1/7 patellar cases.
- Similar results in other studies by Browne et al (2005), Minas and Bryant (2005), Fu et al (2005), Lindahl et al (2001), and Peterson et al (2002) with assessments ranging from 2-5 years following the procedure.

ACI- Long Term Results

- Moseley et al (2010)- 10 year follow-up
  - 75% of patients reporting improvement 5 years out
  - 87% of these patients sustained the improvement at 10 years
- Peterson et al (2010)- 10 to 20 year follow-up of n=331
  - 224 respondents
  - 74% reported status as same or better
  - 92% satisfied and would repeat procedure if needed

ACI Rehabilitation

- Accelerated vs traditional protocol.
- Traditional: FWB 11 weeks. First 2 wks NWB, 20% at 2 wks, 50% at wk 6, and ↑ by 10% each week.
- Accelerated: FWB at week 8. First 2 wks NWB, 20% at 2 wks, ↑ by 10% wks 3-6, then ↑ 20% wks 7-8.
- Better pain ratings and knee extension motion early on in accelerated group and good outcomes in both groups at 5 years.


Glucosamine

Proposed Mechanisms

- Facilitate GAG production
- Rebuild AC
- Improve lubrication of synovial fluid
- Improved absorption compared with chondroitin molecule
Glucosamine

Reginster et al. Randomised, double-blind study of 212 patients with knee OA. Treatment group administer 1500 mg glucosamine for 3 years. Placebo group had continued narrowing of their joint space and a 9.8% worsening of their WOMAC scores. Treatment group had essentially no change in joint space and 24.3% improvement in their WOMAC scores. Lancet. 2001 Jan 27;357(9252):251-6.

• Richy et al. Meta-analysis of 15 out of 500 studies on efficacy of glucosamine and chondroitin for knee OA. Decrease in pain and less joint space narrowing. Arch Internal Med 2003;163:1514-1522.
• James CB, Uhl TL. Review article. May not be effective for patients with severe OA. J Ath Train 2001;6(4):413-419.
• Better results with glucosamine sulfate than glucosamine hydrochloride

Glucosamine Precautions

• Asthma
• Diabetes
• Shellfish allergies
• Pregnant/breast feeding
• Life-threatenig if taken with Warfarin (Coumadin)


Additional Therapies

• PRP involves the centrifuging of one’s own blood to get concentrated cells. Injected into cell with US guidance. Thought that growth factors within the platelets facilitate reparative cell action. Hart R et al, 2013
Additional Therapies

• Hyaluronic Acid, or Synvisc. Weekly injections for 3-5 weeks of this viscosupplementation fluid in attempt to restore the cushioning and lubrication capability of the synovial fluid.
• Good support for several months of pain relief in most patients. Gigante & Callegari, 2011; Pavelka & Uebelhart, 2011.

Immobilization and Remobilization

• Animal models demonstrate as much as a 50% reduction in AC thickness with 2 weeks of immobilization.
• Activation of muscles can spare some of the atrophy
• Remobilization following immobilization can restore normal thickness and function of AC
• “Exercise” caution during the period of AC recovery that the clinician and patient do not overload the AC and induce “post-rehabilitation” OA

Ah, But They’re Bunnies!

• Significant decreases in volume and thickness of ankle joint cartilage following 7 weeks of post-op partial weight bearing. Hinterwimmer et al, 2004
• Heldemaier (2006) documented 14% ↓ in knee articular cartilage thickness following 6 weeks of NWB compared to the contralateral WB knee.
• Aggressive WB will not feel good on these joints until the AC recovers.

Articular Cartilage
Facilitating the Repair Process

• Glucosamine Sulfate
• Chondroitin Sulfate
• Growth Hormone
• Electromagnetic Fields
• Laser Stimulation
Articular Cartilage
Effects of Malalignment

Contact Pressure (CP)
- Contact Force (CF) - Determined by GRF and soft tissue forces that cross the joint
- Contact Area (CA) - alignment and intervening soft tissues (i.e., menisci)

\[
CP = \frac{CF}{CA}
\]
### Medial Thrust Gait vs Pole Walking

Fregly et al (2009) – case study of 83 year old male with instrumented TKA to measure knee loading
- Medial thrust gait pattern taught to move knee joint center medially to decrease GRF moment arm, decrease STF, and increase CA
- Walking poles in each hand
- Both conditions significantly reduced knee loads with greatest decrease realized from walking with the poles

### Influence of Lateral Wedge

- Brings knee joint center closer to the foot and reduces moment arm of the ground reaction force.
- Kerrigan DC et al. Studied 15 subjects with medial knee joint OA. A 5 degree wedge reduced peak knee varus torque by 6%, and 10 degree wedge by 8%.
  

### Walking in Bare Feet & Cane/Railing Use

- 20 subjects with medial knee OA have decreased varus loading walking in bare feet compared with shoes. Kemp et al, 2008
- Cane use in contralateral hand decreased varus loading by 10%
- Railing use with the contralateral hand should do the same.

### Cane/Railing Use

#### Knee Varus vs. Valgus

Which Hand? Contralateral or Ipsilateral?
Lateral Wedge versus Knee Brace

- 3-point bending knee unloader brace versus 6° lateral wedge in patients with medial compartment knee OA. (Arazpour M, 2013)
- Both groups ↓ in pain, ↑ ROM during gait and gait speed, and ↓ in adduction moment from GRF
- More knee ROM in wedge group possibly from brace constraints

Do Your Patient’s Like Their High Heeled Shoes?

- Wearing a shoe with a 1.5 inch heel lift increased peak knee varus torque by 14% and knee flexion torque was prolonged during stance by 19% in younger women (mean age 26.7)
- Heeled shoe increased peak knee varus torque by 9% and prolonged knee flexion torque during stance by 14% in older women (mean age 75.3)

More on High Heeled Shoes

- Knees more flexed
- Knee extension moment increases
- Angle between the quad and patellar tendons decreases
- Quad and patellar tendon forces increase
- Double Whammy on patellofemoral joint contact force!!

Another Special Population

- Ambulatory patients who have cerebral palsy often are walking with frontal plane knee malalignment and with a crouched gait in knee flexion.
- Excessive frontal plane and sagittal plane loading
  Carter & Tse, (2009)
Articular Cartilage

Effects of Meniscectomy

• loss of CA
• dramatic increases in CP
• focal concentrations of high CPs
• osteoarthrosis (OA)

Articular Cartilage

Ligamentous Instability

• With ligamentous instability, we have an absence of restraint to shearing forces—primarily shearing forces imposed by soft tissues
• increased abrasive wear of articular cartilage
• OA defects

Articular Cartilage

Implications for Intervention

Decrease Skeletal Malalignment

Example: use of foot orthotics to effect decrease in varus or valgus malalignments at tibiofemoral joint

\[ \text{CP} \downarrow = \frac{\text{CF} \downarrow}{\text{CA} \uparrow} \]

Articular Cartilage

Implications for Intervention

Decrease Contact Force

• decrease in body weight
• shock absorption via change in ground surface, shoes, orthotics, stronger muscles, change in movement patterns
• stretch tight soft tissues that cross the joint
Articular Cartilage Implications for Intervention

Decrease Contact Force
• avoid locations in the ROM for which the joint “talks”
• protected weight-bearing
• decrease running velocity
• avoid downhill running

Decrease Abrasive Wear
• bracing?
• redirecting activities
• slowing down
• exercise taking advantage of fluid film lubrication coefficient of friction