Knee Chondral Repair: Review of Surgical Techniques and Post-Operative MR

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4/9/09

Chondral Injuries

- Very common
- Present in 63-66% patients undergoing arthroscopy
  - 11-19% full-thickness lesions
- Up to 79% patients with ACL deficient knee have some form of chondral injury

Shindle MK. J Bone Joint Surg Am. 2006;88:27-46.

Cartilage Trauma and Degeneration

- Does not heal spontaneously
  - relative **avascularity of articular cartilage**
- If injury extends to subchondral bone, usually more substantial natural healing process
- Repair tissue composition of hyaline cartilage and fibrocartilage

Shindle MK. J Bone Joint Surg Am. 2006;88:27-46.

Surgical procedures

- **R**estoration
- **R**eplacement – Allograft
- **R**elief- Osteotomy
- **R**esection – Joint Arthroplasty

Chondral Restoration/Replacement

- Debridement/Abrasion Arthroplasty
- Microfracture
- Autograft (OAT and Mosaicplasty)
- Allograft
- Autologous Chondrocyte Implantation
- Biodegradable Pins

Post-operative MR Followup

- MR imaging and arthroscopy complementary
- **MR is less invasive than arthroscopy**
- **MR more comprehensive evaluation of repaired tissue**

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Post-operative Followup

- Standard MR imaging techniques may be used postoperatively
- **International Cartilage Repair Society recommendations** (Table 1)
- Postoperative appearance of the joints after repair varies according to the surgical technique and stage of healing
  - Important to be familiar with surgical techniques and characteristic MR imaging features at various postoperative intervals

Table 1
ICRS-recommended MR Imaging Sequences for Evaluation of Cartilage Repair

Intermediate-weighted fast SE
With fat saturation
Without fat saturation (with moderate TE)
T2-weighted fast SE
With fat suppression
Without fat suppression
T1-weighted GRE
With chemical fat suppression
With water excitation*

*This sequence is not available on all MR imaging systems but, if available, can be substituted for chemical fat suppression, which requires more acquisition time.

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Future Techniques

- Newer techniques, which include delayed gadolinium-enhanced imaging and mapping of T1ρ and T2 values, may provide useful supplemental information about the histologic and biochemical contents of reparative tissue

MR Imaging - Basics

- Degree of defect filling (should be same thickness as normal cartilage)
- Extent of integration with adjacent tissues (should be continuous)
- Graft appearance
- Underlying bone appearance
- Presence of proud subchondral bone formation (should be smooth)

Table 2
Parameters of MR Imaging Assessment after Microfracture Procedures and Autologous Autograft Transplantations

Microfracture procedures
Degree of filling of defect
Morphologic characteristics of reparative tissue
Presence or absence of delamination
Extent of peripheral integration (presence of fissures)
Autologous autograft transplantations
Degree of filling of defect by transplanted osteochondral plugs
Restoration of radial curvature of joint surface
Presence or absence of displacement
Peripheral integration of repair cartilage and osseous components
Morphologic characteristics of the repair site
Integrity of host cartilage

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Restoration

- Two methods
  - Enhance intrinsic healing capacity of tissue
    - Stimulate growth of fibrocartilage from bone marrow stem cells
    - Mainly Type I collagen rather than Type II collagen in hyaline cartilage
    - Structural properties are inferior to normal tissue
  - Regenerate new cartilage

Restoration

- Mechanical Repair - Debridement
- Abrasion Arthroplasty
- Microfracture

Mechanical Repair

- Unstable cartilage at defect is removed with arthroscopic debridement and lavage
- Usually palliative, short term relief
- Cleanup

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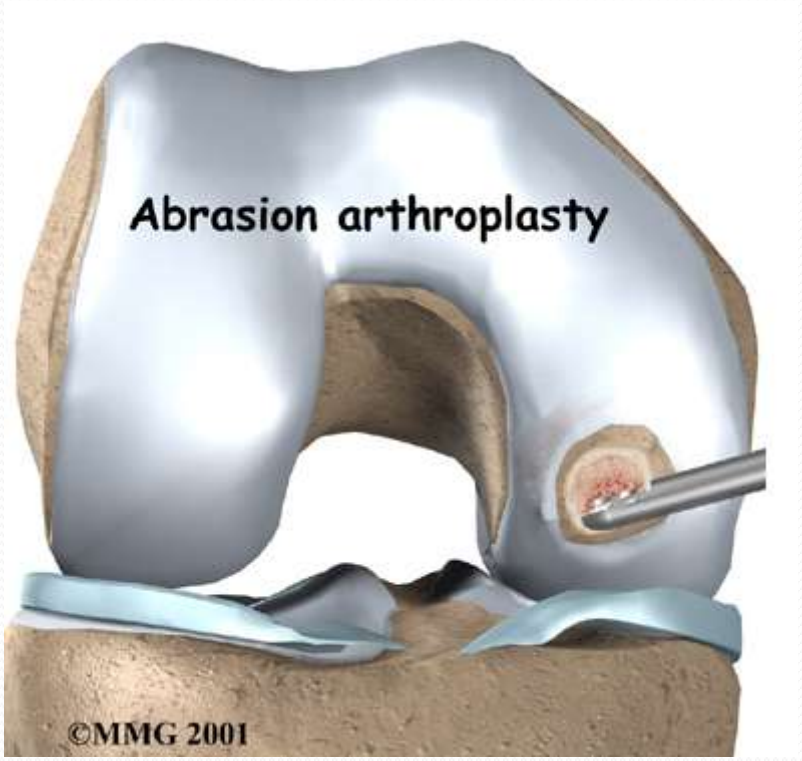
Abrasion Arthroplasty

- Exposed surface bone is excised by burr or shaver to a depth of 1-3 mm beneath cartilage defect
- Results in formation of fibrin clot at the defect site



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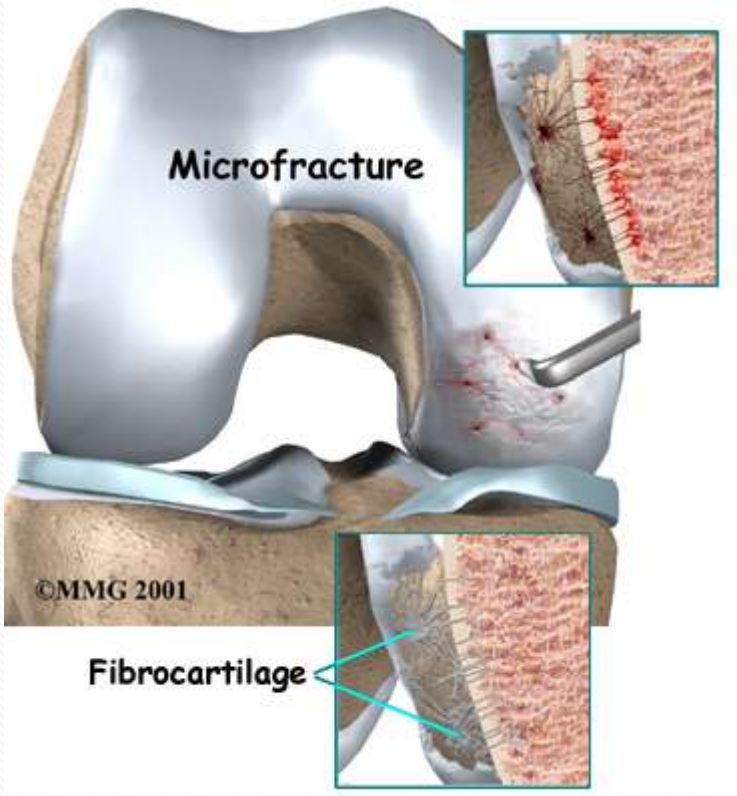
Microfracture

Microfracture

- Unstable cartilage debrided
- Stable edge of viable cartilage formed
  - Helps hold the marrow clot
- Calcified cartilage layer removed by curette
- Angled awl used to create 2-4 mm deep pits perpendicular in subchondral bone
  - Spaced 3-4 mm apart
  - Start at periphery and move inwards
- Non-power tools preferred due to decreased risk of thermal necrosis



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Microfracture

- Exposed bone is debrided of all remaining unstable cartilage
- Stable perpendicular edge of viable cartilage is formed around the defect
  - Helps hold the marrow clot
- Calcified cartilage layer removed by curette
- Angled awl used to create 2-4 mm deep pits perpendicular in subchondral bone beneath the cartilage defect
  - Spaced 3-4 mm apart
  - Start at periphery and move inwards
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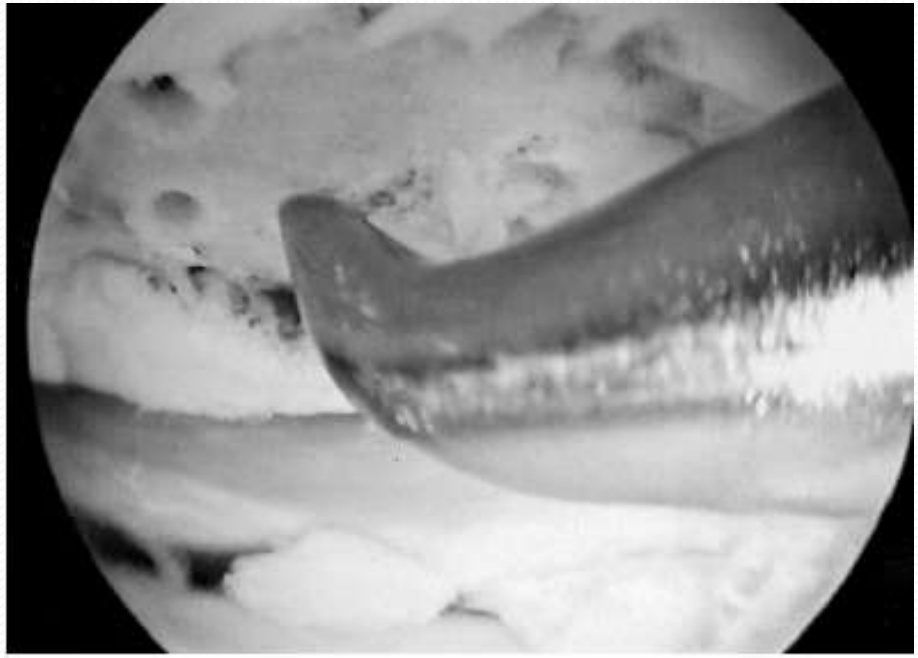

Microfracture holes are continued into the central portion of the defect. Awl is penetrating subchondral bone approximately 2-4mm in depth.

Steadman JR. et al. Clin Ortho Rel Resrch 2001;391S:S362-369.

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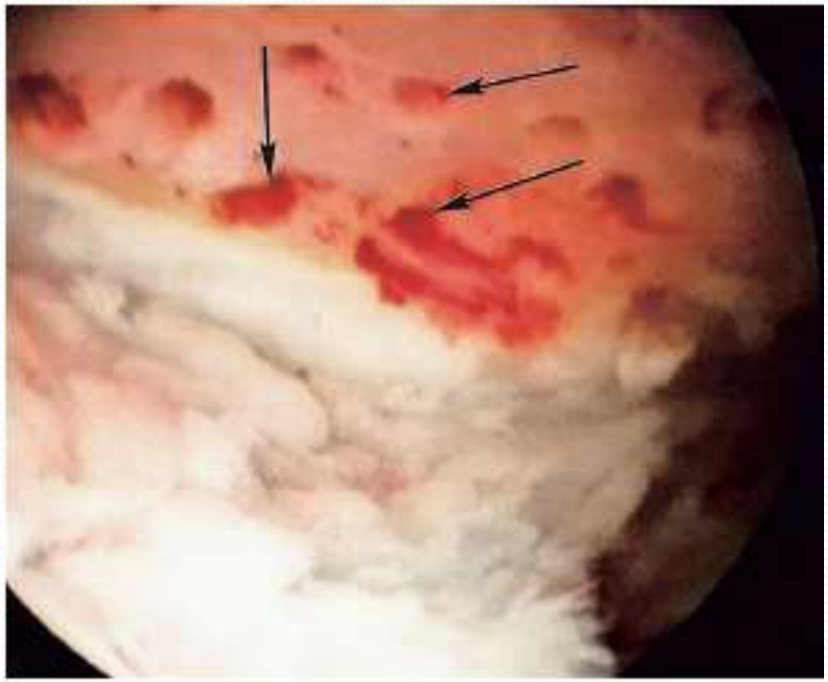


Marrow elements including blood and fat droplents can be seen coming from microfracture holes.

Steadman JR. et al. Clin Ortho Rel Resrch 2001;391S:S362-369.

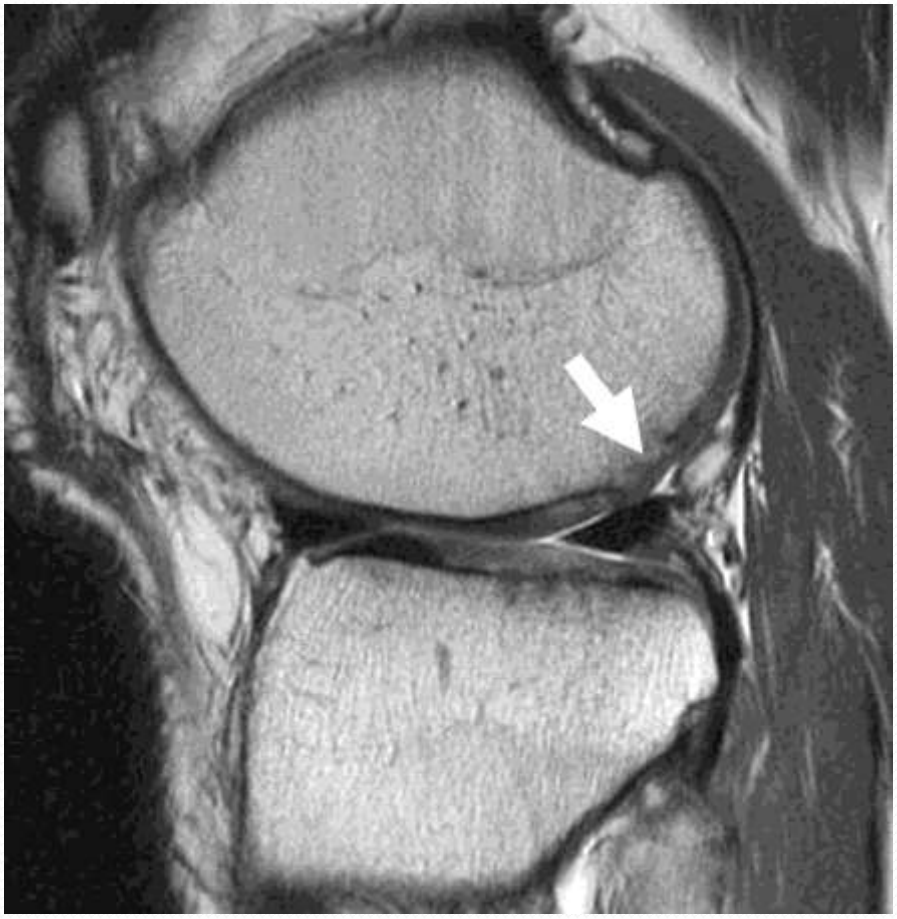
Microfracture

- Most commonly performed cartilage repair procedure
  - Likely no improvement for at least 3-6 months
  - Improvement slowly and steadily for 2 years
- Best short-term results observed with good fill grade, low body-mass index, and short duration of preoperative symptoms
  - Will help decrease pain and return to function short term
  - Several high profile athletes never returned to full function after surgery
  - Some returned too early in the recovery period and reinjured same/contralateral knee
- Recommended for focal grade III/IV lesion surrounded by normal cartilage in young patient

Microfracture MR features

- Appearance of lesion evolves over time
  - Early postoperative period
    - Thin and indistinct
  - 1-2 yrs after surgery
    - Filled defect
    - Smooth and well-defined
- **Bone overgrowth in 25-49% patients**
  - **Does not have negative effect on clinical outcomes**
- Signal of reparative fibrocartilage
  - Hyperintense due to less organized matrix and increased water mobility
  - Signal decreases as tissue matures
  - Subchondral bone marrow edema decreases
- Treatment failure
  - Incomplete filling of defect with thin and irregular tissue
  - Persistent bone marrow edema

12 months



overgrowth of subchondral bone (arrow), thin overlying reparative fibrocartilage, and hyperintense signal in native cartilage

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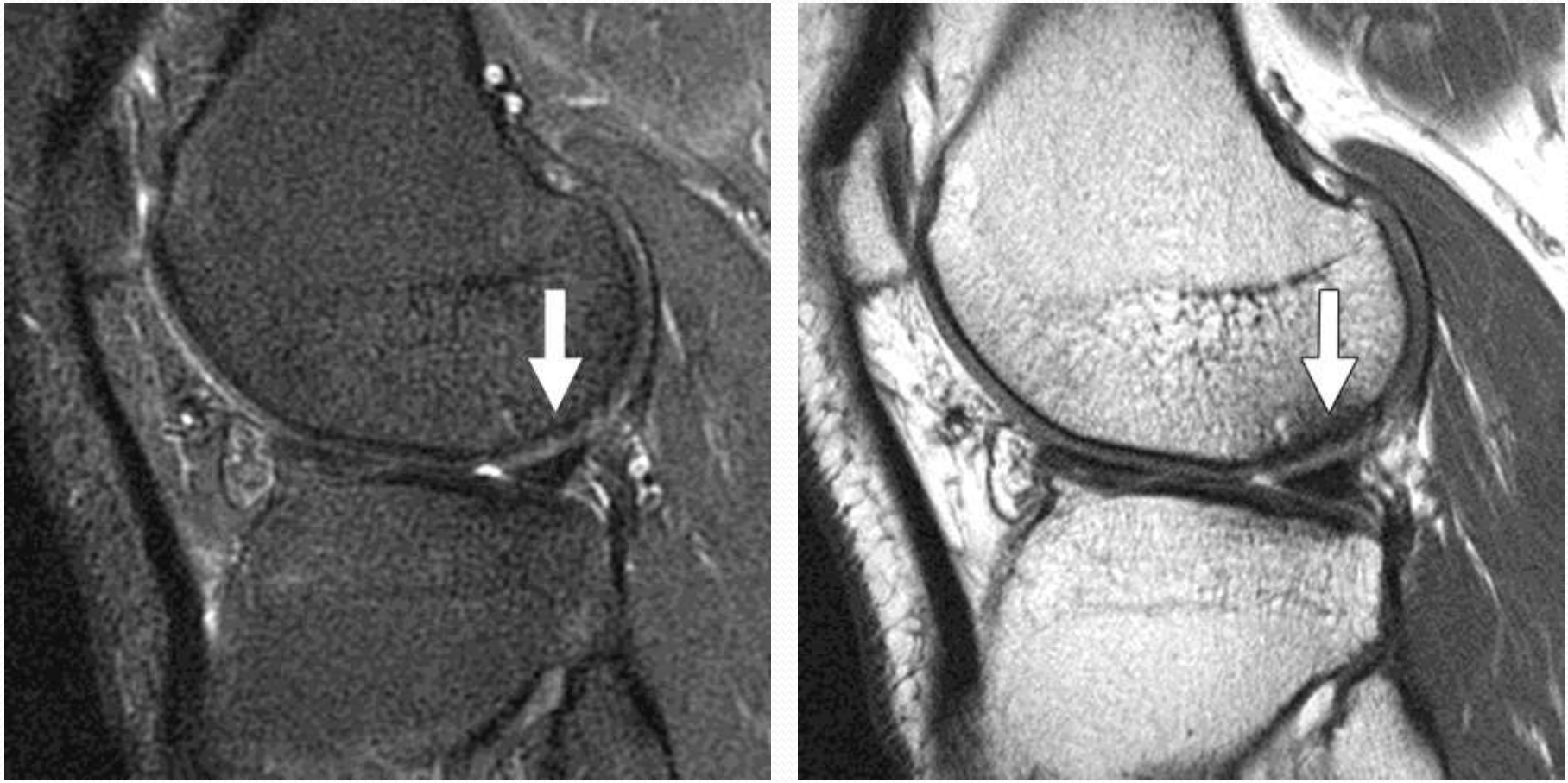
Microfracture

- 6 months after surgery



Sagittal inversion-recovery fast SE and sagittal intermediate-weighted fast SE images acquired 6 months after a microfracture procedure in a 29-year-old man show **hyperintense signal** in the repair cartilage with **good fill** over the lateral femoral condyle (arrow)

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Microfracture

6 months after surgery

6 months after surgery

Sagittal and coronal intermediate-weighted fast SE images acquired 6 months after a microfracture procedure in a 50-year-old man show **hyperintense** signal and **superficial irregularity** in the reparative cartilage over the medial femoral condyle (arrow)

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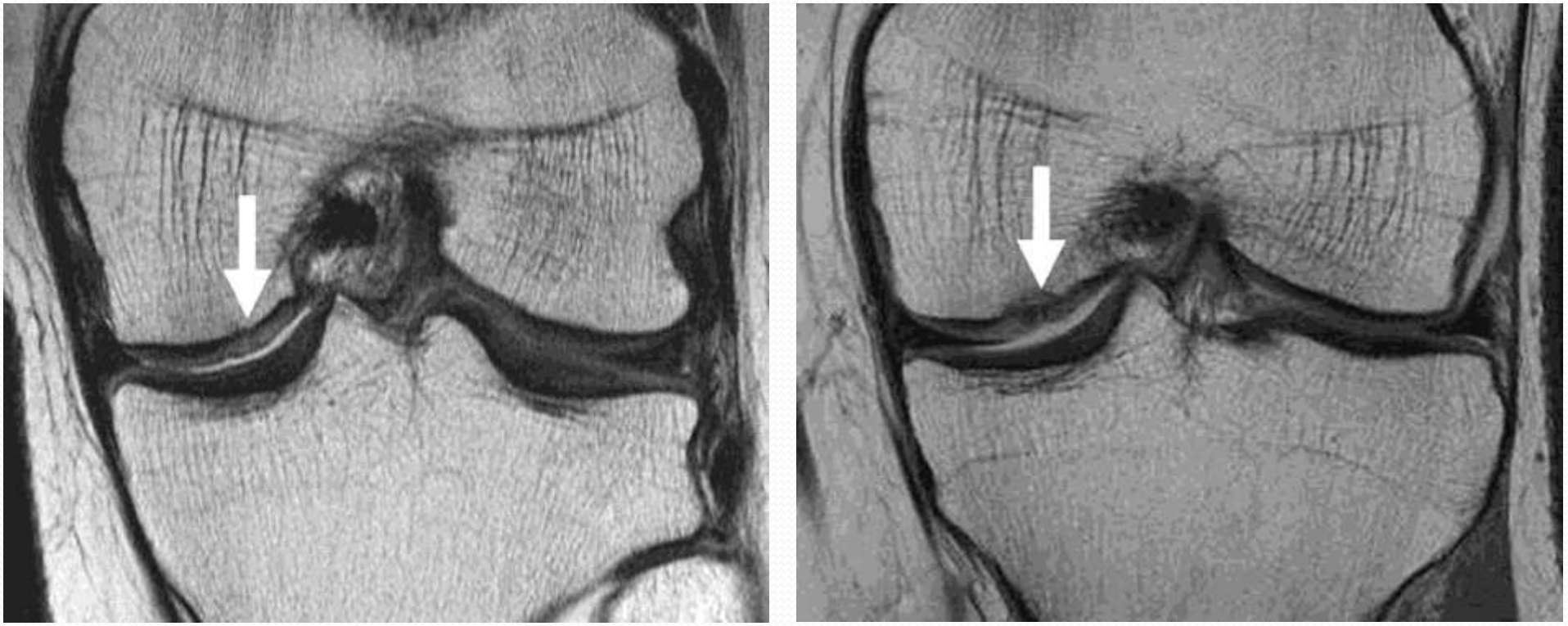
Microfracture

6 months after surgery

4 years after surgery



Four year follow-up exam (right) shows **superficial irregularity** of the reparative fibrocartilage, but no exposed subchondral bone

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Restoration

- Transplantation of chondral/osteochondral plugs
  - Autologous
  - Allograft
- Transplantation of chondrocytes

Osteochondral Autograft Transplantation

- OAT
- Transfer of osteochondral plug from non-weight bearing region of knee to site of chondral damage
  - Most common harvest site
    - Lateral femoral condyle non-weight bearing surface
      - Intercondylar region
      - Peripheral portion of LFC
- Most frequently performed in knee and ankle

http://www.arthrexvetsystems.com/en/products/upload/Single-Use-OATS-mini.pdf

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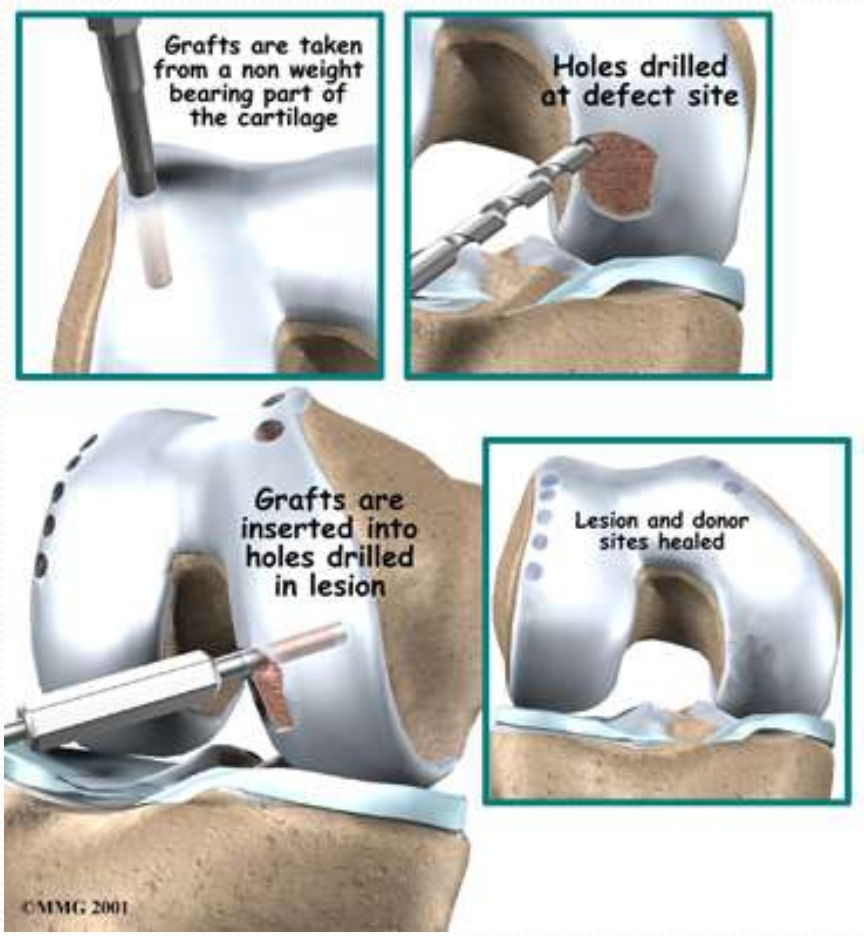

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Osteochondral Autograft Transplantation

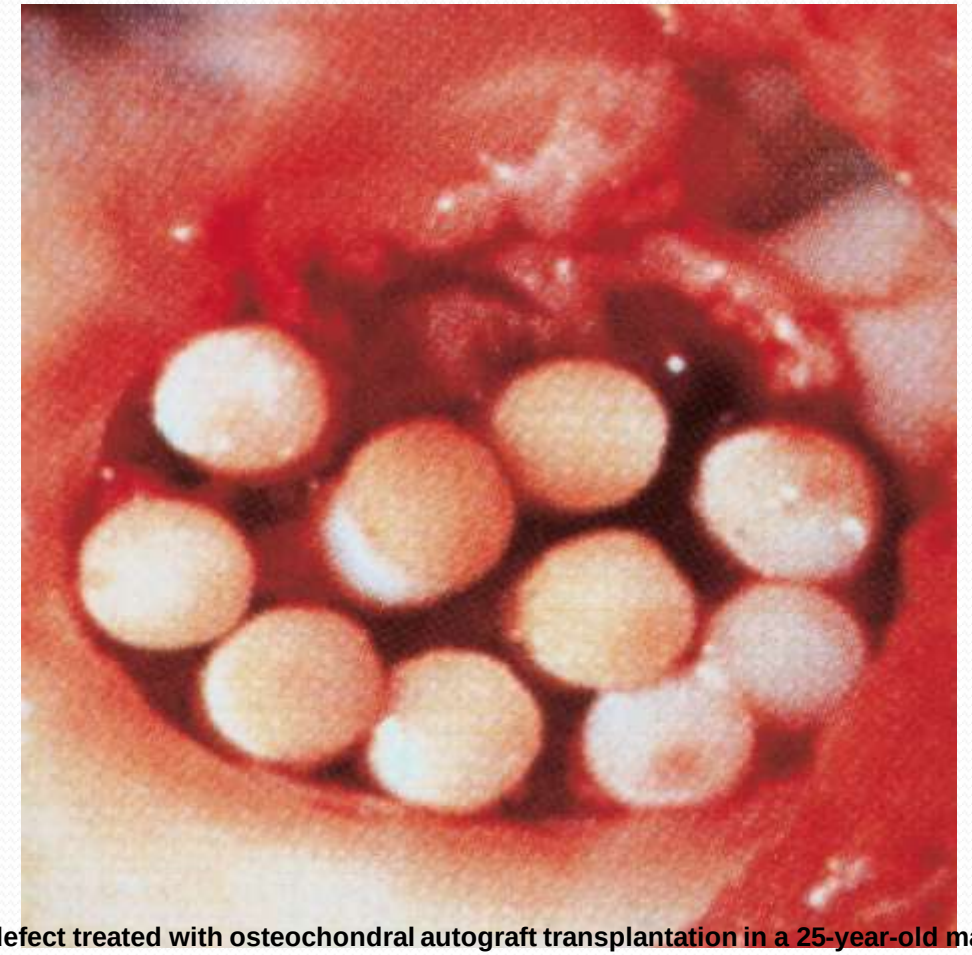
- Key to success is viability of chondrocytes
- Best suited for 1-4 cm^2 lesions, osteochondritis dissecans, and osteonecrosis
- Preferred treatment at some institutions for patella defects
- Large grafts may produce incongruent surface
  - Articular surface should be flush
  - Proud plug is subjected to increased shear forces

Osteochondral Autograft Transplantation

- Advantages
  - Graft availability
  - Absence of disease transmission compared to allograft
  - Less likely to evoke immune response
  - Single-stage operation
  - Overall success rate 80-90%, suitable for small or medium sized defects
- Disadvantages
  - Donor site morbidity
  - limited graft volume availability and age of cartilage
  - Difficulty recreating contour of articular surface

Mosaicplasty

- Several smaller osteochondral grafts are transferred to defect rather than single large graft
  - Diameter 2.7-15 mm
  - Depth 10-15 mm
- Well suited for smaller osteochondral defects 1-4 cm^2 in younger patients
- Donor site integrity is generally maintained



Chondral defect treated with osteochondral autograft transplantation in a 25-year-old man

Recht, M. P. et al. Radiographics 2002;22:765-774

Autografts

- MR assessment
  - Degree of defect filling by osteochondral plug
  - Morphologic characteristics of autologous bone
  - Cartilage surface contour
  - Peripheral integration of reparative cartilage and bone
  - Donor site assessment

2 years after surgery

Coronal intermediate-weighted fast SE image acquired 2 years after mosaicplasty in a 36-year-old woman shows **good integration** of osteochondral plugs into the medial femoral condyle, with **a slight prominence of cartilage over the most medial plug** (arrow)

Choi, Y. S. et al. Radiographics 2008;28:1043-1059

Autografts

- MR assessment
  - Peripheral integration of reparative cartilage and bone
  - Gaps between cartilage plug and native cartilage can be seen
- Fluid signal at interface between graft and native bone suggest incomplete incorporation and potential instability
- Restoration of normal curvature is important

Axial intermediate-weighted image after mosaicplasty in 17 year old boy. Subchondral plate is flush, **small fissure at medial margin** of articular surface. Plugs have incorporated.

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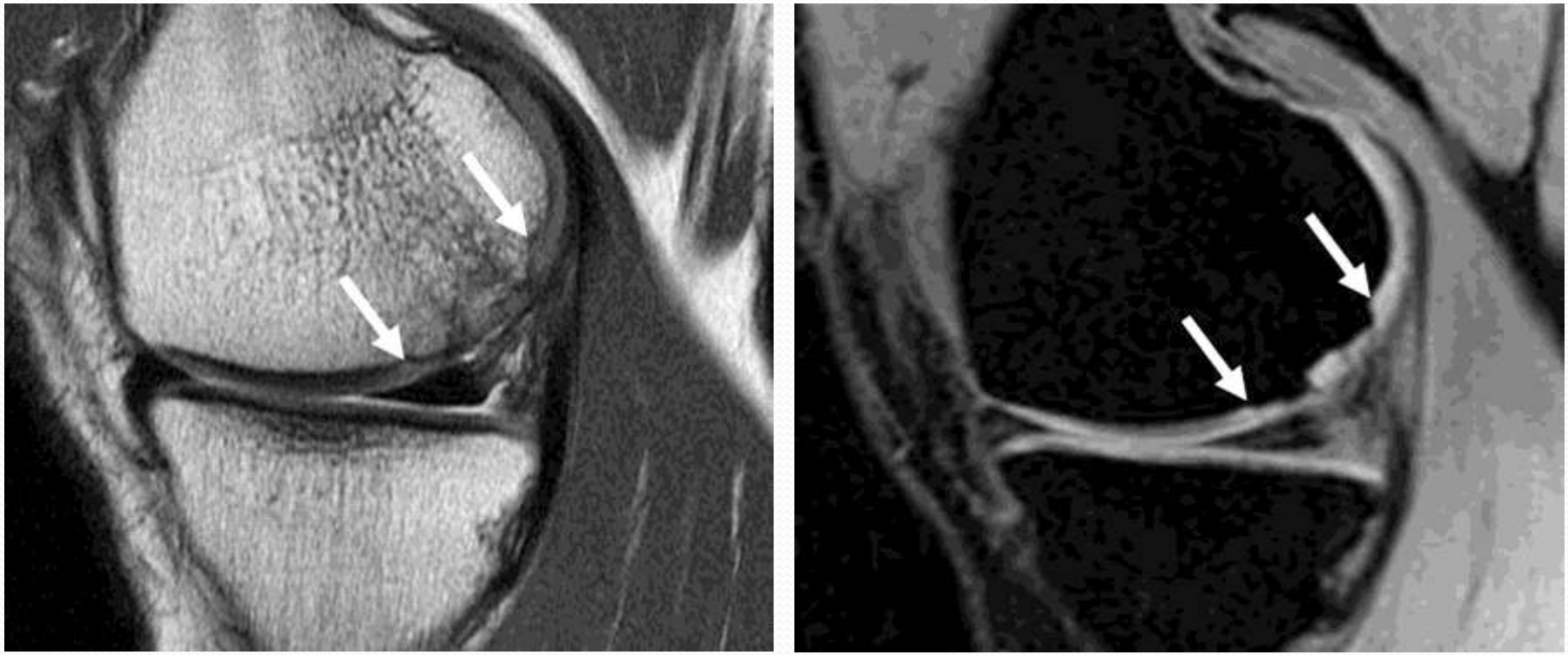
Autograft
Restoration of curvature

5 years after surgery



Sagittal intermediate-weighted fast SE and 3D fat-suppressed T1-weighted GRE) images acquired 5 years after autologous osteochondral transplantation in a 23-year-old man show that the **osseous portions of the plugs (arrows) are proud** relative to the subchondral bone (ie, extend into the repair tissue), whereas the reparative cartilage lies relatively flush with the native cartilage

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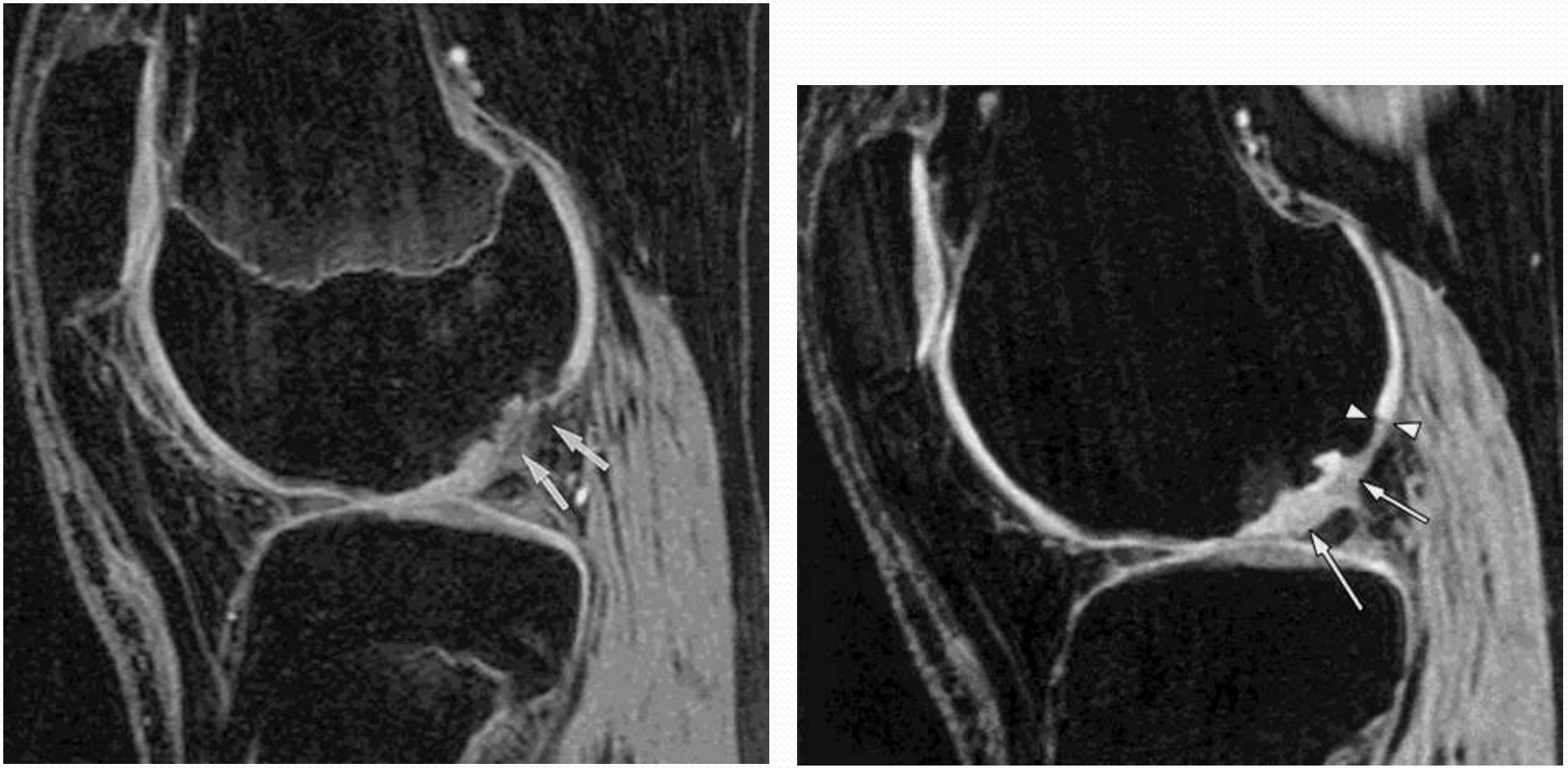
Incongruent Autograft



Graft incongruence in a 27-year-old man after osteochondral autograft transplantation

Recht, M. P. et al. Radiographics 2002;22:765-774

Autograft

0 months 4 months 16 months

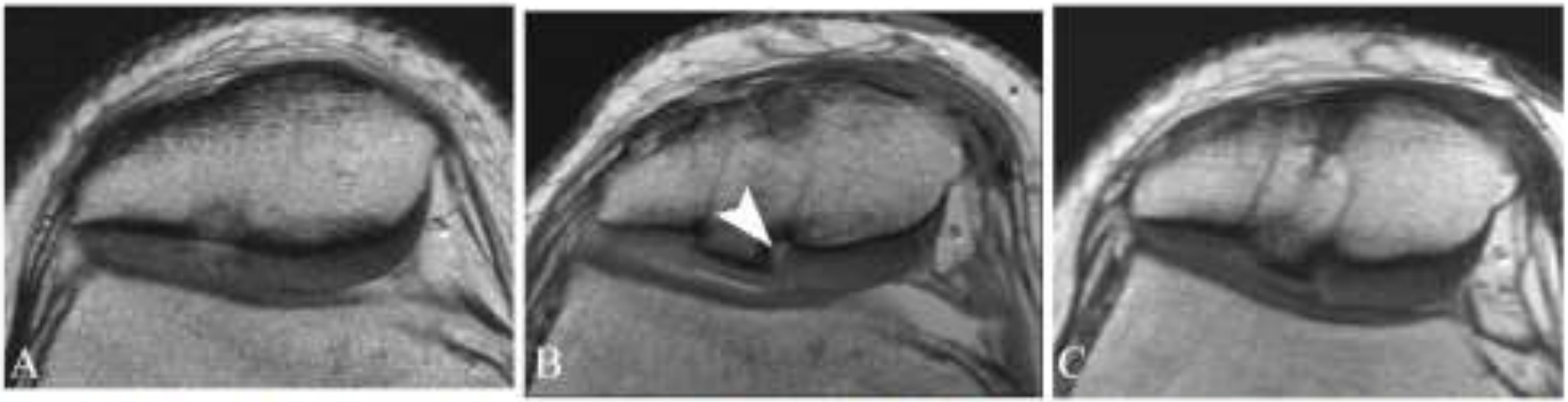


Figure 3. Axial cartilage sensitive fast spin-echo magnetic resonance images in an 18-year-old patient with a patellar autologous osteochondral plug. Before surgery (A), a focal full-thickness cartilage defect affecting the central lateral patellar facet was demonstrated. Four months after surgery (B), the repair cartilage was flush with adjacent native cartilage and isointense signal, despite the offset of the underlying subchondral plate and tidemark. A large fissure was noted at the medial interface (white arrowhead). Sixteen months after surgery (C), the repair cartilage remained isointense. The medial fissure had filled in with presumed reparative fibrocartilage.

Nho SJ, et al. Am J Sports Med 2008; 36: 1101-1109.

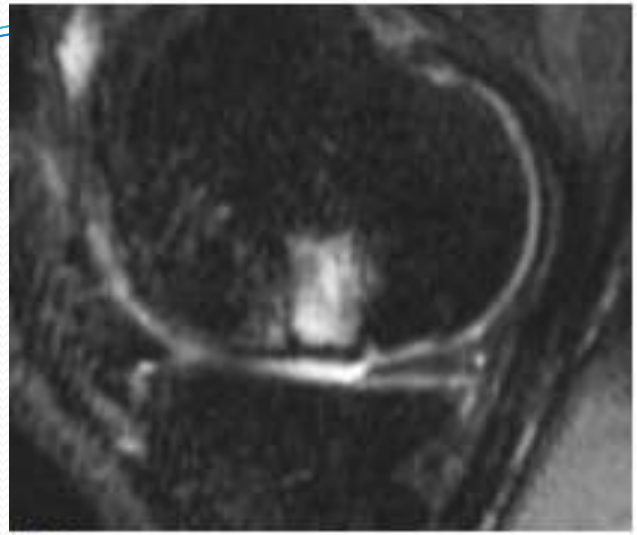


Fig. 28-A

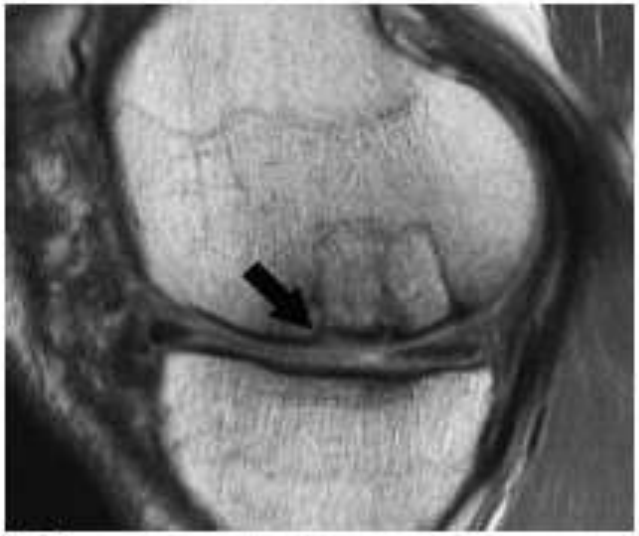


Fig. 28-B

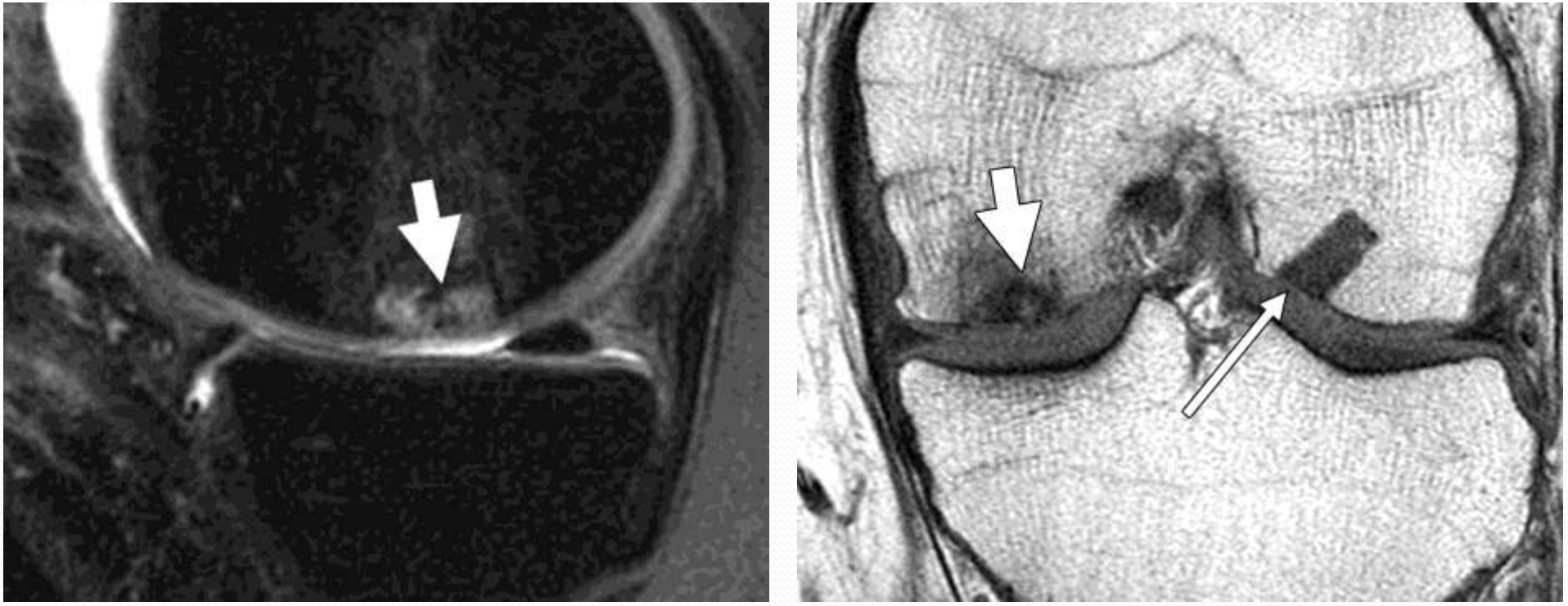
Fig. 28-C

Fig. 28-D

Figs. 28-A through 28-D Magnetic resonance images of the knee in a fifty-two-year-old patient, made after the transfer of two autologous osteochondral plugs. Sagittal fat-suppressed (Fig. 28-A) and non-fat-suppressed (Fig. 28-B) fast-spin-echo images demonstrate osseous incorporation of the plugs. Note the slight sclerosis in the side wall of the plugs in the axial plane (white arrowheads, Fig. 28-C), reflecting the "press-fit" technique. Although there is slight depression of the subchondral bone over the anterior plug (Fig. 28-B, black arrow), the cartilage surface remains flush. A fissure at the lateral interface with the native cartilage is seen on the coronal magnetic resonance image (Fig. 28-D, white arrow). There is a degenerative pattern of partial-thickness cartilage loss over the medial tibial plateau.

Autograft

3 month after surgery



Sagittal inversion-recovery fast SE and coronal intermediate-weighted fast SE images acquired 3 months after mosaicplasty in a 40-year-old man. Good incorporation of plugs, however there is focal collapse of subchondral bone, central cystic change, and subchondral depression. Donor site is filled with fibrocartilage.

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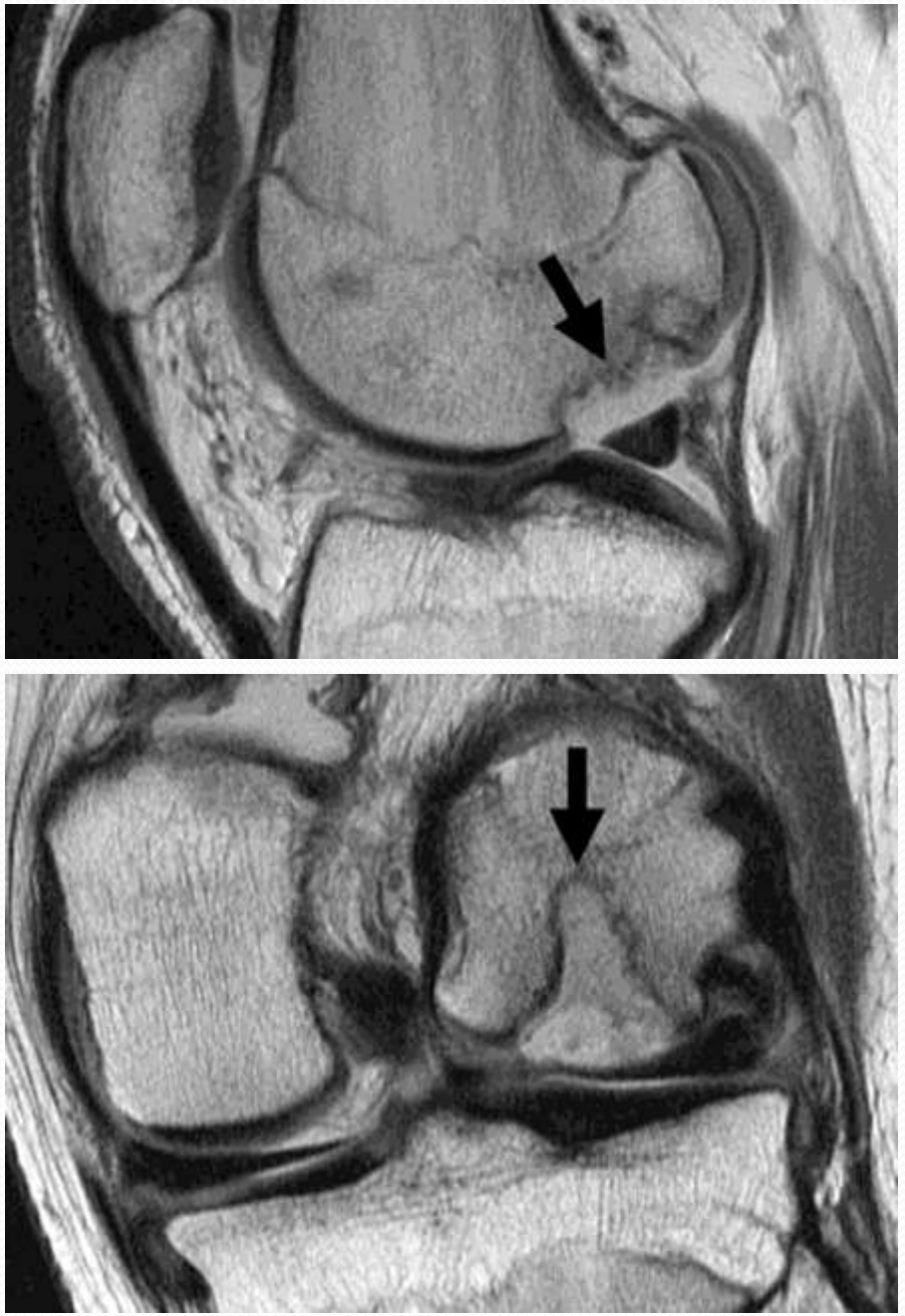
Autograft Failure

- Poor integration of graft with native bone
  - Subchondral cysts with fluid signal
  - Graft osteonecrosis
  - Depressed subchondral bone
- Severe fibrillation of adjacent cartilage
- Persistent synovitis
  - Normal effusion and synovitis may persist up to 2 years
- Persistent bone marrow edema in/around graft
  - Normal edema in 50% patients during first 12 months with gradual reduction afterwards

- 5 months after surgery



Sagittal and coronal intermediate-weighted fast SE images acquired 5 months after transplantation of an osteochondral autograft over the lateral femoral condyle in a 14-year-old boy show a failure of repair

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Osteochondral Allograft

- Cadaver harvest is transplanted
- Useful for large defects
- No donor-site morbidity
- Risks of immune rejection and disease transmission
- Cell Viability 10-30%

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Osteochondral Allograft

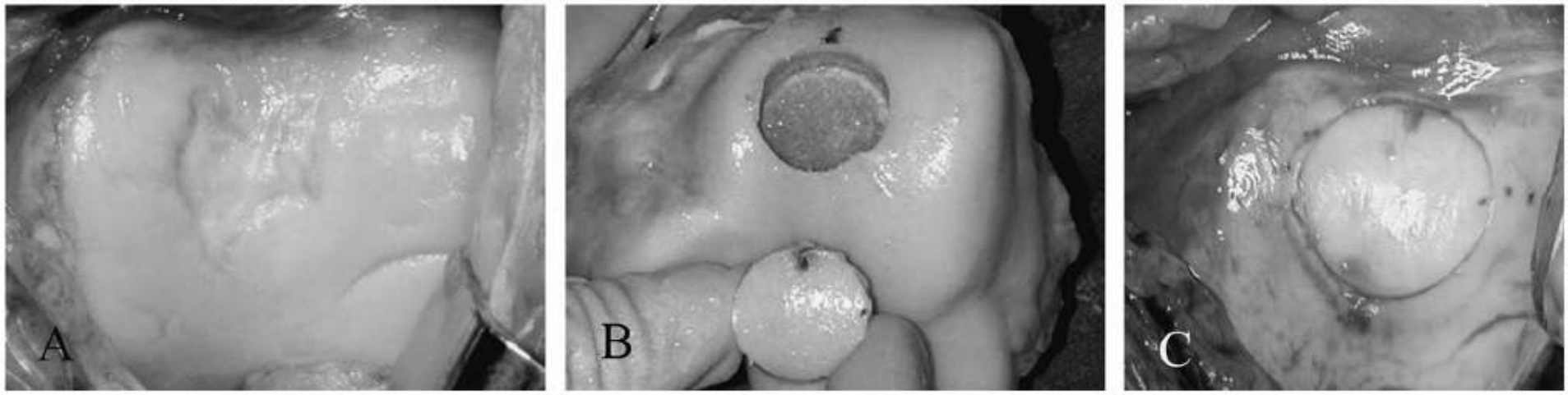

Fig 1A–C. (A) An intraoperative photograph shows a large full thickness articular cartilage defect of the trochlea. (B) An allograft plug is taken from a matching portion of the allograft trochlea. (C) The trochlear graft is placed into the recipient site with minimal step-off and smooth transitions to recipient articular surface.

Jamali AA, et al. Clin Ortho Rel Research, 2005; 437:176-185.

Osteochondral Allograft • 20 months

- Early postoperative period (0-3 months) has bone marrow edema
- Late postoperative period (3-6 months) decreased bone marrow edema
- Rejection or incomplete incorporation
  - Edema more than 12 months
  - Fluid signal at graft-host interface
  - Surface collapse
- Patient on right has intense edema and proud graft anteriorly indicating poor integration

Sagittal fast SE images acquired with and without fat suppression 20 months after a fresh osteochondral allograft in a 32-year-old woman show intense bone marrow edema in the graft

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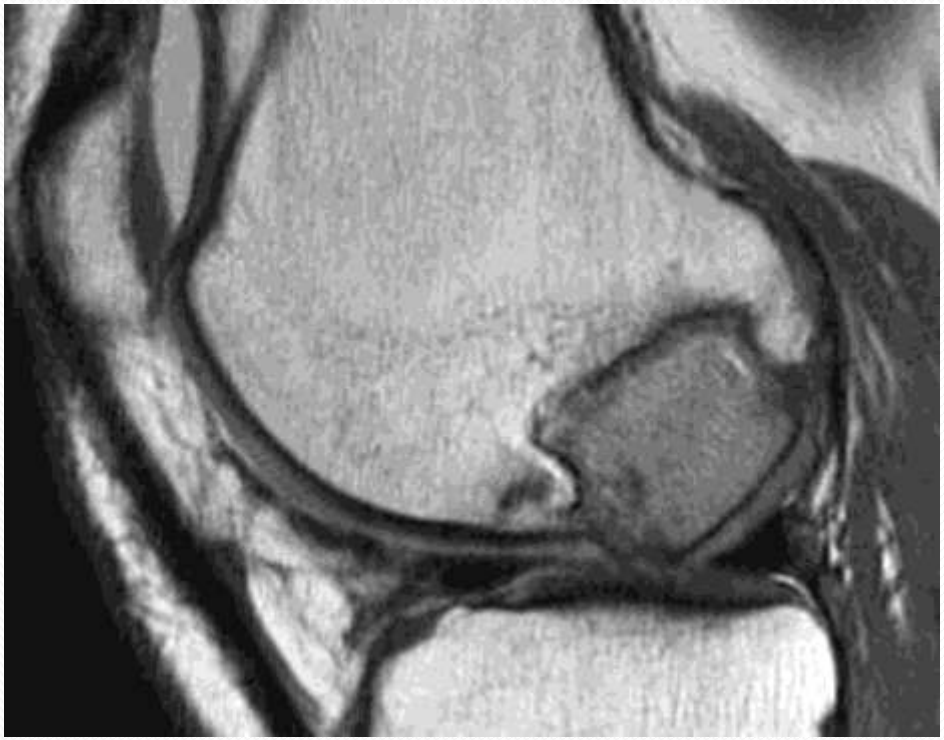
Allograft Revision with Autograft plug

20 months post initial surgery



18 months after second surgery

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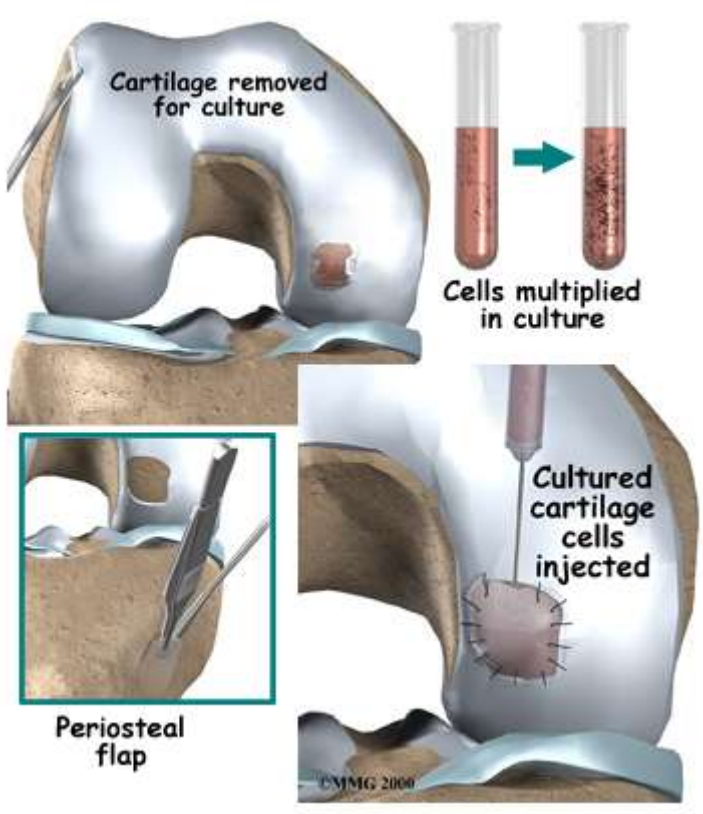
Autologous chondrocyte implantation

- Two-stage procedure introduced in 1994
  - First biopsy of normal hyaline cartilage
    - Typically trochlea or intercondylar notch
    - In vitro culture of chondrocytes for 6 wks
  - Second reimplant condrocytes into cartilage defect that is covered by watertight autologous periosteal flap or commercially available membrane
    - Periosteal flap harvested from proximal medial tibia
    - flap secured by fibrin glue or sutures



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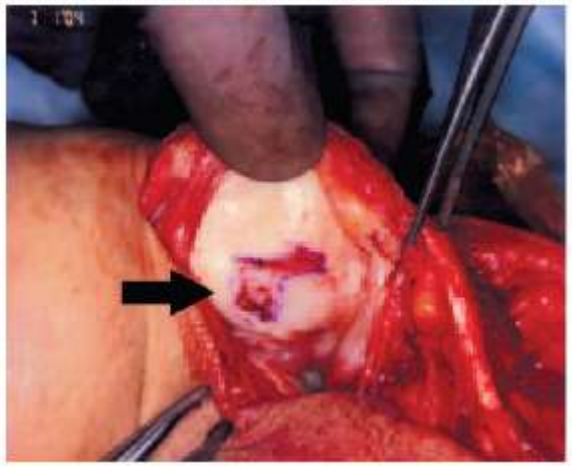

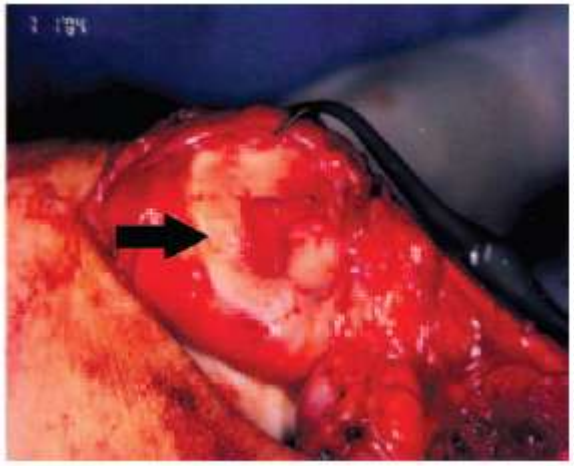

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Autologous Chondrocyte Implantation

- Three-Stage Healing Process
  - Stage I – proliferative stage 0-7 wk, soft jellylike tissue formed
  - Stage II – transition stage 7-12 wk, type II collagen framework and proteoglycans
  - Stage III – remodeling and maturation stage 13wk-3yrs, tissue similar to native hyaline cartilage forms
- Best suited for well contained or shallow defects **2-10 cm^2**
- Also used for hip, elbow, ankle and glenohumeral joint

MR Observations of Cartilage Repair Tissue (MOCART)

- May help compare different cartilage repair outcomes
- Good interobserver reproducibility for scoring

Table 3
MOCART Scoring System for Evaluation of Autologous Chondrocyte Implants

Scoring Category and Variable	MR Imaging Characteristic
Degree of defect repair and defect filling	
Complete	Hypertrophy of implant
Incomplete	Partial exposure of subchondral bone
Integration with border zone	
Complete	Absence of a fissure
Incomplete	Presence of a fissure
Quality of repair tissue surface	
Intact	Smoothness, regularity
Damaged	Fibrillation, irregularity
Structure of repair tissue	
Homogeneous	Absence of cleft
Inhomogeneous	Presence of cleft
Signal characteristics of repair tissue	
T2-weighted fast SE imaging with or without fat saturation	Hyperintensity or isointensity
Three-dimensional GRE imaging with fat suppression	Hyperintensity or hypointensity
Status of subchondral lamina	
Intact	Smooth low-signal-intensity line
Damaged	Interrupted low-signal-intensity line
Integrity of subchondral bone	
Intact	Absence of edema, granulation tissue, and cysts
Disrupted	Presence of edema, granulation tissue, or cysts
Presence of complications	Depiction of adhesions, joint effusion

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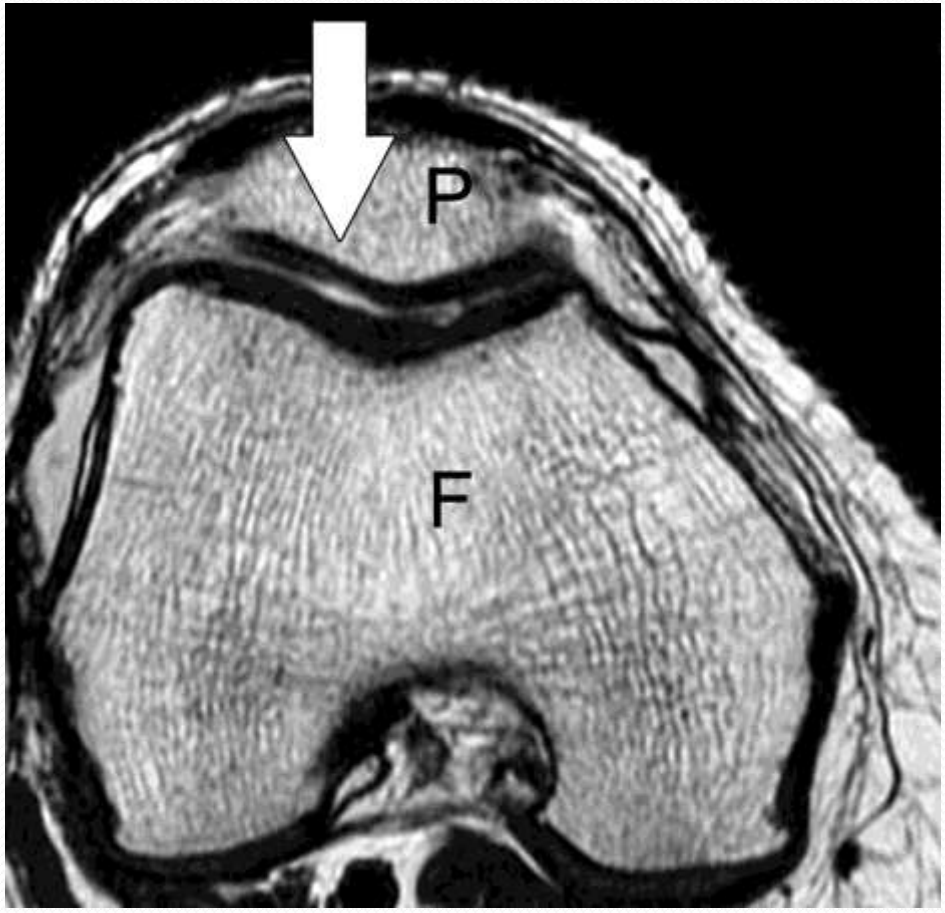
Autologous Chondrocyte Implantation

- MR imaging effective to evaluate underfilling
  - Fill less than 50% depth of adjacent native cartilage
- 2% of cases – underfilling severe enough to need further surgery
- Graft hypertrophy can occur 3-7 months after surgery in 10-63% patients

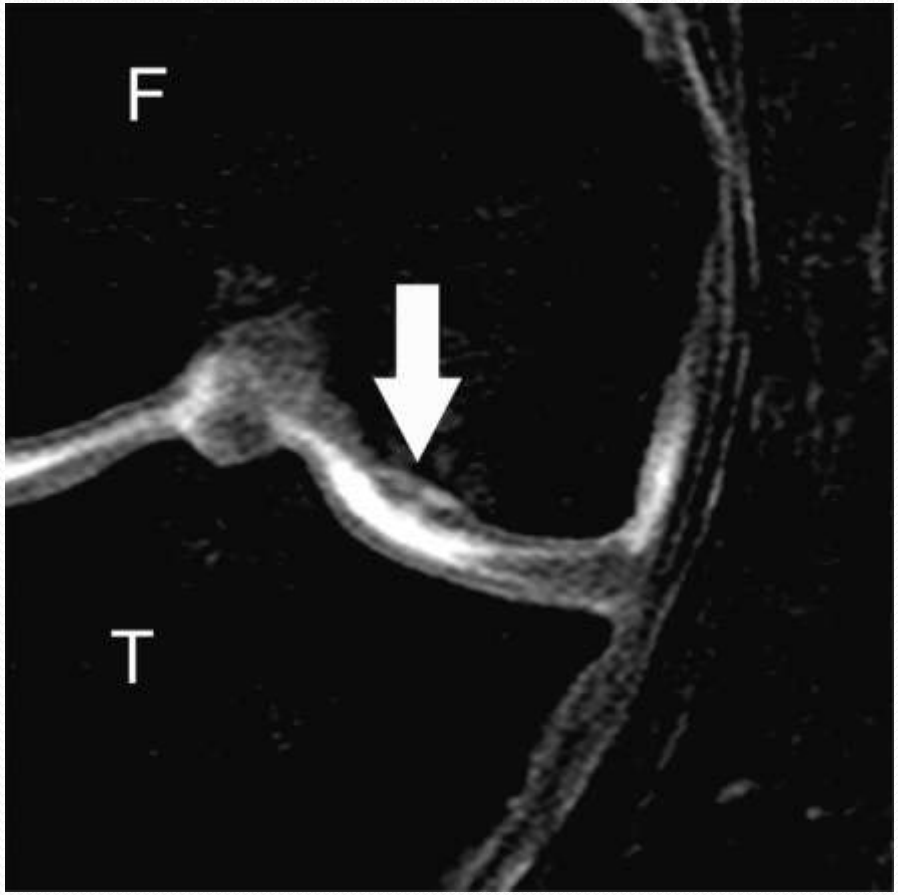


Axial MR image obtained in a 21-year-old man 17 months after autologous chondrocyte implantation shows near-perfect graft incorporation at the right patella (arrow)

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- MR imaging effective to evaluate underfilling
  - Fill less than 50% depth of adjacent native cartilage
- 2% of cases – underfilling severe enough to need further surgery
- **Graft hypertrophy can occur 3-7 months after surgery in 10-63% patients**
  - **May cause catching in 25%**



Coronal spoiled GRE MRA in 18 yr old 44 months after ACI shows heterogenous hypertrophic tissue repair (arrow)

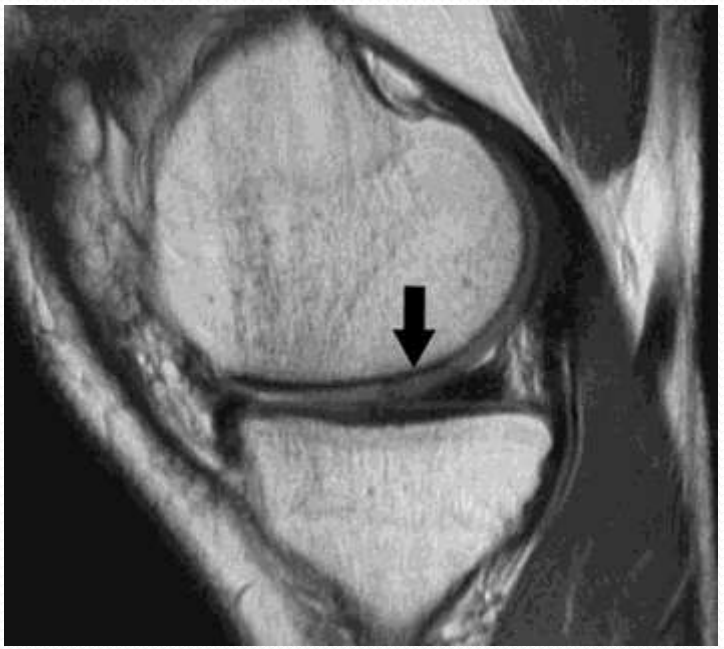
Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- Signal Intensity-PD
  - Initial hyperintense
  - Late postoperative period signal decreases steadily until approaching that of native cartilage

6 months

20 months

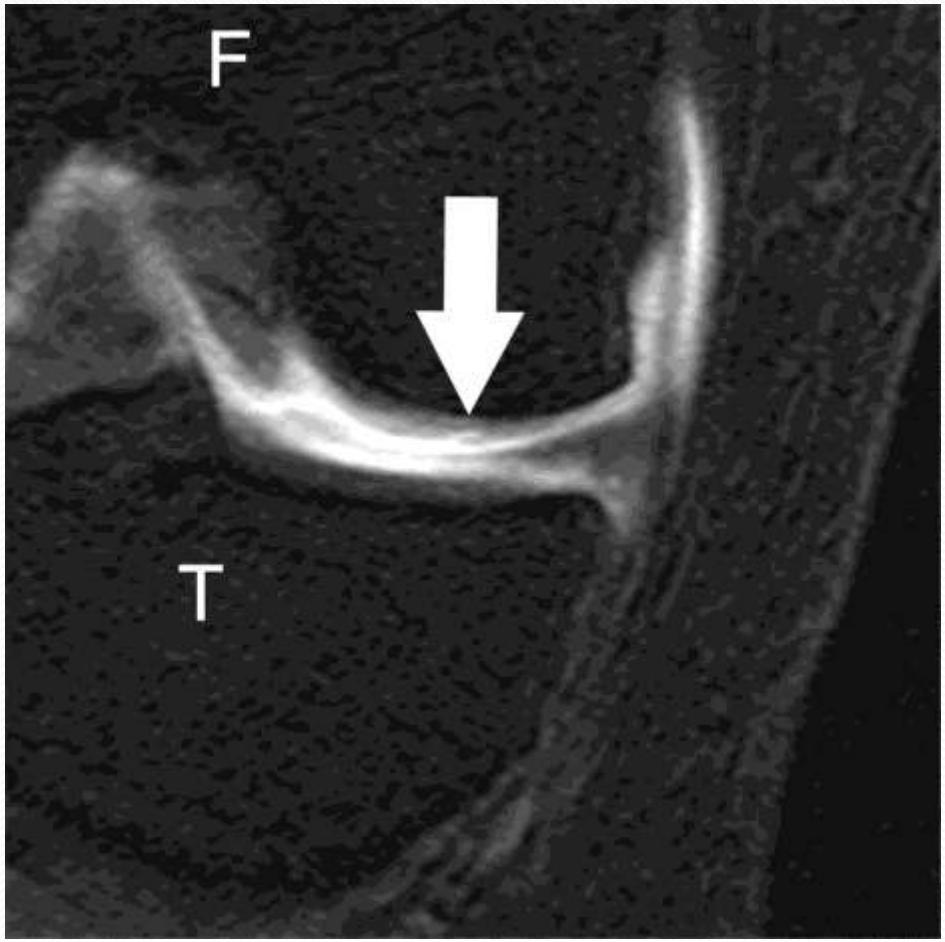


Sagittal intermediate-weighted fast SE images acquired after implantation of an autologous chondrocyte graft over the medial femoral condyle in a 31-year-old man show gradual maturation of the graft

Choi, Y. S. et al. Radiographics 2008;28:1043-1059

Autologous Chondrocyte Implantation

- Integration between repair tissue and native tissue is complete when no fissure is present between the two

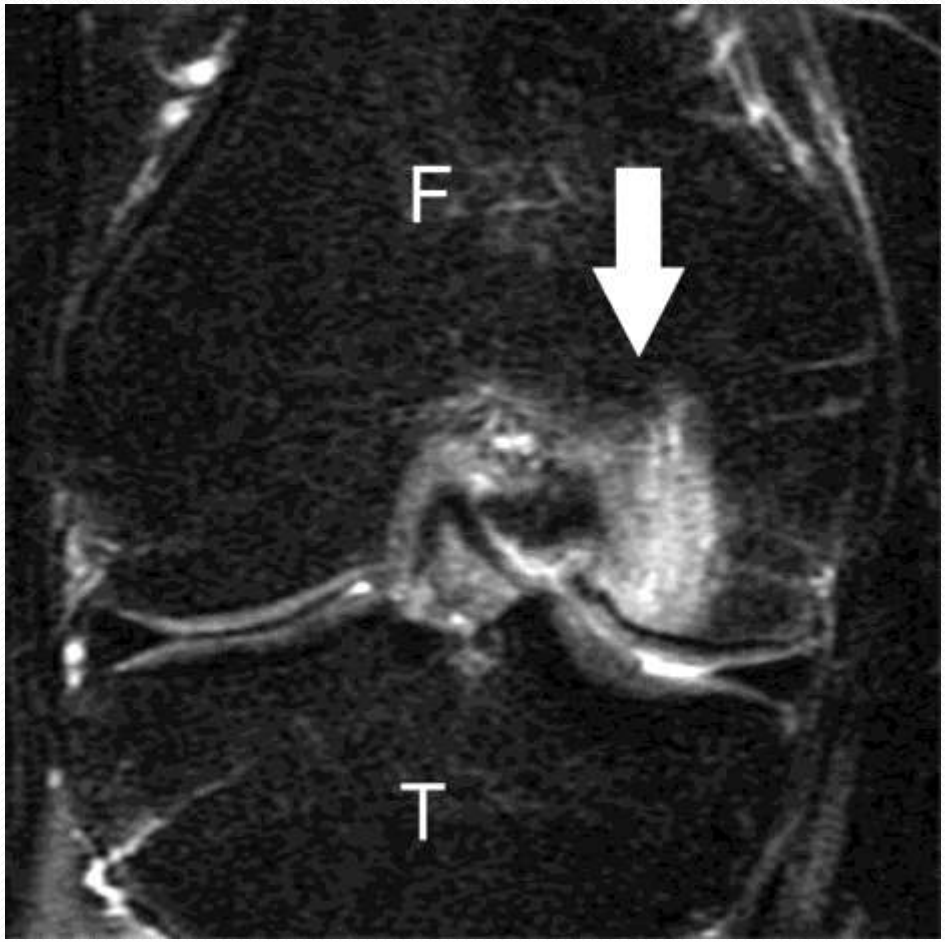


Coronal spoiled GRE MR arthrograms obtained in a 51-year-old man 8 months after autologous chondrocyte implantation show near-perfect incorporation of cartilage at the right medial femoral condyle, with only a tiny cartilage fissure (arrow)

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- **Edema in subchondral bone typically decreases with time**
  - **Persistence beyond 12 months requires close follow-up**
- Fluid signal between repair tissue and subchondral bone indicates delamination
  - Most common first 6 months
  - Subchondral cyst beneath interface also suggests failure of intergration
- Less common complications
  - Intraarticular adhesions
  - Hypertrophic synovitis

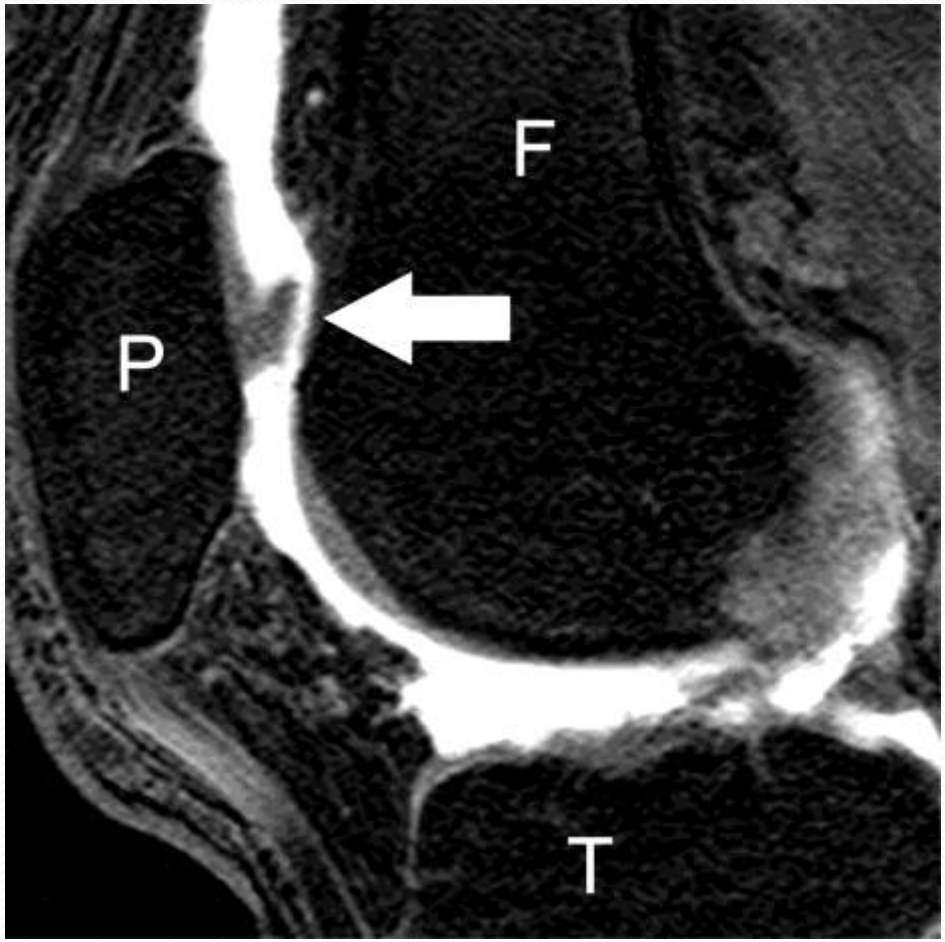


Coronal STIR image obtained after autologous chondrocyte implantation in a 39-year-old man shows signal intensity characteristic of edema in the marrow adjacent to the site of cartilage repair

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- Edema in subchondral bone typically decreases with time
  - Persistence beyond 12 months requires close follow-up
- **Fluid signal between repair tissue and subchondral bone indicates delamination**
  - **Most common first 6 months**
    - **Occurs in 5% patients**
    - **With/without displacement, loose body**
  - **Subchondral cyst beneath interface also suggests failure of intergration**
- Less common complications
  - Intraarticular adhesions
  - Hypertrophic synovitis

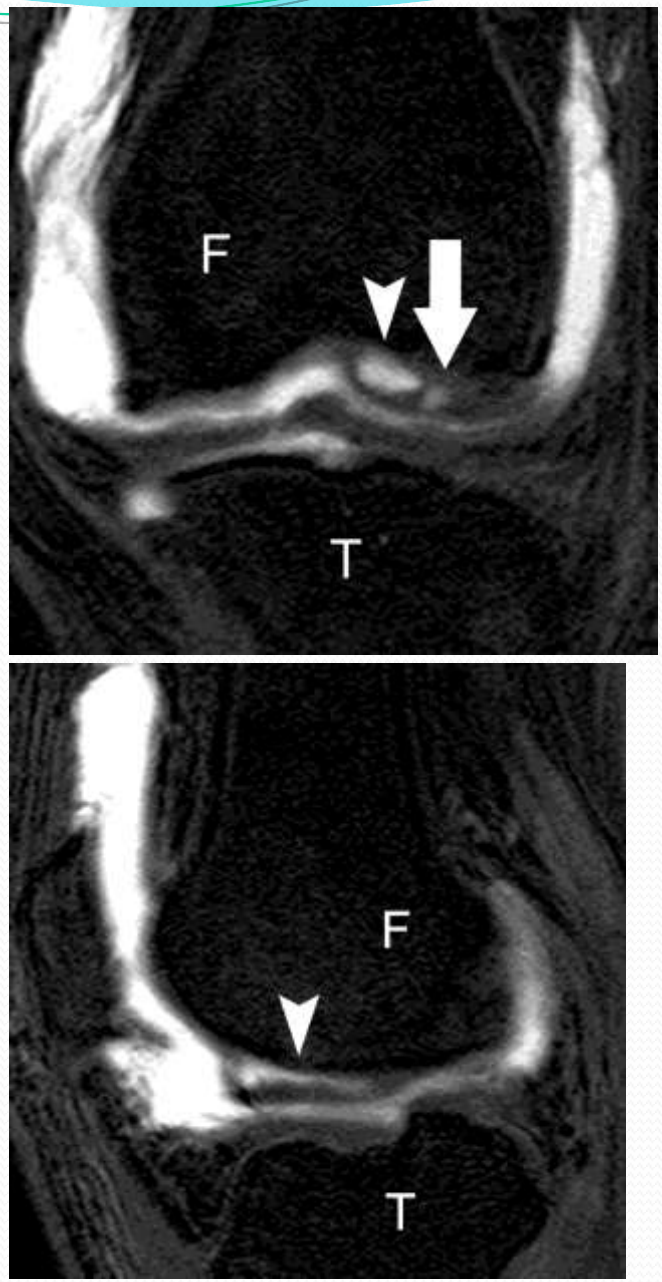


Sagittal spoiled GRE MR arthrogram, obtained in a 30-year-old man 10 months after a right patellar autologous chondrocyte implantation, shows displaced delamination with folding of a retropatellar cartilage flap (arrow)

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- Edema in subchondral bone typically decreases with time
  - Persistence beyond 12 months requires close follow-up
- **Fluid signal between repair tissue and subchondral bone indicates delamination**
  - **Most common first 6 months**
  - **Subchondral cyst beneath interface also suggests failure of intergration**
- Less common complications
  - Intraarticular adhesions
  - Hypertrophic synovitis

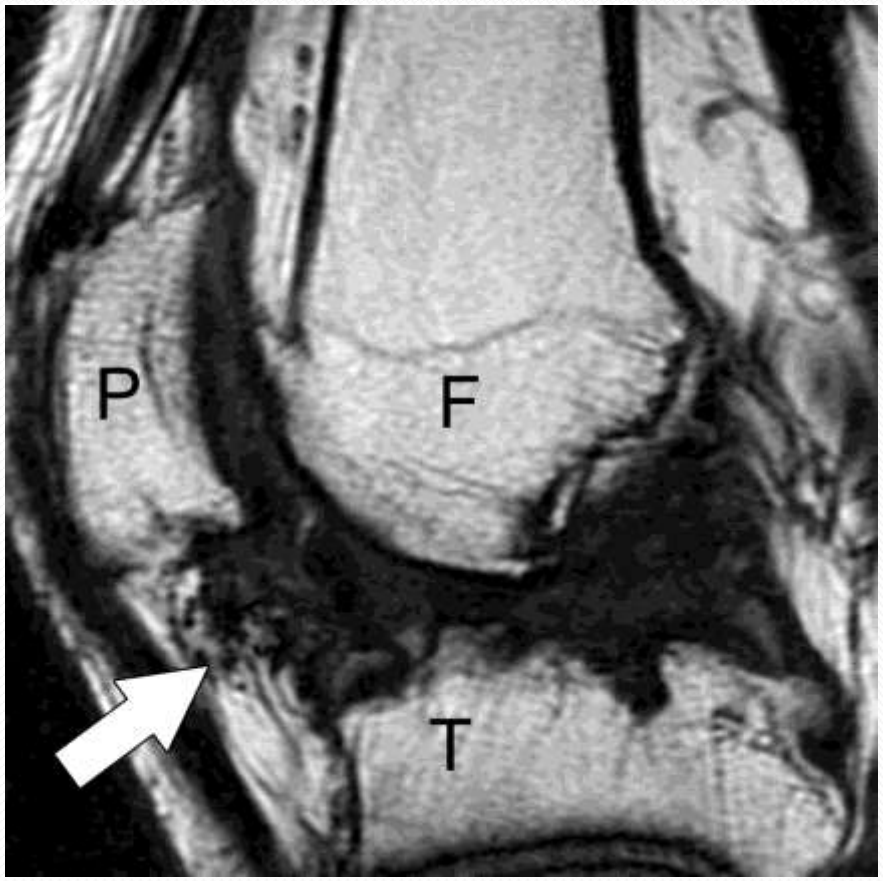


Coronal and sagittal spoiled GRE MR arthrograms obtained in a 59-year-old woman 1 month after autologous chondrocyte implantation show a small cyst (arrow) and adjacent partial delamination (arrowhead) in the interface between native and transplanted cartilage at the left lateral femoral condyle

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Autologous Chondrocyte Implantation

- Edema in subchondral bone typically decreases with time
  - Persistence beyond 12 months requires close follow-up
- Fluid signal between repair tissue and subchondral bone indicates delamination
  - Most common first 6 months
  - Subchondral cyst beneath interface also suggests failure of intergration
- Less common complications
  - **Intraarticular adhesions**
    - **5-10% patients**
  - Hypertrophic synovitis

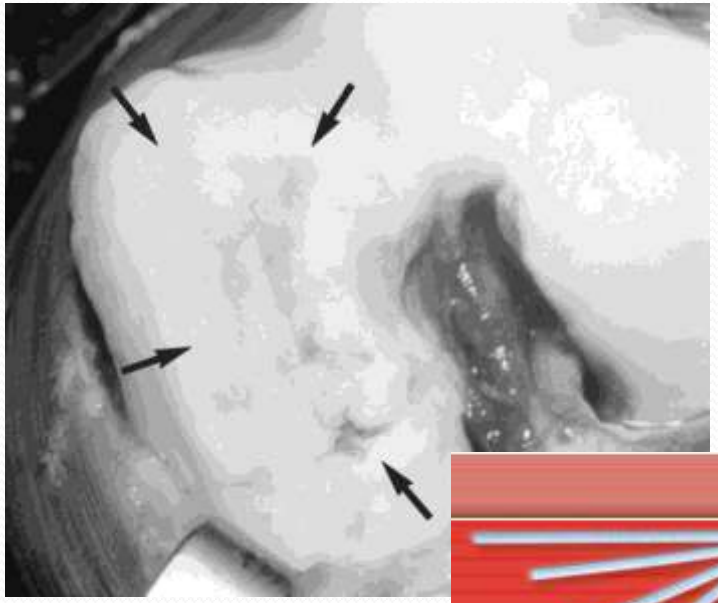


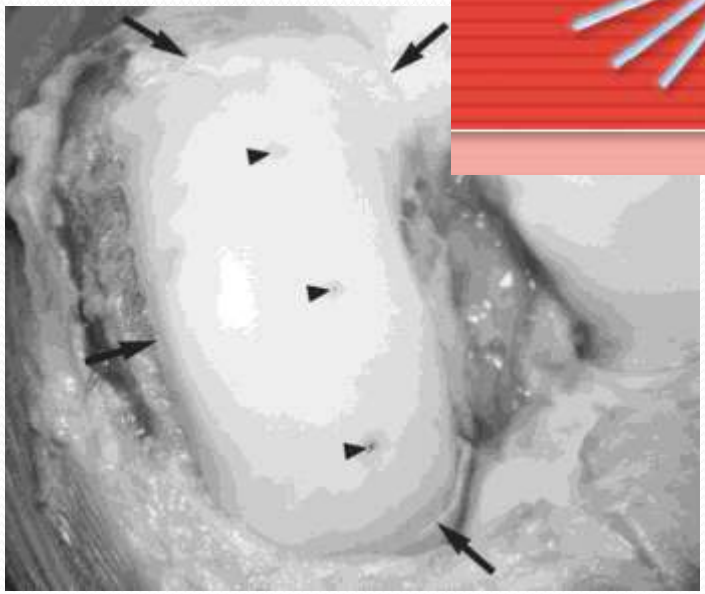
58-year-old man 18 months after autologous chondrocyte implantation and surgical elevation of the tibial tubercle, shows low-signal-intensity material (arrow) suggestive of intraarticular adhesions in the infrapatellar fat pad)

Ho, Y. Y. et al. Radiographics 2007;27:207-220

Fixation with Biodegradable Pins

- Biodegradable pins made of polydioxanone or other
  - Osteochondral fractures
  - Chondral flaps
  - Allografts
- Strength lost 18-36wks
- Generally resorb within 6-24 months
- Resultant synthetic debris cleared predominately by macrophages

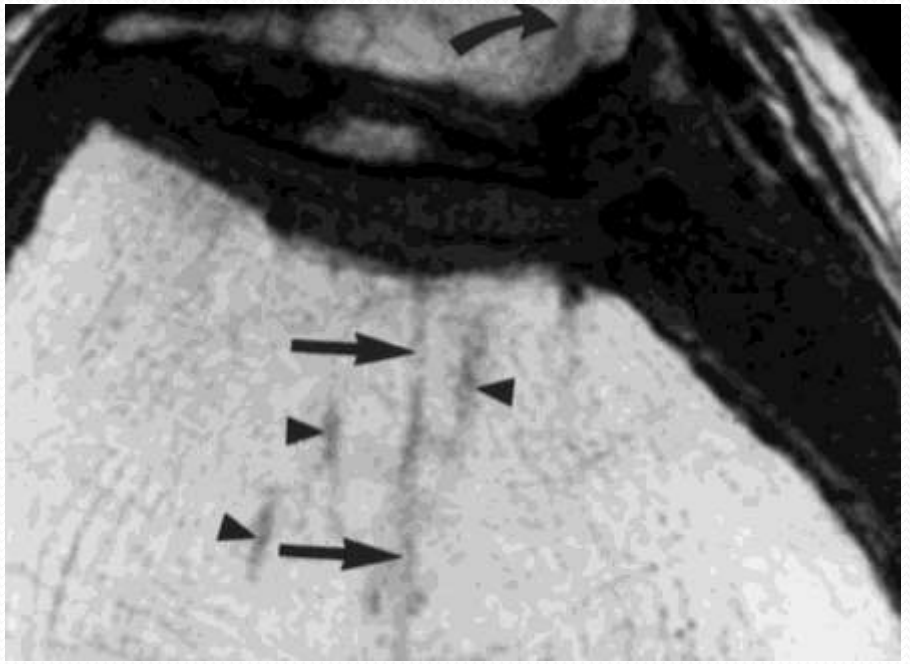




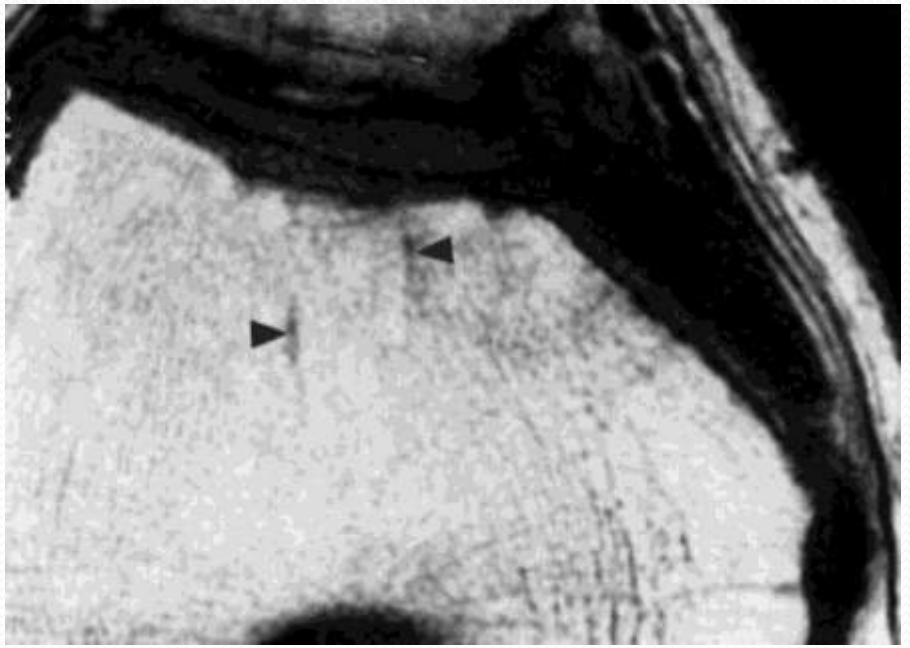
Sirlin, C. B. et al. Am. J. Roentgenol. 2001;176:83-90

Biodegradable Pins

- Biodegradable Pins
  - Linear low T1 signal intensity during first 6 months
  - By end of 1st year, pin sites have high linear T2 signal due to hydrolyzed debris or fluid
  - After 2 years, 80% pins are not visible at MR



6 mo

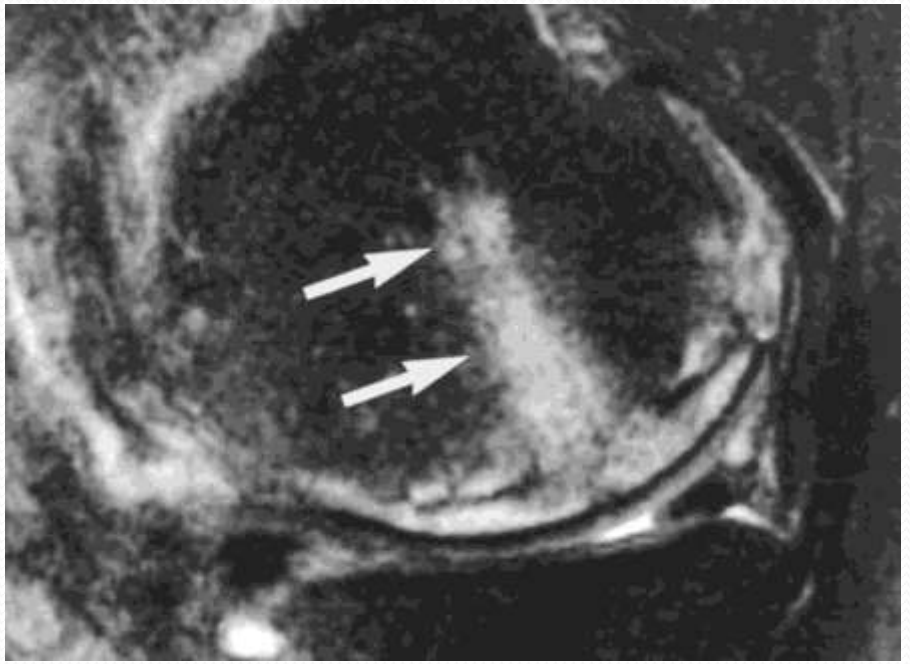


12 mo

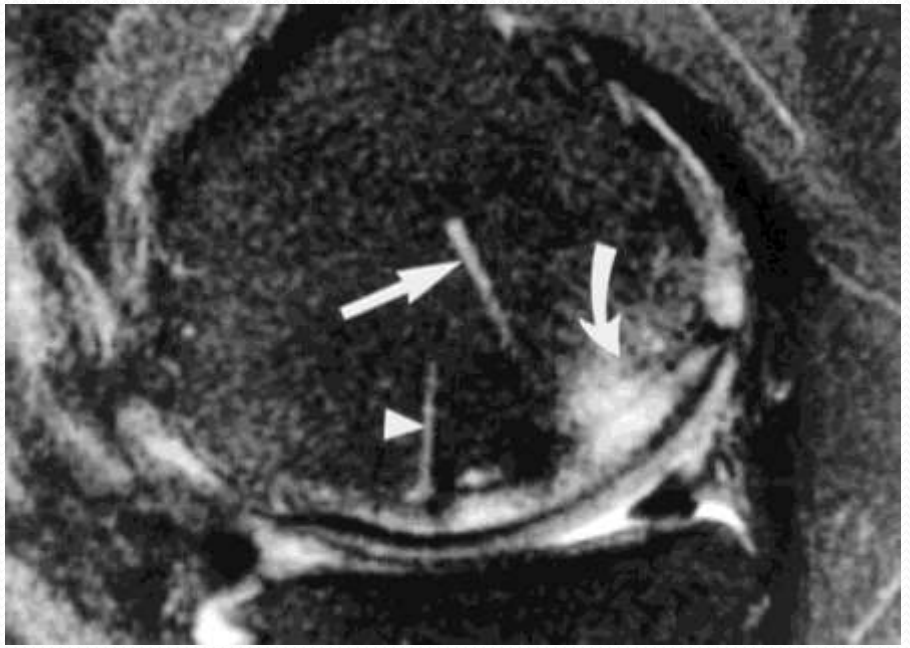
Sirlin, C. B. et al. Am. J. Roentgenol. 2001;176:83-90

Biodegradable Pins

- Biodegradable Pins
  - Linear low T1 signal intensity during first 6 months
  - By end of 1st year, pin sites have high linear T2 signal due to hydrolyzed debris or fluid
  - After 2 years, 80% pins are not visible at MR



3 mo



6 mo

Sirlin, C. B. et al. Am. J. Roentgenol. 2001;176:83-90

Biodegradable Pins
Unstable Osteochondritis Dissecans

Coronal and sagittal intermediate-weighted fast SE images acquired in a 16-year-old boy show features of unstable osteochondritis dissecans, with a focal fissure (arrow) that extends into the interface between the donor site and devitalized subchondral bone

Choi, Y. S. et al. Radiographics 2008;28:1043-1059

Osteochondritis Dissecans status post pinning

Coronal (a) and sagittal (b) intermediate-weighted fast SE images acquired in a 16-year-old boy show features of unstable osteochondritis dissecans status post pinning

Choi, Y. S. et al. Radiographics 2008;28:1043-1059

Conclusion

Chondral Surgery

- Microfracture
- Autograft
- Allograft
- Autologous Condrocyte Implantation
- Biodegradable Pins

MR Follow-up evaluation

- 3-6 months, 1 yr images
- Extent of defect filling
- Degree of peripheral tissue integration
- Signal and structure of repair tissue
- Native bone/cartilage integrity

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