Subchondroplasty: What the Radiologist Needs to Know

Christoph A. Agten[1,2,3]
Daniel J. Kaplan[3,4]
Laith M. Jazrawi[3,4]
Christopher J. Burke[2,3]

OBJECTIVE. Subchondroplasty is a novel minimally invasive procedure that is used to treat painful bone marrow lesions in patients with knee osteoarthritis or insufficiency fractures. The objective of this article is to describe the surgical technique and the pre- and postoperative imaging findings of a small case series acquired at a single center.

CONCLUSION. The radiologist should be familiar with the anticipated postoperative imaging appearances after subchondroplasty and the potential complications.

Keywords: bone marrow edema, bone marrow lesion, calcium phosphate, knee, MRI, postoperative imaging, subchondroplasty

DOI:10.2214/AJR.16.16521

Received March 26, 2016; accepted after revision June 17, 2016.

This work was supported by a grant from the Swiss National Science Foundation and a grant to C. A. Agten from the Swiss Society of Radiology.

[1]Center for Musculoskeletal Care, NYU Langone Medical Center, New York, NY. Address correspondence to C. A. Agten (christoph.agten@gmail.com)

[2]Department of Radiology, Hospital for Joint Diseases, New York, NY.

[3]Department of Radiology, NYU Langone Medical Center, New York, NY.

[4]Department of Orthopedic Surgery, Hospital for Joint Diseases, New York, NY.

AJR 2016; 207:1–6

0361–803X/16/2076–1

Subchondral bone marrow edema—often more accurately referred to as bone marrow lesions due to the histopathologic lack of edema—is a frequent finding on MRI of the knee [1]. In the setting of knee osteoarthritis, patients with subchondral bone marrow edema often undergo faster joint degeneration [2, 3] and experience more pain [4, 5] than those without bone marrow edema.

Subchondroplasty is a new procedure performed by orthopedic surgeons to treat painful bone marrow edema in the knee [6]. The two main indications are painful osteoarthritis-associated bone marrow edema and bone marrow edema in the setting of increased bone stress or early insufficiency fractures [7]. The procedure is usually performed in conjunction with arthroscopy, and the decision to perform the procedure is made before surgery. During subchondroplasty, the surgeon injects synthetic calcium phosphate into the region of bone marrow edema to fill the intertrabecular space, thereby providing local mechanical support to the bone at that site. This injection preserves preexisting trabeculae and, in theory, induces improved bone remodeling [8].

There are several studies about subchondroplasty in the orthopedics literature, but they focus principally on the surgical technique and outcomes [9–12]. No large series or controlled studies to date have shown subchondroplasty to be superior over established conservative approaches. There is a lack of data with regard to the indications for subchondroplasty and the long-term outcomes of the procedure. The criteria for selecting patients who might or might not benefit from subchondroplasty in the long term are unclear, and currently treatment with subchondroplasty is regarded as experimental.

To date, there are no studies in the literature that describe the imaging aspects of the procedure, which may be confusing, and imaging findings may possibly be misinterpreted if the radiologist is not familiar with the expected postprocedure appearances. The aim of this article is to describe the subchondroplasty technique, show the normal postoperative imaging findings and abnormal imaging findings suggestive of potential complications, and discuss our experiences with cases performed at our institution.

Patients

The patients discussed in this article are a subset of patients whose outcomes after subchondroplasty have been reported [10]; however, the pre- and postoperative imaging findings of the patients were not specifically addressed in that study [10]. Only nine of this cohort of 22 patients underwent preoperative MRI at our institution, and five of the nine patients had postoperative imaging studies (radiography, CT, or MRI) available for review. We present the imaging findings of these nine patients (four women and five men; mean age, 56.1 ± 9.5 [SD] years; age range, 38–70 years).

The time interval between the procedure and the first postoperative radiographic study was 3 months for all nine patients. One patient underwent CT 2.5 years after the procedure

as part of the preoperative planning for unicompartmental arthroplasty (MAKOplasty, MAKO Surgical), and another patient underwent MRI 6 months after the procedure because of persistent knee pain. Nevertheless, this series represents the largest one to date.

Preoperative Imaging

Bone marrow edema is well depicted on fluid-sensitive MRI, such as STIR, fat-saturated intermediate-weighted, and fat-saturated T2-weighted sequences [13]. Lesions appear as hyperintense regions within the trabecular subchondral bone often at the site of increased mechanical stress [14, 15] (Fig. 1). The presence of an associated horizontal hypointense linear focus suggests an associated insufficiency fracture (Figs. 2 and 3).

In patients with knee osteoarthritis, subchondroplasty is most frequently performed to treat bone marrow edema in the medial compartment (i.e., medial tibia plateau, medial femoral condyle, or both for "kissing" contrecoup lesions) [7]. Other possible target sites for subchondroplasty include the lateral compartment, patella, and trochlea [7].

In our cohort of nine patients, preoperative MRI showed bone marrow edema in the medial tibia plateau ($n = 5$), medial femoral condyle ($n = 3$), and lateral femoral condyle ($n = 1$). The cause of bone marrow edema was related to high-grade chondral loss ($n = 5$) or insufficiency fractures ($n = 4$).

The surgeons at our institution use a standardized volume of 5 mL of calcium phosphate as instructed by the manufacturer; however, some operators prefer to modify the volume of injected calcium phosphate according to the extent of bone marrow edema shown on preoperative MRI [7, 9, 10]. The average cross-sectional area of bone marrow edema in our series of nine patients was 4.6 ± 3.6 cm in the transverse plane, 4.2 ± 3.6 cm in the coronal plane, and 4.1 ± 2.9 cm in the sagittal plane. Regions of bone marrow edema associated with an insufficiency fracture were statistically significantly larger in all three planes (Mann-Whitney *U* test) than those associated with osteoarthritis: transverse plane, 2.3 versus 7.3 cm, respectively ($p = 0.032$); coronal plane, 1.9 versus 7.1 cm ($p = 0.016$); and sagittal plane, 2.0 versus 6.6 cm ($p = 0.016$).

Subchondroplasty Surgical Technique

The procedure is performed with the patient under general, regional, or spinal anesthesia [16]. Diagnostic arthroscopy is performed before the injection to assess the intraarticular space, particularly the structures overlying the bone marrow edema. The cartilage, both menisci, and cruciate ligaments are assessed for stability and tears. Any concomitant abnormalities should be treated (e.g., débridement chondroplasty for loose chondral flaps, meniscal repairs or meniscectomies for meniscal tears, and anterior cruciate ligament [ACL] reconstructions for ACL tears) [7].

Subsequently, the operative knee is positioned for anteroposterior (AP) and lateral fluoroscopic imaging, which is cross-referenced with the preoperative MRI study and used to triangulate the exact placement of a guide pin directly into the bone marrow edema. Pin placement is continuously checked with fluoroscopy (Figs. 2 and 3). Alternatively, a tibial navigation guide is available. The guide is placed circumferentially around the knee using anatomic landmarks. The pinpoint of entry in the guide is determined using preoperative MRI. A fenestrated cannula is then inserted over the guide pin, and the guide pin is removed. A calcium phosphate–filled syringe is inserted through the cannula. Steady digital pressure is applied to the plunger to inject synthetic bone substitute into the area of the bone marrow edema until a darkened blush corresponding to the region of the bone marrow edema pattern on MRI is visible on fluoroscopy [7, 17].

After the injection, the trocar is reinserted to push the remaining calcium phosphate out of the cannula and is kept in place for 5 minutes to allow the material to set. A final arthroscopic look is performed to confirm lack of intraarticular leakage. Because calcium phosphate is hydrophilic, any intraarticular material can be flushed out of the joint with the arthroscope and shaver [16]. Final fluoroscopic AP and lateral views are obtained to ensure there is no extravasation of material into the surrounding soft tissues, which can be a source of postoperative pain. If extravasation occurs, the symptoms are treated conservatively. Adverse reactions to calcium phosphate have not been reported to date [7].

Postoperative Imaging

Postoperative radiographs should be compared with preoperative radiographs to identify deposits of the injected calcium phosphate. As one would expect, conventional radiographs show increased density in the bone at the location of the injected calcium phosphate (Fig. 1). The area of the injected calcium phosphate on radiography should match the area of bone marrow edema on preoperative MRI. There may be leakage of calcium phosphate into the soft tissues along the needle track for the injection (Figs. 2–4), similar to that occasionally seen in vertebral augmentation procedures [18]. This extravasation should not be mistaken for trauma-related heterotopic ossification. Soft-tissue deposits of leaked calcium phosphate may resolve over time [19] (Fig. 4). Postoperative intraarticular leakage is another potential complication and may need to be addressed arthroscopically [7].

On MRI, the injected calcium phosphate appears as a focal hypointense area or region of low signal intensity at the previous site of bone marrow edema (Fig. 5). During the first 6 months after subchondroplasty, the injected calcium phosphate may show a surrounding fine rim of high signal intensity on fluid-sensitive images (Fig. 5). If calcium phosphate leaks into the soft tissue, hypointense deposits can be seen on imaging (Fig. 5).

On CT, the drill hole can be seen (Fig. 6) and is typically surrounded by hyperdense material corresponding to the injected calcium phosphate. If present, soft-tissue contamination can be easily seen on CT.

In our cohort, the injected calcium phosphate was well depicted on postoperative radiographs of all patients. The site of the injected calcium phosphate on postoperative radiographs matched the site of bone marrow edema on the preoperative MR images in four of the five patients. In the remaining patient, postoperative radiography showed the injected calcium phosphate only partially filled the bone marrow lesion. Soft-tissue contamination was depicted in three of the five patients.

There are several significant limitations to our study. The small size of this case series and the fact that we did not have complete sets of pre- and postoperative imaging examinations preclude definitive conclusions regarding the optimal indications for the procedure and the postinterventional imaging findings. Furthermore, the technique is experimental, and there is a paucity of long-term follow-up data to support its superiority over established conservative approaches.

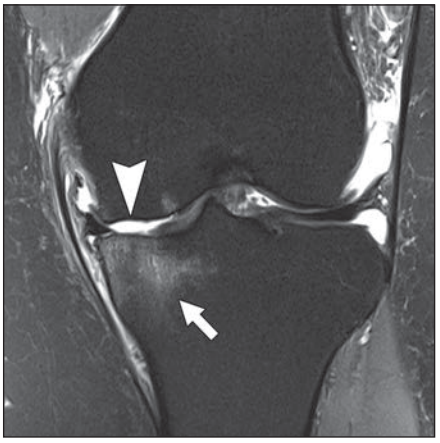
Conclusion

Subchondroplasty is a new minimally invasive procedure with reported efficacy in the treatment of painful bone marrow edema that is usually performed in combina-

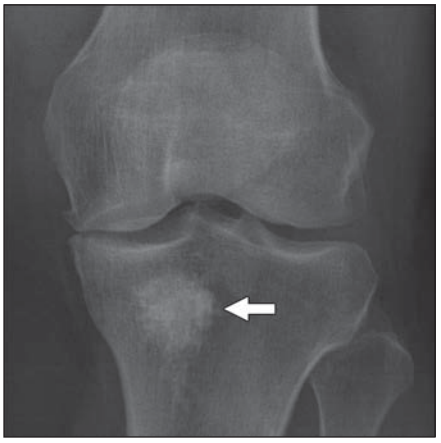
tion with arthroscopic débridement. Postprocedural findings such as leakage of injected calcium phosphate into the soft tissues may be misinterpreted and may lead to recommendations for unnecessary follow-up or additional imaging. Radiologists should be familiar with this technique and its indications, and anticipated postoperative appearances.

References

1. Xu L, Hayashi D, Roemer FW, Felson DT, Guermazi A. Magnetic resonance imaging of subchondral bone marrow lesions in association with osteoarthritis. *Semin Arthritis Rheum* 2012; 42:105–118
2. Scher C, Craig J, Nelson F. Bone marrow edema in the knee in osteoarthrosis and association with total knee arthroplasty within a three-year follow-up. *Skeletal Radiol* 2008; 37:609–617
3. Roemer FW, Guermazi A, Javaid MK, et al.; MOST Study Investigators. Change in MRI-detected subchondral bone marrow lesions is associated with cartilage loss: the MOST Study—a longitudinal multicentre study of knee osteoarthritis. *Ann Rheum Dis* 2009; 68:1461–1465
4. Felson DT, Niu J, Guermazi A, et al. Correlation of the development of knee pain with enlarging bone marrow lesions on magnetic resonance imaging. *Arthritis Rheum* 2007; 56:2986–2992
5. Felson DT, Chaisson CE, Hill CL, et al. The association of bone marrow lesions with pain in knee osteoarthritis. *Ann Intern Med* 2001; 134:541–549
6. Sharkey PF, Cohen SB, Leinberry CF, Parvizi J. Subchondral bone marrow lesions associated with knee osteoarthritis. *Am J Orthop* 2012; 41:413–417
7. Farr J, Cohen SB. Expanding applications of the subchondroplasty procedure for the treatment of bone marrow lesions observed on magnetic resonance imaging. *Oper Tech Sports Med* 2013; 21:138–143
8. Welch RD, Zhang H, Bronson DG. Experimental tibial plateau fractures augmented with calcium phosphate cement or autologous bone graft. *J Bone Joint Surg Am* 2003; 85:222–231
9. Cohen SB, Sharkey PF. Subchondroplasty for treating bone marrow lesions. *J Knee Surg* 2015 Dec 7 [Epub ahead of print]
10. Chatterjee D, McGee A, Strauss E, Youm T, Jazrawi L. Subchondral calcium phosphate is ineffective for bone marrow edema lesions in adults with advanced osteoarthritis. *Clin Orthop Relat Res* 2015; 473:2334–2342
11. Collins J, Beutel B, Bosco J, Strauss E, Youm T, Jazrawi L. Bone marrow edema: chronic bone marrow lesions of the knee and the association with osteoarthritis. *Bull Hosp Jt Dis (2013)* 2016; 74:24–36
12. Abrams GD, Alentorn-Geli E, Harris JD, Cole BJ. Treatment of a lateral tibial plateau osteochondritis dissecans lesion with subchondral injection of calcium phosphate. *Arthrosc Tech* 2013; 2:e271–e274
13. Roemer FW, Frobell R, Hunter DJ, et al. MRI-detected subchondral bone marrow signal alterations of the knee joint: terminology, imaging appearance, relevance and radiological differential diagnosis. *Osteoarthritis Cartilage* 2009; 17:1115–1131
14. Segal NA, Kern AM, Anderson DD, et al. Elevated tibiofemoral articular contact stress predicts risk for bone marrow lesions and cartilage damage at 30 months. *Osteoarthritis Cartilage* 2012; 20:1120–1126
15. Brem MH, Schlechtweg PM, Bhagwat J, et al. Longitudinal evaluation of the occurrence of MRI-detectable bone marrow edema in osteoarthritis of the knee. *Acta Radiol* 2008; 49:1031–1037
16. Cohen SB, Sharkey PF. Surgical treatment of osteoarthritis pain related to subchondral bone defects or bone marrow lesions: subchondroplasty. *Tech Knee Surg* 2012; 11:170–175
17. Colon DA, Yoon BJ, Russell TA, Cammisa FP, Abjornson C. Assessment of the injection behavior of commercially available bone BSMs for Subchondroplasty® procedures. *Knee* 2015; 22:597–603
18. Zhu SY, Zhong ZM, Wu Q, Chen JT. Risk factors for bone cement leakage in percutaneous vertebroplasty: a retrospective study of four hundred and eighty five patients. *Int Orthop* 2016; 40:1205–1210
19. von Rechenberg B, Génot OR, Nuss K, et al. Evaluation of four biodegradable, injectable bone cements in an experimental drill hole model in sheep. *Eur J Pharm Biopharm* 2013; 85:130–138



A



B

Fig. 1—38-year-old woman with left-sided medial knee pain and swelling.
A, Preoperative coronal intermediate-weighted fat-saturated MR image (TR/TE, 4100/48) shows focal bone marrow edema in medial tibia plateau (*arrow*) and extensive cartilage loss in medial compartment (*arrowhead*).
B, Postoperative radiograph obtained after subchondroplasty shows focal opacification (*arrow*) in medial aspect of tibial metaphysis that corresponds to injected calcium phosphate during subchondroplasty. Note that location of injected calcium phosphate in **B** only partially matches location of bone marrow edema in **A**.

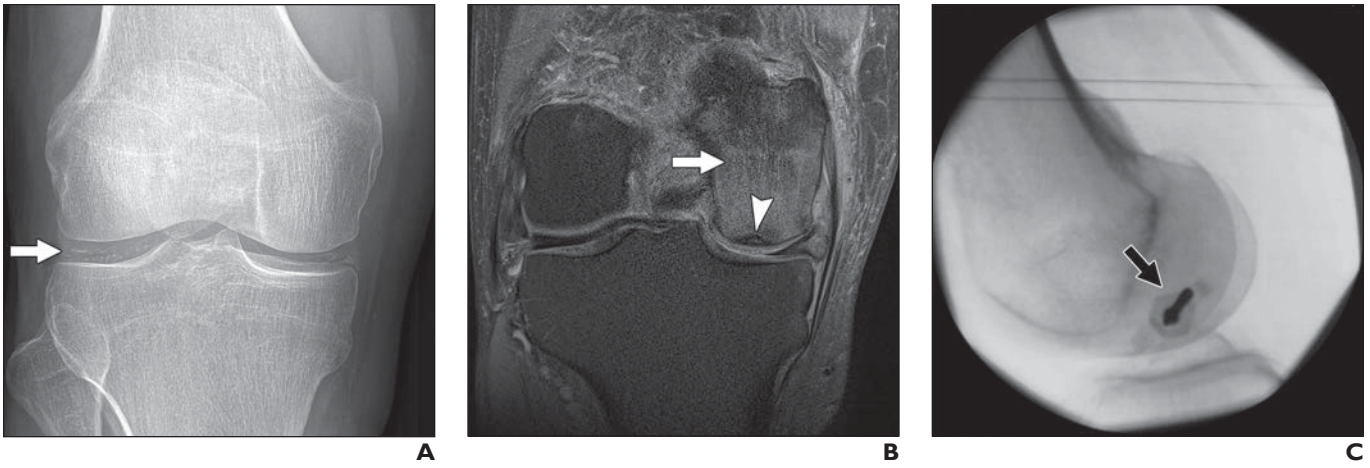


Fig. 2—70-year-old man with knee pain on right side.
A, Preoperative radiograph shows chondrocalcinosis (*arrow*) in both menisci.
B, Preoperative coronal intermediate-weighted fat-saturated MR image (TR/TE, 2750/24) shows extensive bone marrow edema (*arrow*) in medial femoral condyle and subchondral linear hypointense fracture line parallel to cortex (*arrowhead*), which are consistent with insufficiency fracture.
C, Intraoperative fluoroscopy image shows needle placement (*arrow*) for subchondroplasty performed via lateral approach.
D and **E,** Postoperative radiographs show new opacification in medial femoral condyle (*black arrowheads*) and preexisting chondrocalcinosis (*arrow*, **D**). Drill hole is visible on lateral image (**E**) in center of injected calcium phosphate. Note that there is minor soft-tissue contamination medial to medial femoral condyle (*white arrowhead*, **D**) along lateral approach.

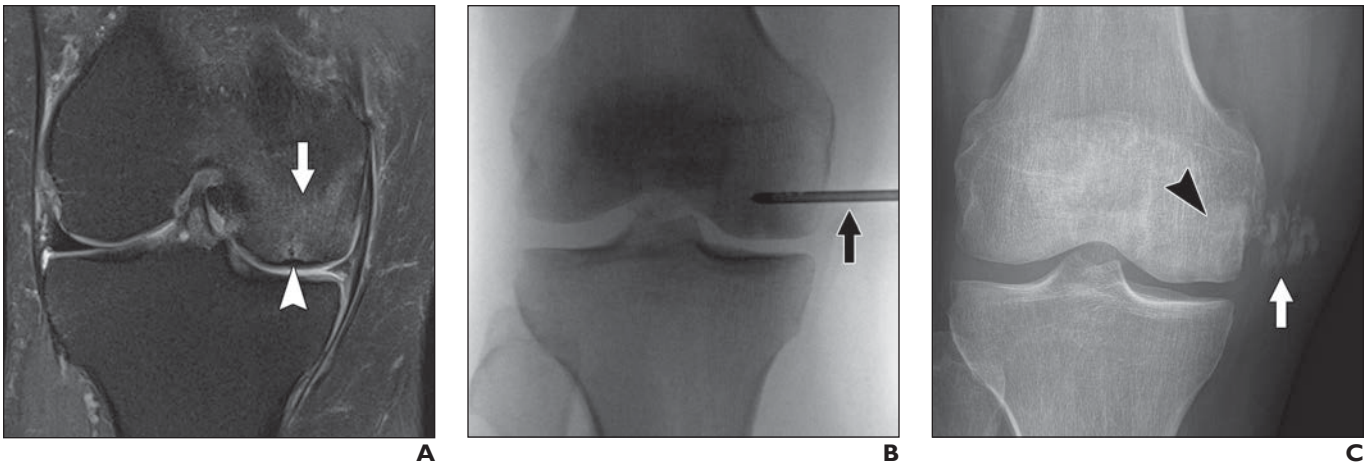


Fig. 3—53-year-old male runner with persistent pain and weakness in right knee after medial meniscectomy 4 months earlier.
A, Preoperative coronal intermediate-weighted fat-saturated MR image (TR/TE, 3000/33) shows large area of bone marrow edema in medial femoral condyle (*arrow*) and small subchondral hypointense line parallel to cortex (*arrowhead*), which are consistent with insufficiency fracture.
B, Intraoperative fluoroscopic image shows lateral approach and needle placement (*arrow*) during subchondroplasty.
C, Postoperative radiograph shows focal region of opacification in medial femoral condyle (*arrowhead*) and prominent soft-tissue contamination (*arrow*) along lateral approach.

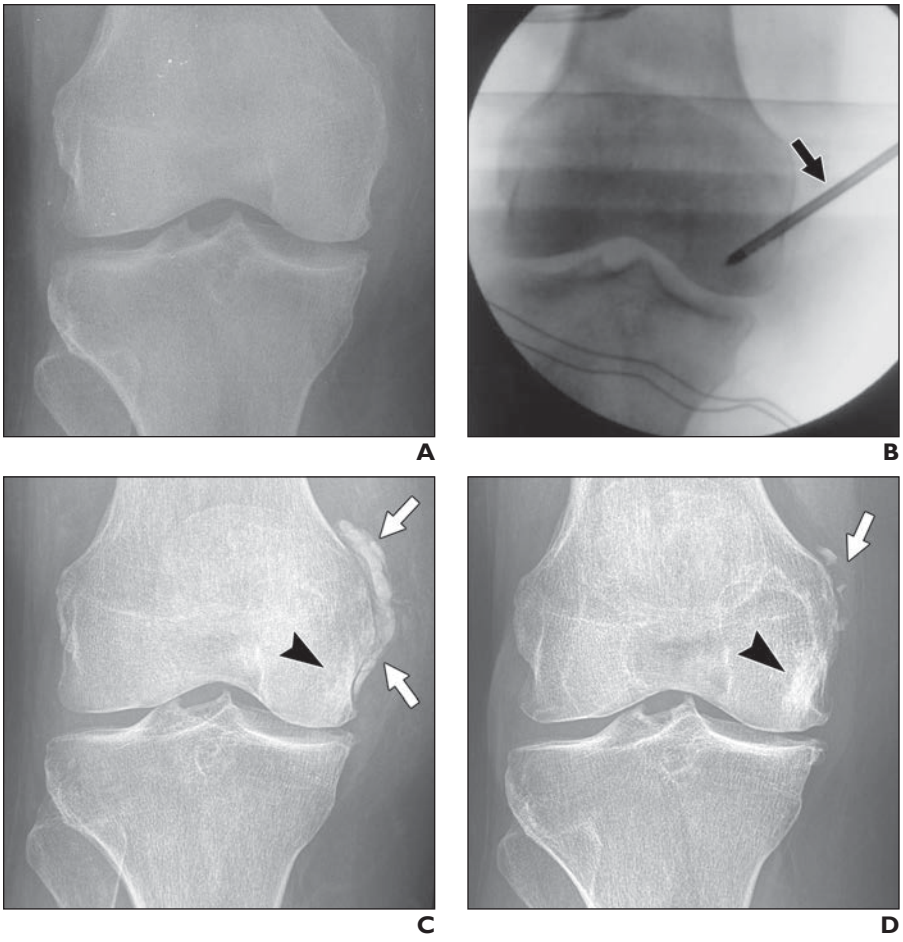


Fig. 4—59-year-old woman with right knee pain after falling 9 months earlier.
A, Preoperative radiograph shows minor osteophyte formation and unremarkable soft tissues. Preoperative MR image (see Fig. 5A) showed focal bone marrow edema in medial femoral condyle.
B, Intraoperative fluoroscopic image shows lateral approach and needle placement (*arrow*) during subchondroplasty.
C, Postoperative radiograph obtained 1 month after procedure reveals major leakage of injected calcium phosphate along medial contour of distal femur (*arrows*). Region of increased density (*arrowhead*) within medial femoral condyle is consistent with injected calcium phosphate.
D, Radiograph obtained 2 years after subchondroplasty shows leaked calcium phosphate in medial soft tissue (*arrow*) has nearly resolved. Sclerotic zone within medial femoral condyle (*arrowhead*) is better depicted.

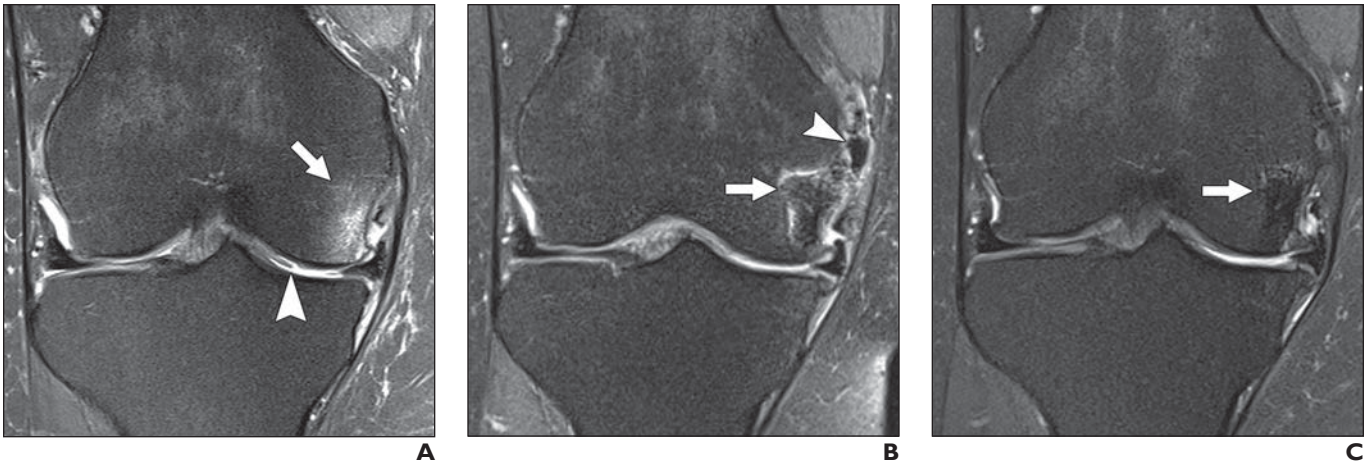


Fig. 5—59-year-old woman with right knee pain after falling 9 months earlier (same patient as in Fig. 4). Temporal evolution of MRI appearance after subchondroplasty is shown.
A, Preoperative coronal intermediate-weighted fat-saturated MR image (TR/TE, 2700/34) shows focal bone marrow edema in medial femoral condyle (*arrow*) and extensive cartilage loss in medial compartment with cartilage delamination in central aspect of medial femoral condyle (*arrowhead*).
B, MR image (TR/TE, 3000/33) obtained 6 months after subchondroplasty shows that injected calcium phosphate is seen as hypointense focal area surrounded by slim hyperintense rim (*arrow*). Note calcium phosphate deposit (*arrowhead*) in medial soft tissue.
C, MR image (TR/TE, 2850/33) obtained 2 years after subchondroplasty shows that hyperintense rim around calcium phosphate (*arrow*) has resolved.

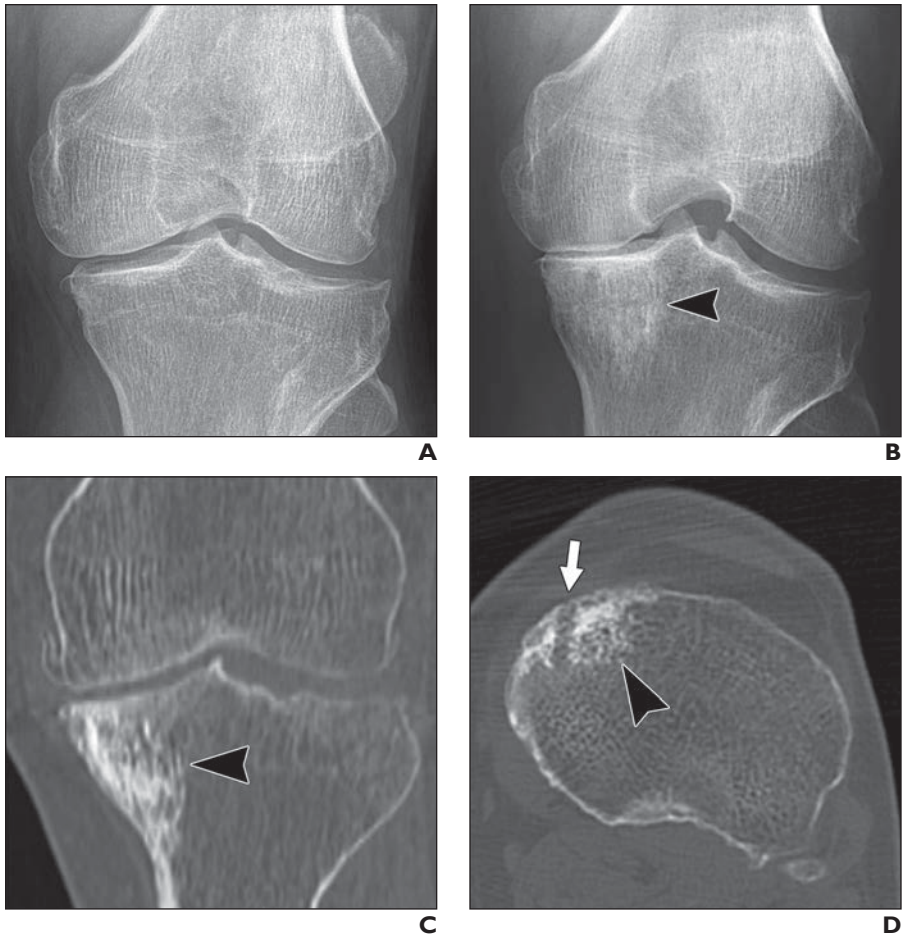


Fig. 6—54-year-old man with left-sided knee pain. **A** and **B,** Preoperative (**A**) and postoperative (**B**) radiographs are shown. After subchondroplasty, there is focal increased density in medial tibia plateau (*arrowhead*, **B**) where calcium phosphate was injected.
C and **D,** Injected calcium phosphate (*arrowhead*) is also well depicted on coronal (**C**) and axial (**D**) CT images that were acquired 2.5 years after subchondroplasty for preoperative planning of medial unicompartmental arthroplasty (MAKOplasty, MAKO Surgical) due to persistent knee pain. Drill hole (*arrow*, **D**) is visible on axial image; needle for subchondroplasty was placed via anterior approach.