Why Worry About Cartilage?

Estimated 385,000 procedures to repair articular cartilage defects in US in the year 1995
Most common location: Patellar articular surface (36%), Medial femoral condyle (34%)
Least common location: Medial tibial plateau (6%)
Successful treatment delicate balance of activities and applied stresses
Mechanism of Cartilage Injury: Direct blunt trauma; Striking joint on helmet or hard surface; Indirect impact loading; Blow to bone; Torsional loading; During tackle; Planting and cutting

Tibiofemoral Joint
Most commonly, articular lesions are located in the area that contacts the tibia between 30-70° of knee flexion.
Medial femoral condyle most common location for full-thickness focal chondral defects

Articular Cartilage
Provides a wear resistant, accommodative surface
Capable of withstanding high compressive and shear loads during weight bearing activities
Has low coefficient of friction which allows ease of movement between joint surfaces
Functions to attenuate force and reduce friction
A **viscoelastic material: "Visco"** – fluid squeezed out; **"Elastic"** – recovers to its resting length after deformation
Designed to tolerate intermittent compression and shear forces
Thickness varies from joint to joint and is thickest at PFJ
Often worn down faster than it can repair itself
Histologic Characteristics
Essentially no blood or lymph vessels; or nerve fibers
Nutrition via imbibition
Cartilage contents: 70-80% Water; 10-20% Dry Weight; 10-15% Proteoglycans and non collagenous proteins; 10-15% Collagen
Chondrocytes (2% of total volume) synthesize collagen, noncollagenous proteins and proteoglycans (PTG's)
Collagen and PTG's 1° building blocks of cartilage: Give cartilage its form and stiffness
Water binds to PTG aggregate which gives cartilage its stiffness and allows it to attenuate force
With ageing – Decrease in PTG content; resulting in less binding sites for water

Hyaline Cartilage Zones
Superficial zone (10-20%)
Consists of "lamina splendens" layer
Tightly packed collagen fibers parallel to articular surface
Cellular layer of flattened chondrocytes.
Protect deeper layers from shear

Transitional or Middle layer (40-60%)
Composed of spherical chondrocytes, PTG's, and obliquely oriented collagen fibers that primarily resist compressive forces
Serves as transition zone between deep and superficial.

Deep zone (30%)
Collagen fibers and chondrocytes oriented perpendicular to articular surface
Resists compressive loads.
Calcified layer: Tidemark that separates subchondral bone from calcified cartilage
Provides complex adhesive properties of cartilage to bone

Outerbridge Classification
0 – Normal cartilage
I – Softening and swelling
II – Partial thickness defect, fissuring < 1.5 cm in diameter
III –Fissures that reach subchondral bone > 1.5 cm in diameter
IV – Exposed subchondral bone

The Problem with Articular Cartilage

Undergoes same necrotic phase as normal tissue
If subchondral plate not disrupted the inflammatory phase almost absent
Process of transudation, exudation, and hematoma formation absent
No fibrin clot for scaffold
No new repair cells – task falls on chondrocytes
Chondrocytes are metabolically active but are incapable of producing required repair products
If injury extends through subchondral bone all 3 phases are stimulated
Underlying bone excellent source of new blood vessels and primitive cells for differentiation and modulation to fibroblasts or chondrocytes
Without penetration of subchondral bone, the absence of an intrinsic vascular system prohibits an injury to articular cartilage from inciting the commonly observed vascular response
Penetration of subchondral plate results in influx of marrow contents including inflammatory cells, undifferentiated mesenchymal cells, cytokines and growth factors.
Loading of articular surfaces causes movement of fluid within the matrix
This dampens and distributes loads within the cartilage and the subchondral bone

Cartilage Injury
Done slowly – cartilage can deform and matrix absorbs force sparing injury
Done rapidly – matrix absorbs more stress
If stress great enough matrix ruptures, cells are damaged and injures subchondral bone
Blunt trauma can damage articular cartilage and calcified zone- subchondral bone region
Yet – leave articular surface intact!
Loss of PTG's or an alteration of structure can occur before signs of cartilage injury occur following even impact loading
Loss of maxtix PTG's will decrease cartilage stiffness and increases its permeability
Increases risk and susceptibility to injury

Nutrition and Metabolism
Chondrocytes require nutrients that are absorbed via diffusion from synovial fluid
Synovial membrane lines surface of joint capsule and secretes synovial fluid
Joint motion necessary for diffusion of nutrients
Degeneration or necrosis of cartilage occurs with prolonged compression or immobilization

Theories on Articular Cartilage Nutrition
Nutrition via diffusion of subchondral bone

Articular cartilage attached directly to subchondral bone
Diffusion directly across the calcified zone of articular cartilage is possible
Nutrition via diffusion of synovial fluid
Fluid imbibitions: Articular cartilage “soaks up” synovial fluid like a sponge
Possible because there is no anatomical barrier between fluid and cartilage
Solutes have been shown to pass freely
Articular cartilage cannot survive without synovial fluid

Joint Movement
Healthy joint deprived of movement, fluid becomes stagnant and nutrients depleted
Movement and intermittent loading create a pumping action
As cartilage is compressed, fluid squeezed out and metabolic waste removed
When load is removed, nutrient rich synovial fluid is reabsorbed in cartilage
Joint Movement – Chondrogenesis
Motion has chondrogenesis producing effects

Clinical Evaluation and Presentation

History
Single injury vs. series of injuries; Focal chondral or osteochondral injury; Cannot recall - Degenerative lesion; If they remember other details; Did it “pop”; Feelings of instability; Locking, catching

Symptoms of Unhealthy Cartilage
Stiffness; Swelling; Pain; Muscle Guarding; Crepitis

Non Surgical Treatment

Rehabilitation Dilemma
Importance of cartilage undisputed
Avascular nature complicates pathology*
No real hemorrhage or fibrin clot formation – no inflammatory response
Minimal potential for regeneration
PROMOTE HEALING: DO NOT OVERLOAD TISSUE
Rehabilitation: Rest; Analgesics; PT – useful for strengthening and increasing ROM
No evidence that PT heals articular cartilage in humans

Rehabilitation Exercise
Animal studies; Exercised horses and dogs
Cartilage stiffer, thicker, and greater concentration of proteoglycan than non-exercised animals

Controversial
Steroid injections; Hyaluronic acid; Glucosamine; Chondroitin Sulfate
May provide temporary pain relief!
No evidence that support application for focal defects

Successful Rehab Requires Knowledge of:
Science of articular cartilage, factors that influence repair and degradation
Specific surgical variables
Nature of lesion (acute vs. chronic)
Location of defect (MFC, LFC, MTP, LTP, Trochlea, Patella)

Size of defect; Depth of defect
Exact surgical procedure
Tailor to exact surgical procedure
Specific patient variables
Age
Desired activity level
Occupation

Overview of Rehabilitation
Do not overstress healing tissue
Create environment and stimulus for cartilage regeneration
Reduce joint effusion
Restore joint motion and flexibility
Reestablish muscular function
Control weight bearing forces and applied loads during rehabilitation
Correct lower extremity alignment
Patient compliance is critical to successful outcome

Articular Cartilage Repair Procedures

Arthroscopic Lavage and Debridement

First line of defense
PWB or WBAT for 1-2 weeks
Full passive knee extension
Gradual restoration of knee flexion usually 0-135° by weeks 2-3
PROM, AAROM and AROM (unloaded) immediately postoperative
Emphasis on isometric and OKC exercises initially
Gradually progress to CKC exercise
Moderate impact loading 6-8 weeks
Progress to high impact loading 8-12 weeks

Abrasion Arthroplasty & Chondroplasty

If injury doesn't extend to subchondral region, there is limited capacity for repair
When injury extends to vessels in the subchondral region, a clot forms
Inflammatory and undifferentiated cells migrate into it and commence repair process
New matrix framework has insufficient proteoglycans, type II collagen, and adhesive molecules.
Hyaline cartilage high in type II collagen
Repair tissue fibrocartilage – primarily type I collagen
Causes marked differences in structural properties
Lacks organization into the layered structure of articular cartilage
Chondral repair tissue is often of intermediate composition and structure between hyaline and fibrocartilage
Does not bond to surrounding hyaline cartilage
Subchondral bone does not form an impermeable barrier, allowing fluid exudation
Repair tissue lacks durability of original tissue
Compared to original tissue – the repair tissue has:
Inferior stiffness
Inferior resilience

Poorer wear characteristics

Arthroscopic Abrasion Arthroplasty
Introduced approximately 20 years ago
Modification of Magnusson “house cleaning” procedure with extensive debridement and Insall-Pirdie open drilling of subchondral bone plate
Superficial scraping of sclerotic lesion with currette or burr until bleeding occurs
Remove entire layer to enhance clot attachment
Generally 1-3 mm of subchondral bone
Clot initially forms into fibrous tissue and eventually fibrocartilage

Mosaicplasty & OATS

Using a collection of small osteochondral cylinders inserted side by side
Better represents the radius of curvature of the normal articular surface
Advantage is placement of spongy bone into spongy bed of recipient
Fibrocartilage forms around cylinders of graft
Surgical site is retracted to remove any loose cartilage. The edges of the cartilage are brought back to right angles and any detatched cartilage is removed.
Then the base of the lesion is abraded to viable sub chondral bone.
Under direct visualization the first tunnel is drilled perpendicular to the surface of the condyle using an appropriate drill bit. Depth of tunnel will vary depending on pathology; 15 mm for cartilage repair, 20-25 mm for OCD.
The graft is then harvested from the medial rim of the femoral trochlea, away from the weight-bearing areas with a tubular chisel of the same diameter as the drill bit use to prepare the hole for the recipient site.
The chisel must be carefully positioned perpendicular to the cartilage surface. Chisel is driven by a hammer to the desired depth, avoiding any overheating that could put the viability of the graft in harm.
Recipient hole is dilated. Cylindrical graft is inserted into the hole using a graduated harvesting tamp enabling the graft to be inserted to the desired depth so that the surface of the graft is level with the adjacent hyaline cartilage.
The grafts should cover at least 70% of the cartilage defect

Autologous Chondrocyte Implantation (ACI)
Advanced cell-based orthobiological technique used for treatment of chondral injuries to the knee.
Used since 1987
Performed on more than 12,000 patients internationally
Rehabilitation guidelines based on:
Expert opinion
Animal studies
Basic science
Clinical biomechanics
Rehabilitation after Autologous Chondrocyte Implantation
In general….. Rehab should address impairments and functional limitations without jeopardizing healing of the lesion.
Rehabilitation after Autologous Chondrocyte Implantation
Classic description is termed autologous chondrocyte transplantation (ACT)
ACT Surgical Steps

First stage is arthroscopic evaluation
Assess containment, depth an potential bone loss
Biopsy performed from superomedial edge of trochlea or the lateral edge of intercondylar notch
ACT Surgical Steps
Total volume of biopsy should be approximately 200-300 mg
3 “Tic-Tac”-sized fragments
ACT Surgical Steps
Second Procedure
Arthrotomy; Preparing defect; Periosteal harvesting; Periosteal patch (First Generation)
Periosteal hypertrophy; More commonly on patella; ? Due to stimuli of higher shear forces
Other Complications: Patellar hypertrophy; Malfusion; Insufficient regeneration; delamination

2nd Generation
Bilayer porcine collagen membrane
Membrane eventually degraded by enzymatic digestion
2 surfaces: External –strong barrier; Inner – porous stimulates cells to produce cartilage-specific matrix molecules
Collagen membrane
Reduced amount of graft hypertrophy
87% good to excellent results
Second Procedure
Suturing periosteum over defect; Testing for water tightness; Fibrin glue sealant; Chondrocyte implantation; Wound closure; Rehabilitation

Disadvantages
Chondrocyte leakage; Dedifferentiation of phenotype (cells grown in monolayer initially)
Uneven distribution; Pereosteal detachment; Pereosteal hypertrophy

Used for larger lesions (> 2 cm^2)
Ideal for symptomatic well-contained chondral or shallow osteochondral defects measuring 2-10 cm^2
May be used as secondary procedure after 1 or more failed alternative cartilage repair procedures.
Still 2nd surgery procedure. Culture time initially 6-8 weeks; Now 3-4 weeks
Minimum 3 weeks needed after initial surgery; Replace synovial fluid; Portal healing
Analgesia/anesthetic recovery
Expanded population of chondrocytes that express a marker predictive of the capacity to form hyaline-like cartilage in vivo
Optimized cartilage cell batches

ACI Rehabilitation
Protective Phase: Day 1- Week 6
WB Guidelines (0- 6 Weeks)
Femoral Condyle: NWB x 1-2 weeks or 25% WB - Brace locked at 0°
TTWB @ weeks 2-3; PWB (25%) @ week 4
Increase WB 25% per week; FWB – 6-7 Weeks
Maintain assistive device until wk 8 post-operative if there is pain/swelling associated with ambulation

Patella/Trochlea
Immediate TTWB 25% BW – brace locked in full extension
50% WB week 2 in brace
75% WB week 3-4 in brace
Maintain assistive device until wk 6 post-operative if there is pain/swelling associated with ambulation
Brace Guidelines – *Femoral Condyle*
Locked at 0 degrees during wt bearing
Sleep in locked brace 2-4 weeks
Brace Guidelines – *Patella/trochlea*
Locked at 0 degrees during wt bearing
Sleep in locked brace 4 weeks
CPM/PROM – Femoral Condyle
8 hours/day starting day 1
Full passive knee extension
Femoral defect: 0-40° flexion
CPM settings increase up to 5-10° per day if no changes in pain or swelling
Continue for 6 weeks
Patellar mobilizations 4-6x's per day
CPM/PROM – Patella/Trochlea
8 hours/day starting day 1
Full passive knee extension
Lesion < 6 cm^2 0-60° flexion
Lesion > 6 cm^2 0-40° flexion
CPM settings increase up to 5-10° per day if no changes in pain or swelling
Continue for 6 weeks
Patellar mobilizations 4-6x's per day
Femoral Condyle & Patella/Trochlea
CPM
Use for 6 weeks (approximately 2 hrs/time)
CPM> than Intermittent motion in stimulating repair of articular cartilage Increase ROM
Decrease adhesions
Decrease pain
Femoral Condyle
RANGE of MOTION

1-2 (3) weeks	90°
3-4 weeks	105°
5-6 weeks	120°

DO NOT PUSH INTO PAIN
CPM, PROM, AAROM
Patella/Trochlea

2-3 weeks	90°
3-4 weeks	105°
6 weeks	120°

DO NOT PUSH INTO PAIN
CPM, PROM, AAROM
Strengthening – ALL
Ankle pumps
QS
Multiple angle isometrics (safe range)

Short arc ROM (active knee extension) that does not irritate or load the repair site *NOT PATELLA/TROCHLEAR
Strengthening – ALL
SLR x 4
Bike when motion allows – ROM only no resistance
Isometric leg press at week 4 (multiple angle)
Functional Activities – ALL
Gradual return to daily activities
If symptoms re-occur, decrease activities appropriately
Extended standing should be avoided.
Modalities
E-STIM
High intensity E-stim to the quadriceps muscle with the knee in 65° of knee flexion was more effective than a CKC exercise program alone restoring strength and improving gait s/p ACL-R.
Modalities: Ice; Elevation; Compression; Modalities
Train negotiation of environment i.e., stairs, hills, uneven ground with assistive device
CV Training
Cycling with light resistance after > 90° ROM
NO cycling with patella/trochlea defect repairs (CPM exercises ONLY)?
Aquatics: Flutter kick only
UBE
Criteria to Progress to Phase II
Full passive knee extension
Knee flexion to 120°
Minimal pain and swelling
Active voluntary quadriceps activation

Transition Phase II: Weeks 6-12
Femoral Condyle
WB Guidelines
Progress WB as tolerated
½ WB by 6 weeks
FWB by 8 weeks
DC crutches at 8 weeks
Delay FWB if large or uncontained lesion

Patella/Trochlea
WB Guidelines
Progress FWB as tolerated
FWB 6 weeks
DC crutches at 6 weeks
Treadmill (slight incline 2-3% to reduce joint loads)
With trochlea defect may use TM after 12th week post-op (walking only)

Brace - Both
DC brace at week 6

ROM – *Femoral Condyle*
Maintain full knee extension
Knee flexion 125-135°

Full ROM (Wk 10-12)
Mobilizations if needed
Stretching

ROM – *Patella/Trochlea*
Gradual increase in ROM
Maintain full knee extension
Knee flexion 120-125° by week 8
Mobilizations if needed
Stretching

Strengthening Exercises – *Femoral Condyle*
> 6 Weeks
Weight shifts 6 weeks
Pressing CKC exercises
Limit weight-bearing to < BW
Calf raises
Stationary bike (low resistance)
Treadmill walking (2-3% grade)
Balance and proprioceptive drills
Front and lateral step ups

Strengthening Exercises – *Patella/Trochlea*
> 8 Weeks
Weight shifts 6 weeks
Pressing CKC exercises (0-60°) week 8
Limit weight-bearing to < BW
Mini-squats (0-45°) week 8
Knee extension without resistance
Calf raises
Stationary bike (low resistance)
Treadmill walking (2-3% grade)
Balance and proprioceptive drills
Front and lateral step ups

Limit dynamic repetitive exercises with trochlea repairs until 16 weeks post-op?
Balance
Proprioception
Bike; Stairmaster (SA); Versaclimber (SA); Rower (SA); Treadmill (2-3% incline)

Criteria to Progress to Phase III: Both
Full ROM
Acceptable strength level
Hamstrings within 10-20% contralateral leg
Quadriceps within 10-20% contralateral leg Femoral condyle
Quadriceps within 20-30% contralateral leg Patella/Trochlea
Balance testing within 30%
Ability to walk for 1-2 miles or bike 30 minutes
Maturation Phase: (12-26 weeks)

Femoral Condyle
Increase work loads in the sagittal plane
Increase strength as tolerated
Increase muscular endurance

Remodeling Phase: (13-32 weeks) *Patella/Trochlea*
Increase work loads in the sagittal plane
Increase strength as tolerated
Increase muscular endurance
Focus on good biomechanics to decrease stress on the knee

ROM- **Both**
125-135° of knee flexion
Exercise Program – Femoral Condyle
Leg press (0-90)
Bilateral squats (0-60)
Step ups – 2" progressing to 8"
Forward lunge
OKC knee extensions (0-90)

Exercise Program – *Patella/Trochlea*
Leg press (0-60) progressing to (0-90)
Bilateral squats (0-60)
Step ups – 2" progressing to 8"
Forward lunge
OKC knee extensions (40-90) 1 # increase every 2 weeks if no pain or crepitus

Femoral Condyle
Mild "impact tolerance" on treadmill without running
Up to 45 min.
Cross training

Patella/Trochlea
Cross training
May run if physician ok at end of phase III
Criteria to Progress to Phase IV: Both
Full non painful ROM
Strength within 80-90% of contralateral
Balance and stability within 75%
No pain, swelling, inflammation.

Functional Activities Phase: (26-52 Weeks) *Femoral Condyle*
Return to unrestricted activities

Maturation Phase: (8-15 Months) *Patella/Trochlea*
Return to unrestricted activities

Exercise Program - *Both*
Maintenance program 3-4 times per weeks
Progress as tolerated or needed
Progress impact loading slowly and make it specialized to patient demands

Low Impact – 6 months
Swimming; Skating; Cycling

Higher Impact
8-9 months for small lesions; 9-12 for large lesions
Jogging; Running; Aerobics

High impact
9-12 for small lesions
Larger lesions up to 18 months
Tennis; Basketball; Football; Baseball

Clinical Importance
Cartilage remodeling of newly formed tissue may take time
At least 18 months after surgery
Biopsies @ 12 months – more fibrocartilage
Biopsies @ 18 months – hyaline
Morphology
Predominately hyaline – 22%
Mixed – 48%
Predominately fibrocartilage – 30%
> amounts of hyaline as time with > time intervals
Continuous remodeling – may become more hyaline with time
Length of training?

Microfracture

A biological response is stimulated by penetration of the subchondral plate
An ideal treatment for cartilage injury should:
Technically simple to perform
Arthroscopic
Low patient morbidity – min. incision
Cost effective
Long-term success rate
Burn no bridges

Microfracture Advantages
Less heat necrosis than drilling
Provides rough surface for blood clot to attach – “superclot”
Maintain subchondral plate
Allow access to mesenchymal stem cells with chondorgenic and osteogenic potential rather than mature chondrocytes

Full thickness lesion
Weight bearing surface tibia or femur
Contact lesion on PF joint
Unstable cartilage overlying subchondral bone
Degenerative changes with normal axial alignment
Focal grade III or IV articular surface lesions without bone loss that are surrounded by normal articular cartilage in a young patient.

Microfracture Technique
Sugical awl to penetrate subchondral bone
Create 3-4 perforations per cm^2
Depth of 2-4 mm
Should access underlying bone, releasing blood and mesenchymal cells
When see fat droplets coming from marrow cavity
Creates bleeding response to form “superclot” over chondral defect

First Post-operative visit
Assess brace status – trochlear groove or combined
Assess weight bearing compliance
Assess fit of crutches (don’t count on medical staff)
Educate of polar pak/theracool
Clinical Assessment: Swelling; Patellar mobility; Quad tone/SLR; Extension/flexion ROM per MD - Treat limitations listed above

Important factors
Weight bearing status
NWB 6-8 weeks if condyle/plateau lesion
WBAT if trochlear groove
CPM machine
Performed 6-8 hours per day every day
1 complete cycle of motion each/min
Ranges of 20-80° or 30-70°

Post Operative Braces
None for isolated condylar or plateau lesion
8-10 weeks for trochlear groove or combined etiology knees
Graduated unlocking progression at appropriate time frames

WB Guidelines (0- 6 Weeks)
Femoral Condyle
Tibial Plateau or Trochlea
Edema Management
Polar Pak with continuous flow bladder
Compression stocking; tube-grip
Ace bandage use
Continuous icing for 1^{st} 7-10 days
Education of patient critical

Brace
Some recommend brace regardless of location.
Tibia or condyle in full extension
PF/Trochlear groove lesion allow 0-20 or 0-30 degrees ROM stop

CPM
Use 6 hours per day x 8 weeks
Full-thickness cartilage defects
Resulted in enhanced gross healing of lesion viewed by post surgery arthroscopy
PWB 4-6 weeks, initially toe touch (<5.0 lbs) then progress to 50%, then 75% BW
*15% WB first 6 weeks

Some advocate NWB for 6-8 weeks
Full passive knee extension*
Gradually increase knee flexion ROM
Full knee ROM at 3-4 weeks
Full passive knee extension*
Flexion contracture will result in gait abnormalities and PF pain/symptoms
Generous PF mobilizations
Instruct in home program of self PF mobs
Performed periodically (5-6 x/day) at home
Emphasize ROM (controlled loading) passive and active assisted
Isometrics progressing to limited arc isotonics
Isometrics
Towel roll under knee for biofeedback
E-stim if having trouble eliciting
Multiple-angle isometrics when ROM improved
CKC ex's bike and pool

MUST KNOW LOCATION OF LESION
Imperative so that therapist can avoid angles that engage the articular cartilage lesion
*Especially important for those that have undergone PF microfracture
Restoration of ROM and Gait
When SLR without pain/extensor lag – p/o brace DC'd
May use knee sleeve with ADL's
Weight-bearing varies with location
Typically at 6 weeks fibrocartilage should have started to fill in defect
Typically full ROM achieved by or before 12 weeks

TF EXERCISE BIOMECHANICS
OKC knee extension
Compressive loads greatest from 60-90 degrees
Shear greatest at 0-40 degrees
TF EXERCISE BIOMECHANICS
CKC knee extension
Shear and compression greatest at 60-100 degree arc
SAFE EXERCISES: CKC leg press 0-60 degrees -Low-load high rep
UNSAFE EXERCISES: PF Joint – OKC knee extensions are not used until after 3 months due to high PF forces
SAFE EXERCISES: Mini squats 0-45; Graduated step up program

Rehabilitation of Microfracture - Weeks 12-18+
Dedicated to restoration of strength
CKC now 0-80 degrees
Assess quality and control of movement rather than simply amount of weight
Slowly begin OKC
Start initially in 90 to 40 degree arcs
Closely monitor signs of pain or swelling
Moderate impact loading at 16 weeks
If meet criteria for strength, ROM and clinical exam may begin jogging on TM
Progress to high impact loading 20-26 weeks

ALWAYS RESPECT THE ARTICULAR CARTILAGE!
THANK YOU!

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