Technical Note

Management of Bone Marrow Lesions of the Hip With Subchondral Calcium Phosphate Injection: Surgical Technique and Tips

Nikhil Kapil, B.S., Linsen T. Samuel, M.D., M.B.A., and Atul F. Kamath, M.D.

Abstract: Bone marrow lesions (BMLs) are localized areas of edema within subchondral bone, which are often due to early chondromalacia changes, subchondral insufficiency stress or microfractures, and/or avascular necrosis. The presence of BMLs worsen outcomes after arthroscopy and arthroplasty, thus making their management important in the preservation of hip function. In recent years, the advent of Subchondroplasty (SCP; Zimmer Knee Creations Incorporated, Exton, PA)—a minimally invasive surgical technique that involves injecting an isothermic calcium phosphate solution to stabilize BMLs—has shown promising results in managing pain from osteoarthritis (OA). The SCP material (AccuFill Bone Substitute Material, Zimmer Knee Creations Incorporated) has a similar physical and chemical structure to native bone mineral. In this Technical Note, we discuss a surgical approach for managing acetabular and femoral head BMLs with SCP. We also review the prior clinical trials reporting on SCP for knee OA. SCP may be a promising technique as part of the treatment algorithm for managing hip OA, and clinical trial enrollment has begun for hip SCP. On the basis of these results, further investigations into this procedure may be warranted.

Osteoarthritis (OA) is estimated to affect approximately 27 million adults in the United States, with a predisposition to degeneration of the hip and knee joint.[1] With some estimates predicting the lifetime risk of OA development in the hip to be 25%, early management is imperative to reduce the burden of disease.[2] The clinical manifestations of OA include chronic pain, inflammation, bone spurs, and decreased joint range of motion, all of which can greatly diminish quality of life[3]; the radiographic evidence of OA is seen as osteophyte formation and joint space narrowing on radiographs.

One factor that increases the risk of OA progression is the presence of a subchondral bone marrow lesion (BML).[4] BMLs have been shown to increase the incidence of OA by a factor of 2.5.[5] These BMLs are defined as localized edema within the subchondral bone, which can be due to early chondromalacia changes, subchondral insufficiency stress or microfractures, and sometimes avascular necrosis. The lesions are visualized as regions of hyperintensity on fat-suppressed T2-weighted magnetic resonance imaging (MRI) sequences.[6,7] Plain radiographic imaging of patients with BMLs will often show femoroacetabular impingement (FAI), which can complicate surgical management if a delamination injury to the acetabular articular cartilage is present.[8-13] Gdalevitch et al.[14] showed that radiographic visualization of delamination cysts—caused by leakage of intra-articular joint fluid into subchondral bone due to microfractures caused by delamination of articular cartilage—in the anterosuperior part of the acetabulum could predict delamination of the acetabular articular cartilage adjacent to labral tears with 80% sensitivity and 96.3% specificity.

From the School of Medicine, Case Western Reserve University, Cleveland, Ohio, U.S.A. (N.K.); and Department of Orthopaedic Surgery, Cleveland Clinic Foundation, Cleveland, Ohio, U.S.A. (L.T.S., A.F.K.).

The authors report the following potential conflicts of interest or sources of funding: A.F.K. receives research support from Signature Orthopaedics; is a paid presenter or speaker for Zimmer Biomet and DePuy Synthes; receives stock or stock options from Zimmer Biomet, Johnson & Johnson, and Procter & Gamble; is a paid consultant for DePuy Synthes and Zimmer Biomet; receives intellectual property royalties from Innomed; is a board or committee member of the American Academy of Orthopaedic Surgeons, The American Association of Hip & Knee Surgeons, and the Anterior Hip Foundation; and is on the editorial or governing board of BMC Musculoskeletal Disorders, outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received November 23, 2019; accepted February 26, 2020.

Address correspondence to Atul F. Kamath, M.D., Center for Hip Preservation, Orthopaedic and Rheumatologic Institute, Cleveland Clinic, 9500 Euclid Ave, Mail Code A41, Cleveland, OH 44195, U.S.A. E-mail: kamatha@ccf.org

2212-6287/191434

https://doi.org/10.1016/j.eats.2020.02.022

Treatment for OA ranges from nonsurgical measures, such as oral analgesics and physical therapy, to surgical treatment, such as hip or knee arthroplasty.[15] Although arthroplasty is the definitive treatment for moderate to severe OA, the procedure comes with potential risks[16] and resulting activity restrictions.[17] Many patients, particularly those who are younger and more active, prefer a less invasive procedure that may preserve natural joint function and offer an option for hip preservation. In recent years, Subchondroplasty (SCP) has emerged as a promising early intervention alternative to arthroplasty in the setting of a BML with no significant degenerative changes in the hip.

SCP, a technique developed in the knee in 2007, involves image- and/or arthroscopic-guided injection of calcium phosphate into the BML.[18] This technique has been shown to be efficacious in several clinical trials in which the calcium phosphate was injected into BMLs within the distal femur and/or proximal tibia.[6,19-22] The clinical outcomes of SCP of the hip have been less studied. This Technical Note will outline the procedural steps to perform SCP of the hip. In addition, various clinical trials on SCP will be discussed, including an ongoing trial related to the hip.

Technique

Preoperative Steps

The BML should be localized and characterized using fat-saturated T2-weighted MRI (Fig 1). Lesions will appear as areas of hyperintensity on this sequence. Clinical and radiographic correlations are important to define these lesions. All concomitant pathology, such as an acetabular labral tear and zones of FAI (Fig 2), should be defined and addressed at the time of surgery. Without treatment of coexisting pathology (e.g. FAI), the ultimate success of SCP for BML treatment may be compromised. Presurgical planning involves identifying the paths of the SCP instruments needed to accurately penetrate the areas of the BML. This will be correlated with intraoperative imaging (e.g. fluoroscopy) and arthroscopic landmarks and findings.

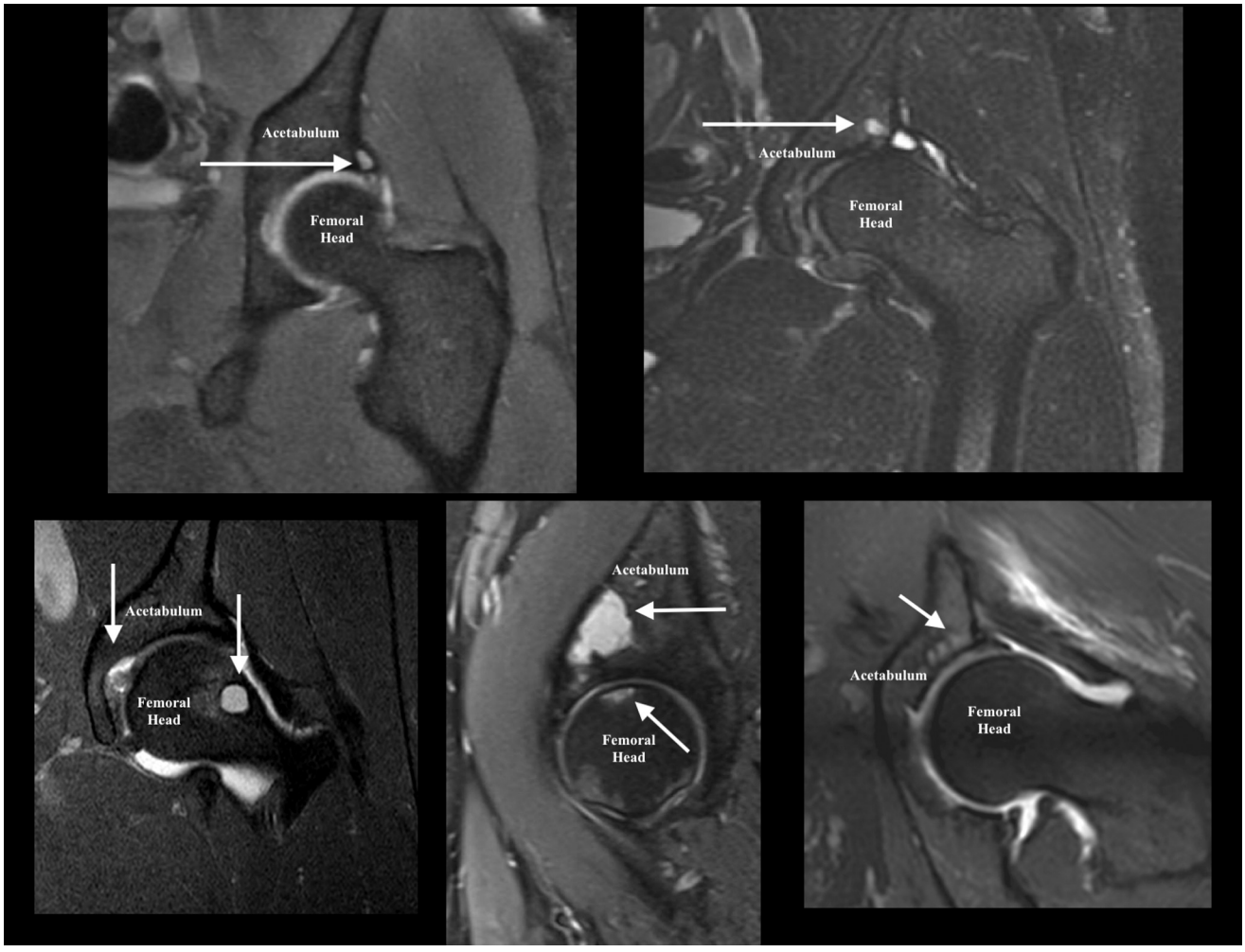

Fig 1. Visualization of a bone marrow lesion in the coronal plane using fat-suppressed T2-weighted magnetic resonance imaging. Lesions are indicated with arrows and appear as areas of hyperintensity. (Reprinted with permission from Zimmer Biomet.)

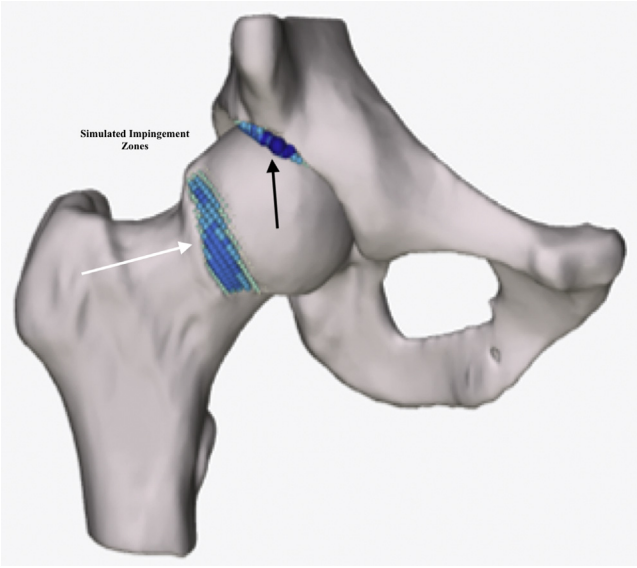

Fig 2. Simulated impingement zones in combined cam-pincer scenario (white and black arrows). The location and treatment of any concomitant pathology, such as zones of femoroacetabular impingement, should be addressed at the time of Subchondroplasty to maximize the results of the Subchondroplasty procedure.

Zonal Anatomy

Figure 3 illustrates the anatomic zones within which BMLs are codified. Acetabular BMLs most often occur in areas of impingement (zone 2), areas of maximal weight bearing (zone 3L), and areas with superior retroversion (zones 1 and 2). When a BML is found in zone 4, it is usually as a late finding of OA. Femoral BMLs occur in areas of weight bearing (zones 2 and 3L) and parafoveal areas (zone 3M).[23]

Intraoperative Steps for Femoral Head BML

The patient is placed in the supine position on a radiolucent table with the fluoroscopy unit coming in from the contralateral side of the table (Fig 4). The table should accommodate hip arthroscopy (e.g. Hana table, Mizuho OSI, Union City, CA) owing to concomitant treatment in the central and peripheral hip compartments and to address any intra-articular pathology. Hip arthroscopy access also allows for any removal of intra-articular extravasation of the hydrophilic injectate.

The operative leg is internally rotated, and the lesser trochanter–neck-shaft angle is marked (Fig 5). After a skin incision is made, a wire driver should be used to assist in placement of the AccuPort trocar-cannula

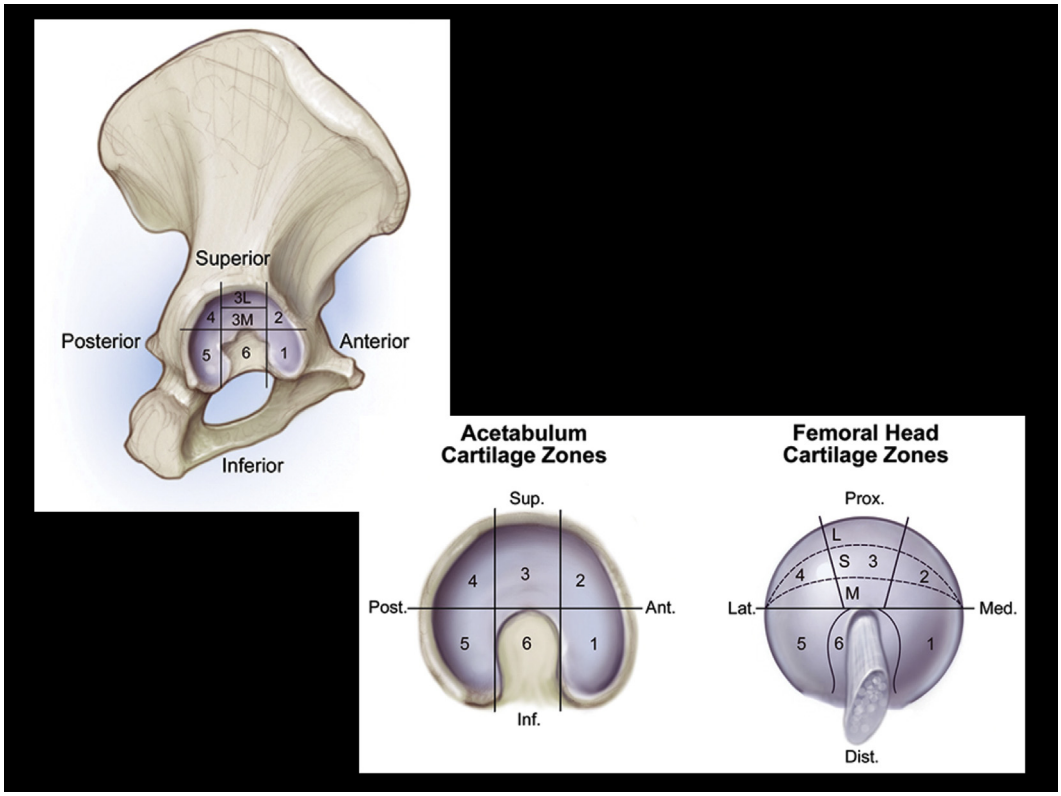

Fig 3. Zonal anatomy of acetabulum and femoral head. Acetabular bone marrow lesions (BMLs) commonly occur in zones 1, 2, 3L, and 4. Femoral BMLs commonly occur in zones 2, 3L, and 3M. Common areas of impingement include zone 2 (acetabulum), areas of maximal weight bearing include zone 3L (acetabulum and femoral head) and zone 2 (femoral head), and areas of superior retroversion include zones 1 and 2 (acetabulum). BMLs found within zone 4 are a common late finding of osteoarthritis. (Ant, anterior; Dist, distal; Inf, inferior; Lat, lateral; Med, medial; Post, posterior; Prox, proximal; Sup, superior.)

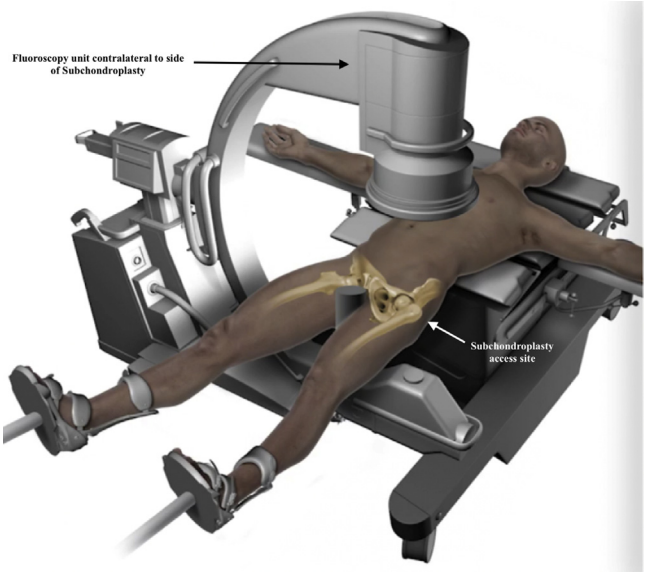

Fig 4. Placement of the patient in a supine position on a radiolucent table compatible with hip arthroscopy; the fluoroscopy unit comes from the contralateral side (black arrow). Using a table compatible with arthroscopy allows for treatment of intra-articular pathologies and removal of extravasated material. The Subchondroplasty access site is shown by the white arrow. (Reprinted with permission from Zimmer Biomet.)

system (Zimmer Knee Creations Incorporated, Exton, PA) through the lateral femoral cortex above the level of the lesser trochanter (Video 1). Keeping the entry point above the level of the lesser trochanter decreases the chance of a proximal femoral fracture. The trocar-cannula system has a length of 200 mm and diameter of 4.2 mm (8 gauge) and is able to support side-delivery, end-delivery, multi-delivery, and zone-delivery configurations (Fig 6). The trocar is advanced up through the intertrochanteric region into the femoral neck. Proper placement of the cannula can be confirmed with fluoroscopy in multiple projections (Fig 7); we suggest keeping the fluoroscopy machine stationary and having the assistant perform frog-leg lateral positioning of the leg (Fig 8) to obtain the lateral view of the neck. It is important to assess the planned trajectory after the cannula has been advanced only to the intertrochanteric line (Fig 9); if a new trajectory is deemed necessary, the cannula can be withdrawn to the cortex and then redirected without creating undue stress in the femoral neck. Subsequent adjustments can be made by backing the cannula out and redirecting under fluoroscopic guidance if needed; redirection should not be attempted when the cannula is embedded in bone. It is best to perform any redirections prior to the tip of the trocar passing beyond the head-neck junction of the proximal femur to avoid any stress risers in the femoral neck. Future instrumentation will accommodate a guidewire for targeting the lesion, prior to drilling (Fig 10). An alternate technique is to access femoral head lesions through an arthroscopic cannula and under arthroscopic visualization, but care should be taken to avoid penetrating the femoral head zones of the articular cartilage.

For a typical femoral head BML, an 8-gauge AccuPort cannula is usually used. Once the cannula has entered the femoral head BML, the stylus should be removed from the cannula by gently reversing the wire driver. To remove any excess heat generated from drilling, 2 mL of saline solution can be injected or the surgeon can wait 2 minutes before proceeding with injection of the calcium phosphate. Performing the calcium phosphate material injection (AccuFill Bone Substitute Material (BSM), Zimmer Knee Creations Incorporated, Exton, PA) prior to any osteochondroplasty (e.g. addressing a cam lesion) is recommended so that the material is "contained" until it completely hardens.

At this point, the AccuFill BSM can be injected. The cannula volume itself is 1 to 2 mL. Generally, 3 to 5 mL of AccuFill BSM is used for a typical femoral lesion. A small test dose can be injected prior to full-volume injection to assess for unwanted extravasation. Verification of proper location, as well as lack of extravasation, can be made with fluoroscopic and/or arthroscopic guidance. Once the material has been fully injected, the AccuFill BSM is allowed to harden over a period of 8 to 10 minutes. The trocar stylus is then reconnected to the cannula, and the cannula is removed. Because of the small-diameter hole of the trocar-cannula system, backfilling of the cannula tract is not required.

Intraoperative Steps for Acetabular BML

On the basis of the location of the BML, the lesion may be accessed through percutaneous incisions or via an arthroscopic cannula (Fig 11). The standard hip arthroscopic portals should be placed at the surgeon's preference, and an accessory portal may be used for the SCP cannula insertion. For an acetabular BML, a 11-gauge AccuPort cannula is usually used. The cannula is advanced to the BML; generally, the tip of the cannula is within several millimeters of the subchondral plate. Fluoroscopy may be used for visualization, in conjunction with arthroscopic visualization and guidance as needed. Once the cannula is placed in the desired location, the stylus should be removed from the cannula by gently reversing the wire driver. Next, approximately 3 mL of AccuFill BSM is injected (it should be noted that the volume of the cannula is about 1 mL) for a typical lesion. After appropriate hardening time of the injectate, the stylus can be reconnected to the cannula, and the apparatus can be removed. It is recommended to perform the AccuFill BSM injection prior to any bony acetabular work (e.g. addressing a

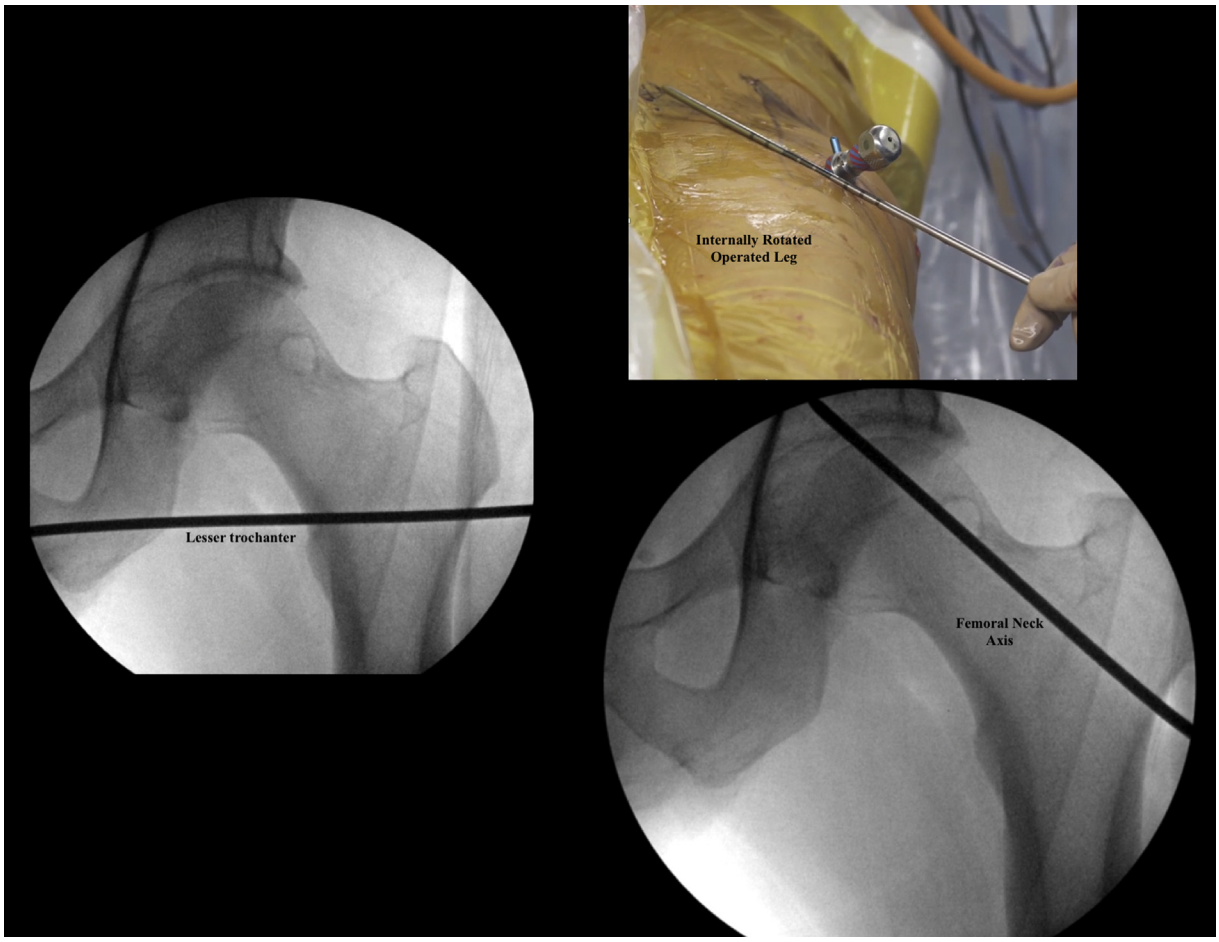

Fig 5. Internal rotation of the operative leg with marking of the lesser trochanter—neck-shaft angle with the patient in the supine position. All portal entry points are kept above the level of the lesser trochanter to reduce the possibility of a proximal femoral fracture. Anteroposterior fluoroscopic views are used to visualize the lesser trochanter and neck-shaft angle. A wire driver is used to assist in placement of the trocar-cannula system. (Reprinted with permission from Zimmer Biomet.)

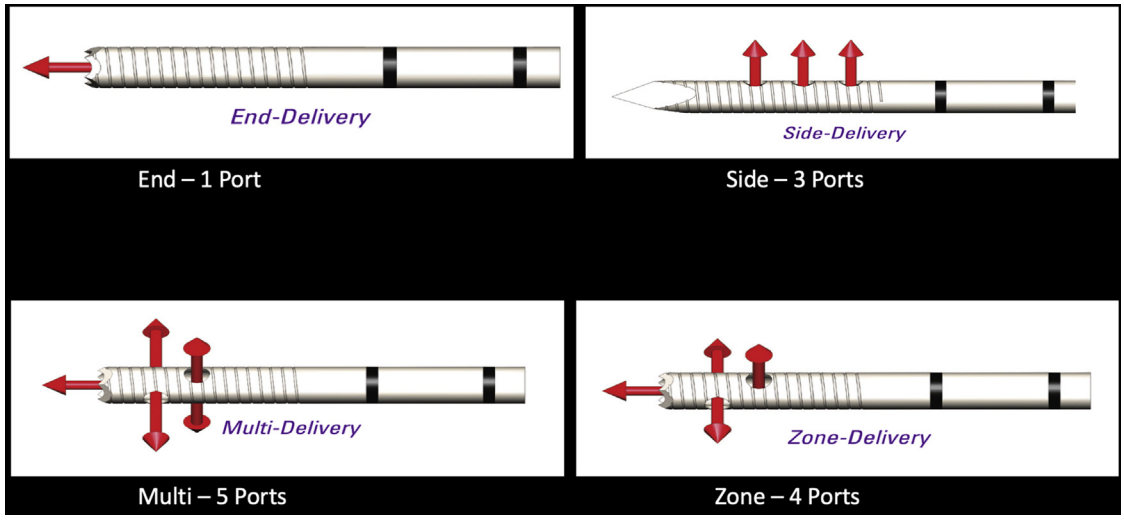

Fig 6. Trocar-cannula system with end-delivery, side-delivery, multi-delivery, and zone-delivery configurations. The trocar-cannula system has a length of 200 mm and diameter of 4.2 mm (8 gauge), allowing ample space for injection of AccuFill Bone Substitute Material (BSM). Approximately 3 mL of AccuFill BSM will be injected into the bone marrow lesion. (Reprinted with permission from Zimmer Biomet.)

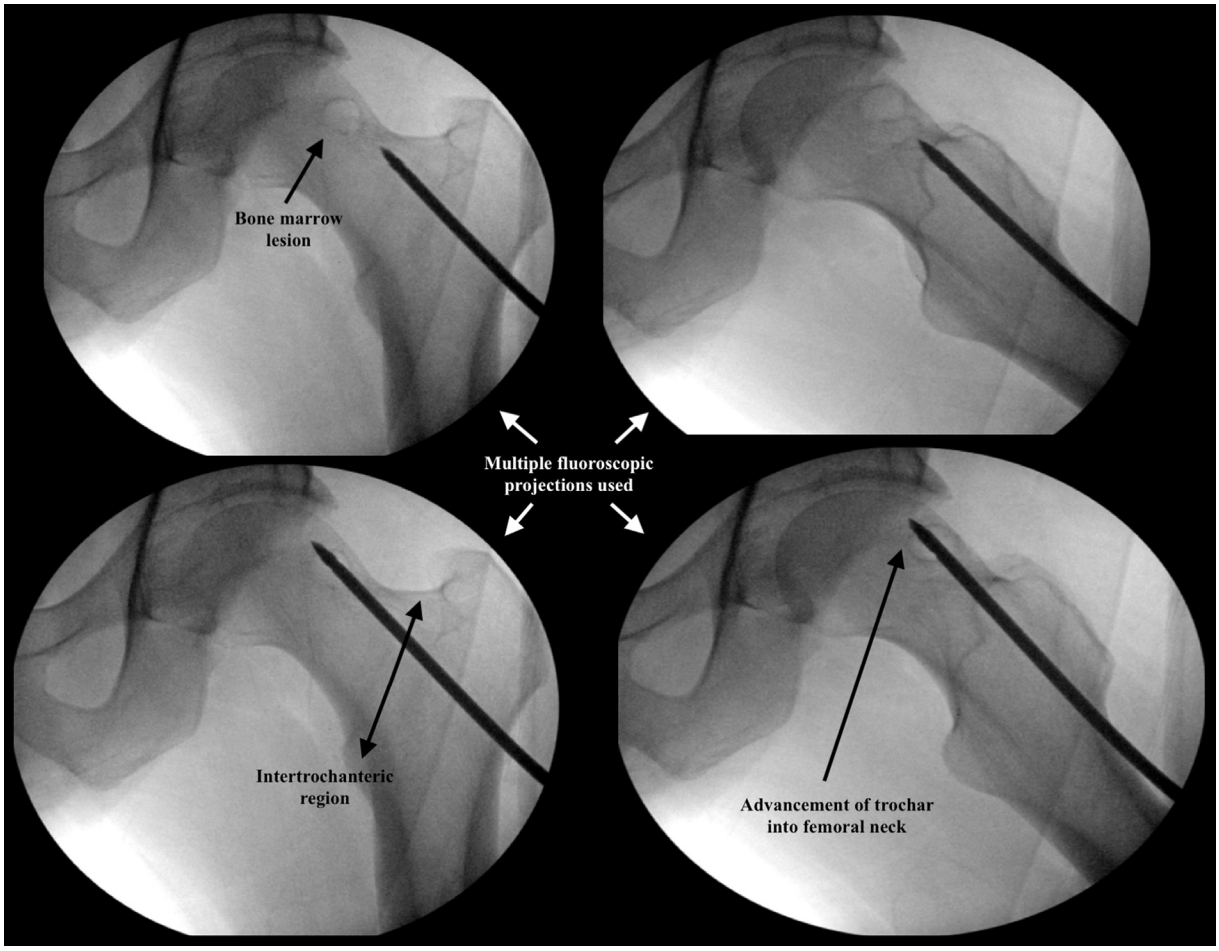

Fig 7. Advancement of the trocar into the femoral neck via the intertrochanteric region using multiple anteroposterior fluoroscopic projections to help with guidance. The bone marrow lesion is visualized as labeled hyperintensity. The patient is kept in the frog-leg lateral position during fluoroscopic projections. (Reprinted with permission from Zimmer Biomet.)

pincer lesion) and placement of anchors so that the material is contained until it completely hardens. Furthermore, the AccuFill BSM may offer additional cancellous bone support in the revision hip arthroscopy setting when placing anchors in compromised bone.

AccuFill Material

AccuFill BSM, which has an average total crystal volume of 1,664 nm^3, is similar to native bone mineral, which has an average total crystal volume of 1,485 nm^3. This crystalline structure, along with flowability, allows AccuFill BSM to flow into intact spongy bone and to be broken down by osteoclasts as native bone apatite. AccuFill BSM is also highly macroporous, allowing for increased surface area for cellular activity. Other parallels to native bone include a similar compressive strength (approximately 7-9 MPa). Isothermic hardening of AccuFill BSM ensures that tissue necrosis does not occur when injected into spongy bone and allows for concomitant use with bone marrow concentrate (e.g. in the setting of core decompression for avascular necrosis). If the hydrophilic AccuFill BSM enters the joint space (Fig 12), it can be removed with an arthroscopic shaver device. A summary of AccuFill BSM properties is presented in Table 1, and a comparison to other commercially available products is shown in Table 2. Pearls and pitfalls of the SCP procedure are shown in Table 3, and advantages and disadvantages are presented in Table 4.

Discussion

BMLs have been shown to increase the risk of OA.[3] It has previously been shown that BMLs often occur at low-cartilage and high-stress areas within the acetabulum and can irritate the numerous nerve fibers that are present in bone marrow.[24,25] Imaging of patients with BMLs will often show concomitant labral tears and FAI. Although BMLs can also be seen on radiographs, fat-suppressed MRI sequences are used to confirm findings.[6]

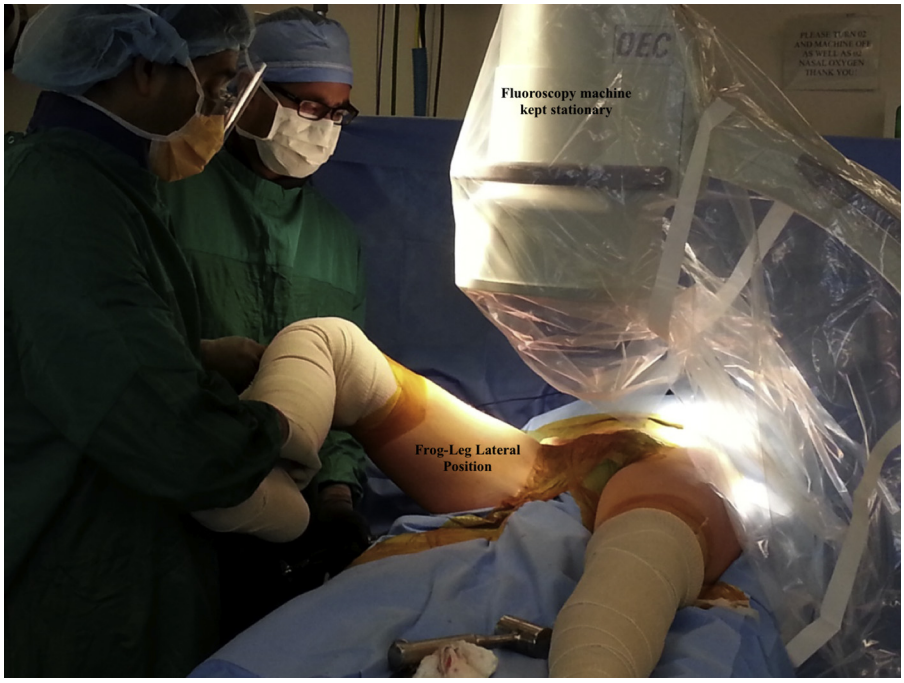

Fig 8. Visualization of a lateral projection of the femoral neck with the patient's leg placed in the frog-leg lateral position. The fluoroscopy machine is held stationary while an assistant places the patient in the correct frog-leg lateral position, thereby allowing for optimal visualization of lesions.

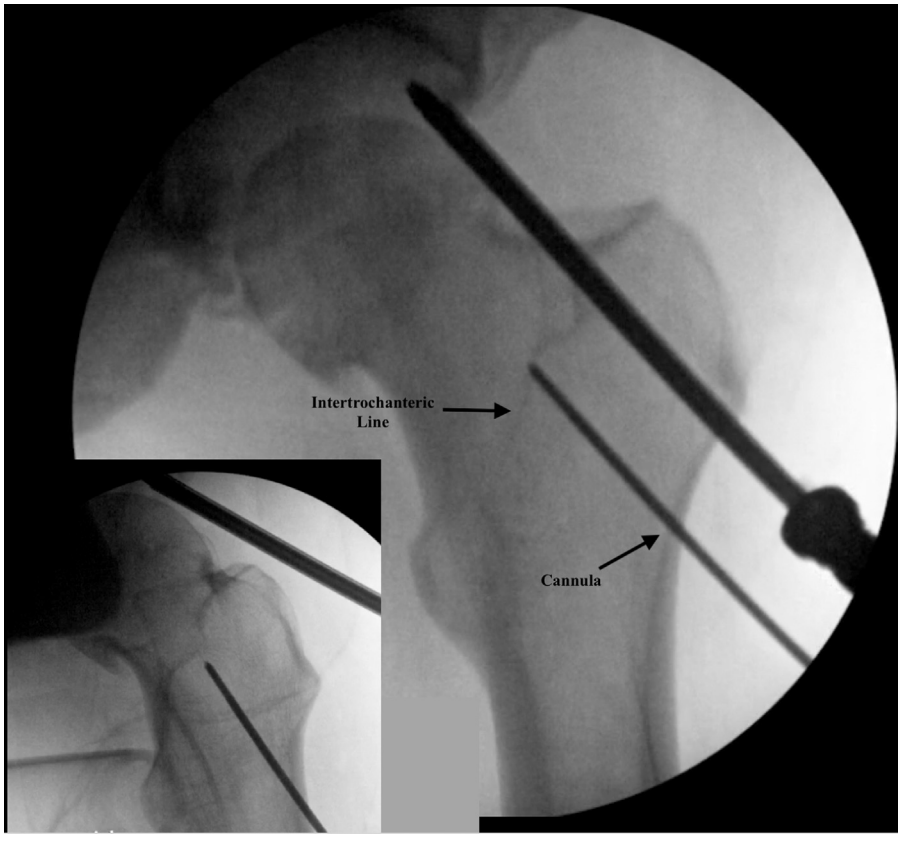

Fig 9. Assessment of the cannula trajectory at the intertrochanteric line using an anteroposterior fluoroscopic view. This assessment allows the surgeon to make adjustments to the planned trajectory by withdrawing to the cortex. Any redirections should be performed before passing the head-neck junction of the femur to prevent any unnecessary stress on the femoral neck. Redirection should not occur if the cannula is embedded in bone. (Reprinted with permission from Zimmer Biomet.)

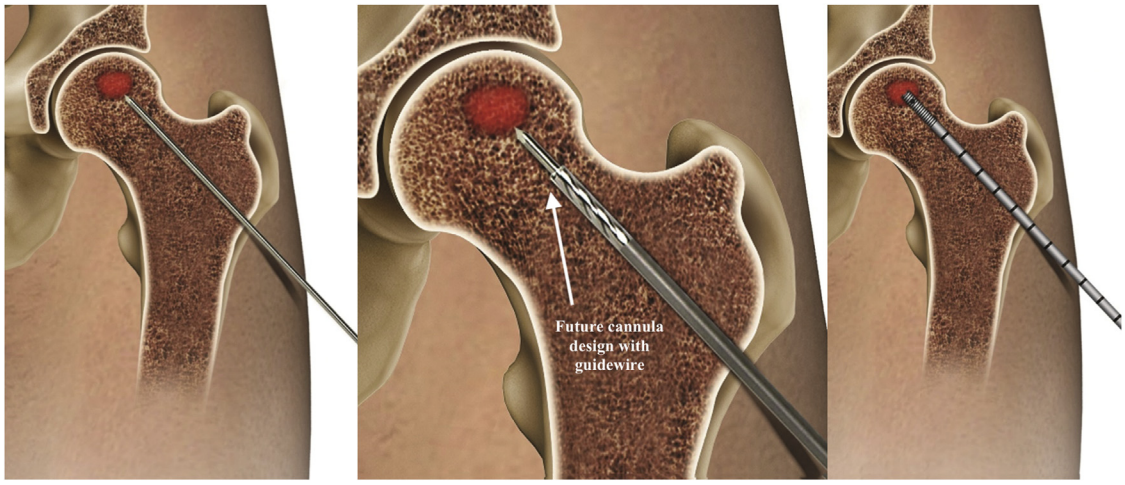

Fig 10. Future cannula design with guidewire (arrow), which will allow the surgeon to target the lesion prior to drilling, thereby reducing the number of steps required to inject AccuFill Bone Subsitute Material within a bone marrow lesion. (Reprinted with permission from Zimmer Biomet.)

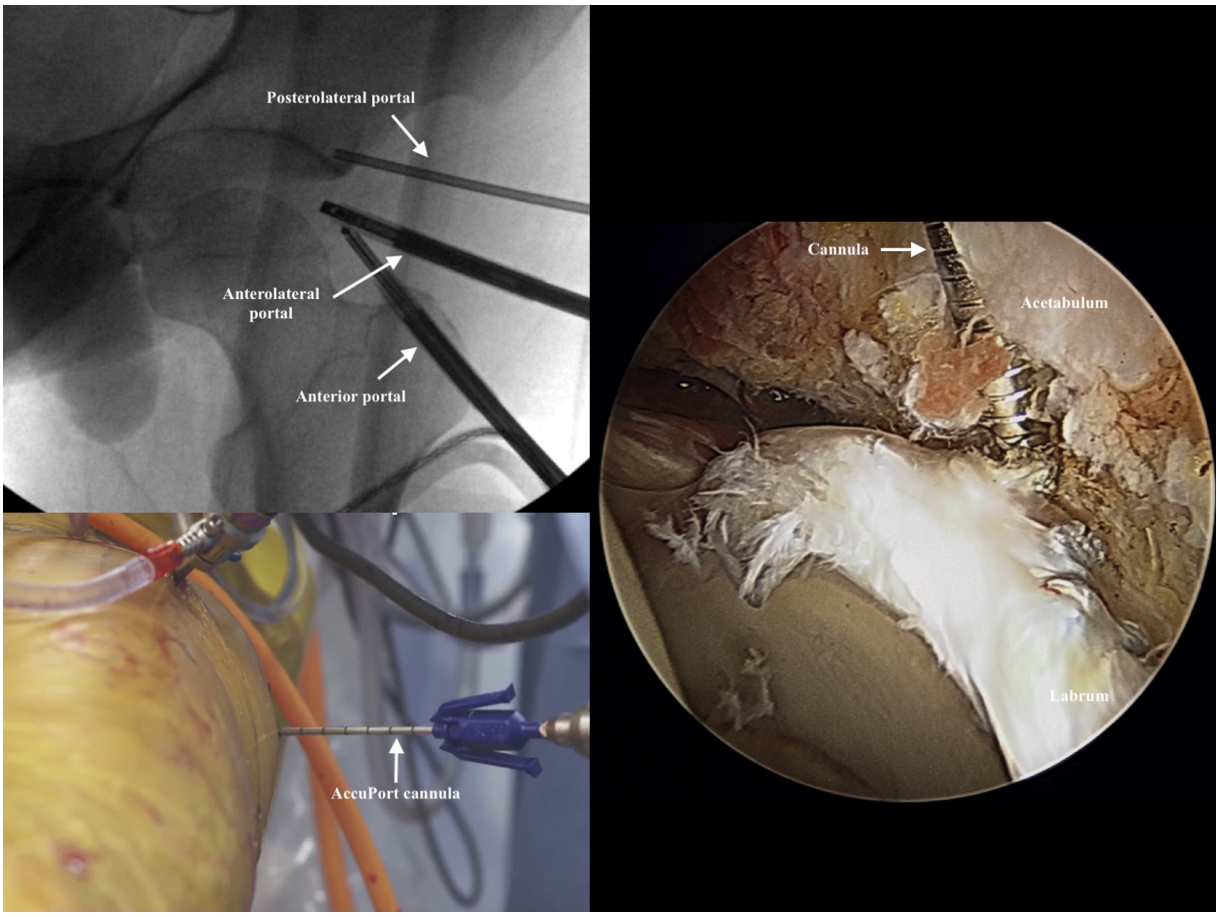

Fig 11. Access to bone marrow lesion using arthroscopic cannula. Standard hip arthroscopic portals (arrows) are used (i.e. anterolateral placed first, anterior placed second, and posterolateral placed third). Both the portals and cannula are accessed from the lateral aspect of the patient. An arthroscope is placed within the anterolateral port using a guidewire. (Reprinted with permission from Zimmer Biomet.)

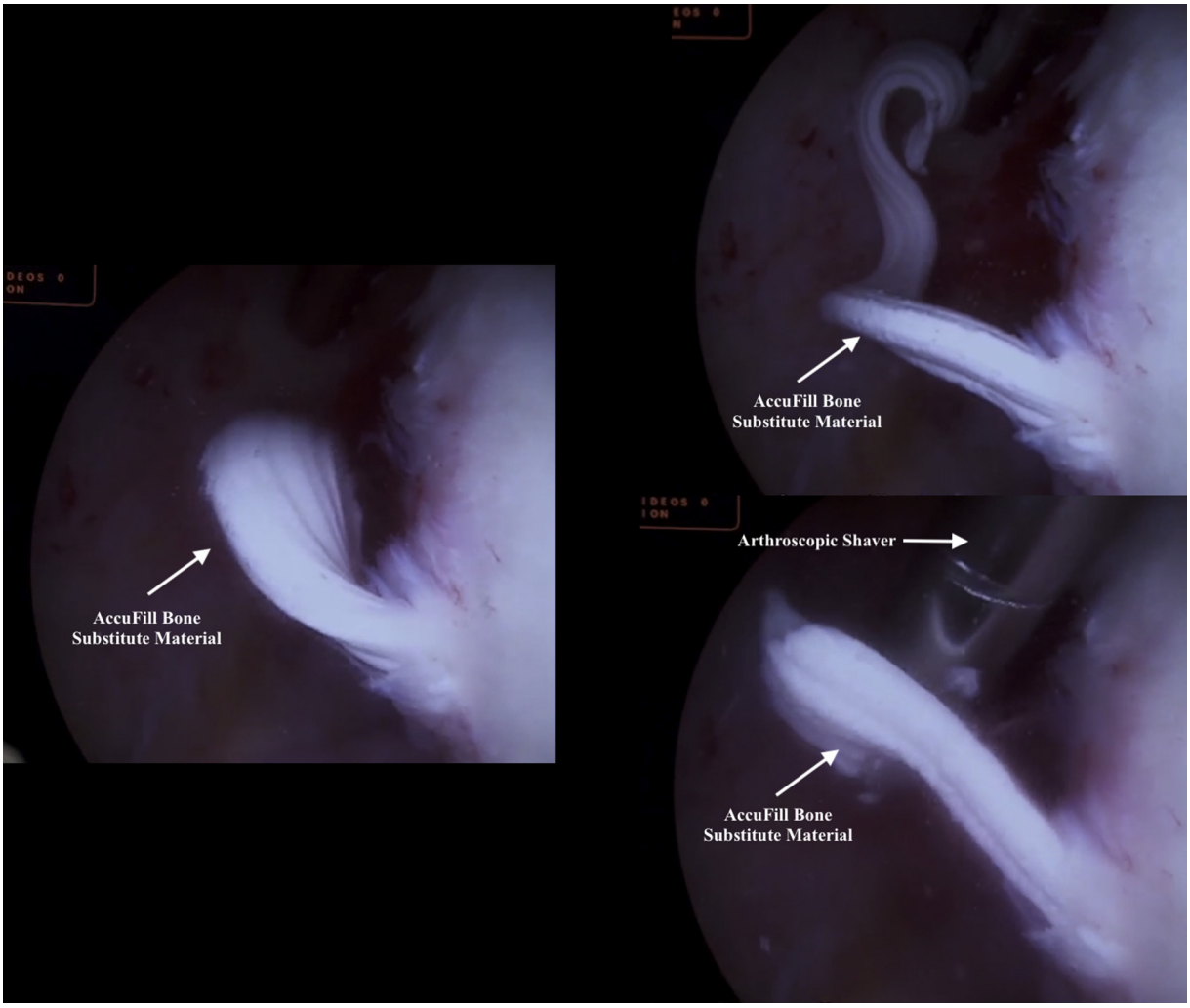

Fig 12. Removal of extravasated AccuFill Bone Substitute Material (BSM) from the joint space using an arthroscopic shaver device. Approximately 3 mL of AccuFill BSM is injected into a bone marrow lesion. The hydrophilic nature of the AccuFill BSM allows it to be easily removed with the arthroscopic shaver device. The arthroscope is inserted from the anterolateral portal. (Reprinted with permission from Zimmer Biomet.)

Risk factors for BMLs include hip impingement, developmental dysplasia of the hip, chondromalacia, insufficiency injuries and stress responses, obesity, and avascular necrosis. These factors lead to numerous micro-insufficiency fractures within the bone.[26] As a result, bone trabeculae are decreased, which causes a reduction in the elastic resistance of bone and numerous microtrabecular fractures. This leads to increased pressure and edema within the bone. As a result of Wolff's law, the bone will respond to the increased pressure by greatly increasing subchondral bone turnover and angiogenesis.[27] The pain associated with BMLs is due to the associated increased vascularity and innervation of bone marrow; lesions that are closer to the subchondral plate will elicit more pain due to the presence of numerous nerve endings.[28] Furthermore, BMLs have been shown to be an independent risk factor that leads to worse outcomes on metrics such as the Hip Outcome Score after hip arthroplasty[29]; therefore, our understanding of early processes that stimulate BMLs may affect patient satisfaction.

Table 1. AccuFill Bone Substitute Material (BSM) Material Data

Material	Average Nanocrystal Length, nm	Average Nanocrystal Width, nm	Average Nanocrystal Height, nm	Total Volume, nm^3
Human bone mineral	23-32	6.7-8.0	6.7-8.0	1,485
AccuFill BSM	26	8	8	1,664

NOTE. Reprinted with permission from Zimmer Biomet.

Table 2. Comparison of Material Data for AccuFill BSM and Other Commercially Available Products

Material And/or Brand Name if Available	Company	Chemical Formula
Human bone mineral	NA	$Ca_{10-x}(M)_x(PO_4)_{6-x}(HPO_4,CO_3)_x(OH)_{2-x}$
AccuFill Bone Substitute Material	ETEX Corporation (Cambridge, MA)	$Ca_{10-x}(M)_x(PO_4)_{6-x}(HPO_4,CO_3)_x(OH)_{2-x}$
Norian Skeletal Repair System	Synthes (West Chester, PA)	$Ca_{10-x}(PO_4)_{6-x}(HPO_4,CO_3)_x(OH)_{2-x}$
BoneSource	Stryker Corporation (Kalamazoo, MI)	$Ca_{10-x}(PO_4)_{6-x}(HPO_4)_x(OH)_{2-x}$
Vitoss (β-TCP)	Stryker Corporation (Kalamazoo, MI)	$Ca_3(PO_4)_2$
Actifuse	Baxter International Incorporated (Deerfield, IL)	$Ca_{10}(PO_4)_{6-x}(SiO_4)_x(OH)_{2-x}$

NOTE. Reprinted with permission from Zimmer Biomet.
NA, not applicable; TCP, tricalcium phosphate.

The most common locations of BMLs are the knee and hip. Knee BMLs occur at high-stress areas such as the medial tibial plateau and medial femoral condyle. Hip BMLs mainly occur in the acetabulum, although femoral head BMLs are routinely seen.[23] The propensity for acetabular BMLs may be due to the concave surface, properties of the subchondral plate, and other factors as shown in finite element analysis.[24]

Subchondroplasty offers a minimally invasive surgical option that has shown promise in alleviating pain and exacerbation of OA in patients with BMLs. Since 2013, there have been 5 main clinical trials that have assessed the use of SCP for BMLs within the knee (Table 5). Most of the clinical trials involving knee SCP have revealed positive results. The largest of these trials, conducted by Cohen and Sharkey,[22] showed that 88% of patients (50 of 57) reported positive improvements in pain scores 6 months after receiving subchondroplasty. Similarly, Bonadio et al.[6] and Farr and Cohen[19] showed improvements in pain metrics such as the visual analog scale score, as well as the Knee Injury and Osteoarthritis Outcome Score, International Knee Documentation Committee score, and 12-item Short Form Health Survey score. Yoo et al.[21] reported that patients who first received SCP and then later underwent total or unicompartmental knee arthroplasty showed no difference in outcomes compared with patients who underwent arthroplasty alone, suggesting that SCP may not compromise the results of subsequent arthroplasty treatment. It is worth mentioning that of the 22 patients in the trial of Chatterjee et al.,[20] 7 reported poor outcomes and 3 reported fair outcomes per the Tegner knee scoring scale; the authors considered these cases to be clinical failures. Unlike other studies, the patients in this trial all had moderate to severe OA, suggesting that SCP is less successful in moderate to severe OA. In our practice, we do not perform SCP in the setting of advanced arthritis.

Although SCP is generally tolerated, the procedure is not without risk. In 1 case report, a 64-year-old male patient who received SCP to treat a BML of the medial femoral condyle contracted *Staphylococcus aureus* osteomyelitis.[30] The patient had reported positive improvement in pain management, although purulent drainage eventually developed, which was ultimately treated with antibiotics and surgical irrigation and debridement. Given the very small sample size of the study, it is likely that the infection arose due to suboptimal sterile technique. This should be contrasted with the results of Farr and Cohen,[19] who found that no infections developed in a sample of 59 patients who underwent SCP (Table 5). Some short-term technical challenges that are seen with SCP include extravasation or leakage of calcium phosphate within surrounding soft-tissue structures, postoperative leakage of calcium phosphate, and postoperative pain.[19,31] Long-term technical challenges with subchondroplasty appear to be minimal, given that Yoo et al.[21] showed that patients who received prior subchondroplasty injections who later underwent arthroplasty did not differ from patients

Table 3. Summary of Pearls and Pitfalls of Subchondroplasty

Pearls	Pitfalls
Visualization of BML is performed using fat-saturated T2-weighted MRI.	Care should be taken not to extravasate injected material into the surrounding soft-tissue structures.
Intraoperative fluoroscopy can help guide the cannula.	Concomitant pathologies (i.e. acetabular labral tear and FAI) should be addressed at the time of surgery.
BML can be accessed via a percutaneous incision or arthroscopic cannula.	The entry point of the cannula system should be kept above the level of the lesser trochanter to reduce the likelihood of a proximal femoral fracture.
	The cannula should not be redirected if directly embedded in bone; rather, the cannula should be backed out and redirected using fluoroscopy to reduce stress on the femoral neck.

BML, bone marrow lesion; FAI, femoroacetabular impingement; MRI, magnetic resonance imaging.

Table 4. Summary of Advantages and Disadvantages of Subchondroplasty

Advantages
Subchondroplasty is minimally invasive, with improvement in pain scores in most patients
Can help delay onset of invasive procedures such as total hip arthroplasty
Preservation of natural joint function
Disadvantages
Lack of familiarity with surgical technique requiring additional training
Lack of efficacy in certain patients
Postoperative pain

without SCP in terms of operative time, blood loss, or surgical revisions.

The first major clinical trial assessing SCP of the hip is currently underway and is industry funded.[32] In total, 100 patients will be enrolled based on the following criteria: BML, insufficiency fracture, or avascular necrosis of the femur and/or acetabulum. The study is expected to enroll patients until March 2022. It is

Table 5. Summary of Key Clinical Trials Involving Subchondroplasty for Management of Knee Bone Marrow Lesions

Authors (Year)	No. of Patients Who Underwent Subchondroplasty	Inclusion Criteria	Exclusion Criteria	Results
Cohen and Sharkey[22] (2016)	66	Presence of BML in tibia or femur Moderate or severe pain for >2 mo Failure of symptom improvement from conservative treatment (i.e. NSAIDs and/or corticosteroids)	Severe malalignment (>8° of varus-valgus) Severe grade IV OA (per Kellgren-Lawrence grading) Pain from cause outside of BML	Of 57 patients with preoperative and postoperative VAS scores, 50 had improvement in symptoms, 4 had no change, and 3 had worsening pain. The mean change in the VAS score was 4.3 after 6 mo and 4.5 after 2 yr of follow up (score >2 considered relevant). Of 48 patients with preoperative and postoperative IKDC scores, 38 had improvement in symptoms, 1 had no change, and 9 had worse pain. The mean change in the IKDC score was 17.2 after 6 mo and 17.8 after 2 yr (score >11.5 considered relevant).
Bonadio et al.[6] (2017)	5	Knee pain for >6 mo Presence of BML confirmed by MRI	Moderate grade III OA (per Kellgren-Lawrence grading) Severe malalignment (>8° of varus-valgus) Alterations of patellofemoral joint (per radiography) Autoimmune and/or renal disease	Mean change in KOOS: 24.6 (1 wk postop), 19.64 (3 wk postop), 19.48 (6 wk postop), 24.9 (12 wk postop), and 32.82 (24 wk postop) Mean change in VAS score: −5 (1 wk postop), −4.8 (3 wk postop), −5 (6 wk postop), −6 (12 wk postop), and −7.2 (24 wk postop)
Yoo et al.[21] (2016)	22 (all of whom eventually underwent TKA or UKA)	Moderate to severe grade III-IV OA (per Kellgren-Lawrence grading) Presence of BML confirmed by MRI Failure of symptom improvement from conservative treatment (i.e. NSAIDs and/or corticosteroids)	Not listed	Mean OKS: 40.6 compared with 40.1 for patients undergoing only TKA or UKA without prior subchondroplasty (insignificant difference, $P = .66$) No major complications in patients who underwent future TKA or UKA after subchondroplasty
Farr and Cohen[19] (2013)	59	Prior knee pain Presence of BML confirmed by MRI	Not listed	TKA or UKA was performed in 15 patients because of unresolved pain. Among patients who did not undergo further surgery, the mean change in the VAS pain score at 6 mo postop was −4.4, the mean change in the IKDC score at 6 mo postop was 22.4, and mean change in the SF-12 score at 6 mo postop was 6.9.

(continued)

Table 5. Continued

Authors (Year)	No. of Patients Who Underwent Subchondroplasty	Inclusion Criteria	Exclusion Criteria	Results
Chatterjee et al.[20] (2015)	33 (22 of whom met appropriate inclusion and exclusion criteria and were available for 6-mo follow-up)	Presence of BML confirmed by MRI Failure of symptom improvement from conservative treatment (i.e. NSAIDs and/or corticosteroids) Moderate to severe grade III-IV OA (per Kellgren-Lawrence grading)	Severe malalignment (>8° of varus-valgus) Nondegenerative meniscal tear near BML lesion Fracture and/or dislocation	The mean change in the KOOS at 6 mo postop was 31.8. The mean change in the Tegner-Lysholm score at 6 mo postop was 29.5. Further analysis of Tegner-Lysholm scores revealed that 7 patients had excellent results, 5 had good results, 3 had fair results, and 22 had poor results.

BML, bone marrow lesion; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; MRI, magnetic resonance imaging; NSAIDs, nonsteroidal anti-inflammatory drugs; OA, osteoarthritis; OKS, Oxford Knee Score; postop, postoperatively; SF-12, 12-item Short Form Health Survey; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty; VAS, visual analog scale.

planned for patients to report outcomes such as pain, activity level, and overall satisfaction up to several years postoperatively. This study may offer insight into the short- and mid-term durability of SCP in the hip, as well as for those patients whom this technique may offer an alternative for early intervention.

Hip SCP is an emerging surgical technique in which a calcium phosphate material is injected into BMLs. As the primary generator of pain, the subchondral bone and associated microfractures associated with increased stress concentrations may offer a surgical target for helping with symptomatic hip pain in patients with preserved overall hip cartilage. A similar procedure and technique have shown promising results in the treatment of BMLs of the knee. A longitudinal cohort study of hip SCP is currently recruiting patients for enrollment. Further study in broader patient populations will help to define the role of SCP in the hip. Furthermore, future work should characterize the utility of SCP for the management of hip pathology and whether this is a durable alternative to OA in patients with BML, focal correctable anatomic issues, and minimal femoroacetabular degenerative changes.

Acknowledgment

The authors thank Matthew Mai, M.D., and Patrick Birmingham, M.D., for shared case material.

References

1. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum* 2008;58:26-35.
2. Murphy L, Schwartz TA, Helmick CG, et al. Lifetime risk of symptomatic knee osteoarthritis. *Arthritis Rheum* 2008;59:1207-1213.
3. Litwic A, Edwards MH, Dennison EM, Cooper C. Epidemiology and burden of osteoarthritis. *Br Med Bull* 2013;105:185-199.
4. Sharkey PF, Cohen SB, Leinberry CF, Parvizi J. Subchondral bone marrow lesions associated with knee osteoarthritis. *Am J Orthop (Belle Mead NJ)* 2012;41:413-417.
5. Brimmo OA, Bozynski CC, Cook CR, et al. Subchondroplasty for the treatment of post-traumatic bone marrow lesions of the medial femoral condyle in a pre-clinical canine model. *J Orthop Res* 2018;36:2709-2717.
6. Bonadio MB, Filho AGO, Helito CP, Stump XM, Demange MK. Bone marrow lesion: Image, clinical presentation, and treatment. *Magn Reson Insights* 2017;10 . 1178623X17703382.
7. Eriksen EF. Treatment of bone marrow lesions (bone marrow edema). *Bonekey Rep* 2015;4:755.
8. Byrd JWT, Jones KS. Microfracture for grade IV chondral lesions of the hip (SS-89). *Arthroscopy* 2004;20:e41 (suppl, abstr).
9. Clohisy JC, McClure JT. Treatment of anterior femoroacetabular impingement with combined hip arthroscopy and limited anterior decompression. *Iowa Orthop J* 2005;25:164-171.
10. Crawford K, Philippon MJ, Sekiya JK, Rodkey WG, Steadman JR. Microfracture of the hip in athletes. *Clin Sports Med* 2006;25:327-335.
11. McCarthy JC. The diagnosis and treatment of labral and chondral injuries. *Instr Course Lect* 2004;53:573-577.
12. O'Leary JA, Berend K, Vail TP. The relationship between diagnosis and outcome in arthroscopy of the hip. *Arthroscopy* 2001;17:181-188.

13. Philippon MJ, Schenker ML, Briggs KK, Maxwell RB. Can microfracture produce repair tissue in acetabular chondral defects? *Arthroscopy* 2008;24:46-50.
14. Gdalevitch M, Smith K, Tanzer M. Delamination cysts: A predictor of acetabular cartilage delamination in hips with a labral tear. *Clin Orthop Relat Res* 2009;467:985-991.
15. 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.
16. Erens GA, Walter B. Complications of total hip arthroplasty. UpToDate. https://www.uptodate.com/contents/complications-of-total-hip-arthroplasty. Accessed April 22, 2020.
17. Martin GM, Harris I. Total Knee Arthroplasty. UpToDate, https://www.uptodate.com/contents/total-knee-arthroplasty. Accessed April 22, 2020.
18. Sharkey PF, Cohen SB, Leinberry CF, Parvizi J. Subchondral bone marrow lesions associated with knee osteoarthritis. *Am J Orthop (Belle Mead NJ)* 2012;41:413-417.
19. 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.
20. 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.
21. Yoo JY, O'Malley MJ, Matsen Ko LJ, Cohen SB, Sharkey PF. Knee arthroplasty after subchondroplasty: Early results, complications, and technical challenges. *J Arthroplasty* 2016;31:2188-2192.
22. Cohen SB, Sharkey PF. Subchondroplasty for treating bone marrow lesions. *J Knee Surg* 2016;29:555-563.
23. Dürr HD, Martin H, Pellengahr C, Schlemmer M, Maier M, Jansson V. The cause of subchondral bone cysts in osteoarthrosis: a finite element analysis. *Acta Orthop Scand* 2004;75:554-558.
24. Dürr HD, Martin H, Pellengahr C, Schlemmer M, Maier M, Jansson V. The cause of subchondral bone cysts in osteoarthrosis: A finite element analysis. *Acta Orthop Scand* 2004;75:554-558.
25. Starr AM, Wessely MA, Albastaki U, Pierre-Jerome C, Kettner NW. Bone marrow edema: Pathophysiology, differential diagnosis, and imaging. *Acta Radiol* 2008;49:771-786.
26. Li G, Yin J, Gao J, et al. Subchondral bone in osteoarthritis: Insight into risk factors and microstructural changes. *Arthritis Res Ther* 2013;15:223.
27. Shabestari M, Vik J, Reseland JE, Eriksen EF. Bone marrow lesions in hip osteoarthritis are characterized by increased bone turnover and enhanced angiogenesis. *Osteoarthritis Cartilage* 2016;24:1745-1752.
28. Eggers GWN, Evans BE, Blumel J, Nowlin DH, Butler JK. Cystic change in the iliac acetabulum. *J Bone Joint Surg Am* 1963;45:669-686.
29. Krych AJ, King AH, Berardelli RL, Sousa PL, Levy BA. Is subchondral acetabular edema or cystic change on MRI a contraindication for hip arthroscopy in patients with femoroacetabular impingement? *Am J Sports Med* 2016;44:454-459.
30. Dold A, Perretta D, Youm T. Osteomyelitis after calcium phosphate subchondroplasty: A case report. *Bull Hosp Jt Dis* 2017;75:282-285.
31. Agten CA, Kaplan DJ, Jazrawi LM, Burke CJ. Subchondroplasty: What the radiologist needs to know. *AJR Am J Roentgenol* 2016;207:1257-1262.
32. SCP Hip Outcomes Study. Zimmer Biomet, https://clinicaltrials.gov/ct2/show/NCT03494660 . Accessed April 22, 2020.