

Percutaneous Skeletal Fixation of Painful Subchondral Bone Marrow Edema of the Knee



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Purpose: To investigate the change in patient-reported pain after percutaneous skeletal fixation (PSF) and to determine the success rate of PSF in the prevention of additional intervention for the treatment of painful subchondral bone marrow edema (SBME) of the knee over a 2-year postoperative period. **Methods:** This was a retrospective, single-surgeon analysis of patients undergoing PSF for painful, atraumatic SBME of the knee confirmed on preoperative magnetic resonance imaging with a minimum 2-year follow-up. Inclusion criteria were age >18 years, pain localized to the area of edema, failure of nonsurgical intervention (4 weeks of physical therapy and non-steroidal medication use), and absence of tricompartmental Kellgren–Lawrence grade 4 osteoarthritis. All patients underwent arthroscopy, followed by isolated PSF without additional chondral procedures. Pre- and postoperative visual analog scale scores were compared. The primary outcome measure of success was defined as a lack of additional intervention. This included viscosupplementation, corticosteroid injection, or conversion to arthroplasty. **Results:** A total of 74 patients with a mean age of 47.2 years and average follow-up time of 38.9 months (range 24–61 months) were evaluated. Successful treatment was noted in 61 patients (82.4%). Of the 13 patients who did not respond to PSF, 5 (6.8%) had been converted to arthroplasty, 11 received viscosupplementation, and 8 required cortisone injections. The average visual analog scale score decreased from 7.55 preoperatively to 3.16 at 2-year follow-up ($P < .001$). The average body mass index of successfully treated patients (28.2) was significantly less than that of the patients experiencing failure (32.2) ($P = .001$). **Conclusions:** Patients undergoing PSF for the treatment of painful SBME may expect a decrease in knee pain and low rates of additional intervention over a 2-year postoperative period. **Level of Evidence:** Level IV; Therapeutic Case Series

With the increasing use of magnetic resonance imaging (MRI) in clinical orthopaedic practice, subchondral bone marrow edema (SBME) has emerged as a central component of many painful, pathologic conditions affecting the musculoskeletal system.¹ SBME

represents a pathologic alteration of subchondral bone and often goes unrecognized on plain radiographs. On MRI, this edema is identified by an area of hyperintense signal on T2-weighted or short tau inversion recovery sequences, as well as a region of hypointense signal on T1-weighted sequences (Fig 1 A and B).^{2–5} Of note, along with bone marrow edema, histopathologic analysis of these bone changes has revealed the presence of bone marrow necrosis and fibrosis, abnormal trabeculae, increased vascularization, and microfractures.^{6–8} Since this discovery, a wealth of publications has emerged describing the association of SBME with a number of musculoskeletal conditions, most notably osteoarthritis. In reference to osteoarthritis of the knee, SBME has been linked to the presence and severity of pain, the degree of joint surface deformation, and the progression of disease.^{9–14} Multiple studies have proven that once SBME is detected in patients with knee osteoarthritis, the need for imminent total knee arthroplasty (TKA) becomes highly predictable.^{3,13} Scher et al.³ found that patients with osteoarthritis of the knee and SBME identified on MRI were nearly 9 times as likely to progress to TKA over a 3-year follow-

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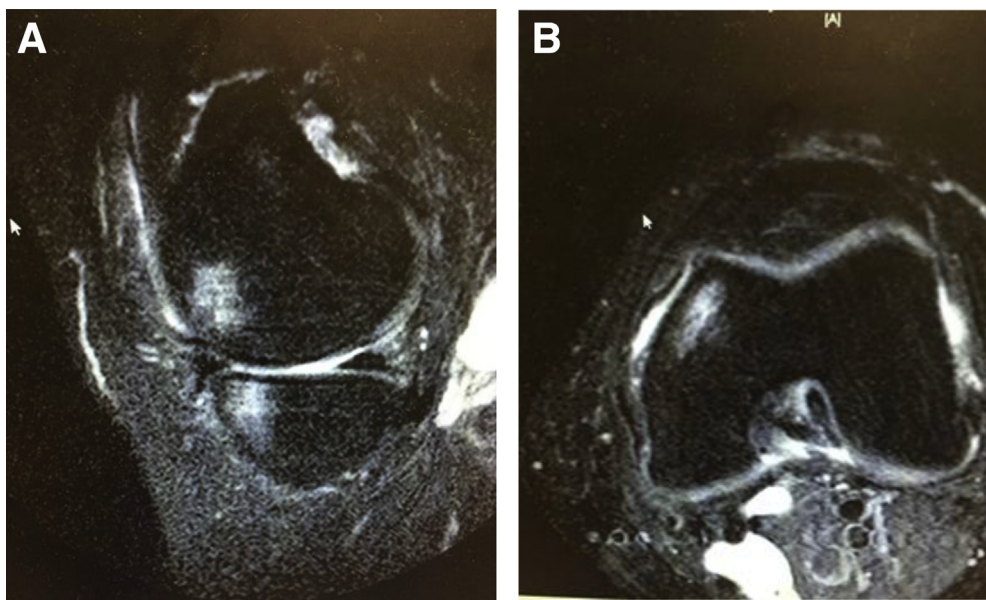


Fig 1. T2 sagittal (A) and axial (B) magnetic resonance imaging of a left knee demonstrating white hyperintense subchondral bone marrow edema in both the medial femoral condyle and medial tibial plateau, known as a “kissing lesion.”

up period as compared with patients with no identifiable SBME.

A number of conservative treatment options have been described, including rest, physical therapy, nonsteroidal anti-inflammatory medications, bracing, and injections of corticosteroid or viscosupplementation.^{15,16} Unfortunately, the relief that many of these options provide has been found to be inconsistent and, at best, short-lived. Nielsen et al.¹⁷ noted a decrease in SBME volume 14 weeks after intra-articular corticosteroid injection when compared with a placebo cohort; however, the difference between the treatment and control groups was negligible by 26 weeks. A surgical treatment option for patients with SBME and associated osteoarthritis that has proven to provide lasting pain relief and halt the progression of disease is TKA.¹⁸ Although TKA has proven to be a durable treatment option, it is a significantly invasive and costly intervention that can be associated with substantial recovery time and complications.^{19,20} Younger patients in particular have been shown to have a substantial risk of aseptic loosening requiring early revision surgery, with 1 study identifying a 12.5% rate of TKA failure secondary to aseptic loosening over an 8-year period in patients younger than the age of 40 years.^{21,22} For these reasons, less-invasive, joint-preserving treatment options are desirable, particularly in younger patients or those seeking to delay total knee arthroplasty.

Percutaneous skeletal fixation (PSF) is a surgical procedure consisting of an injection of a calcium phosphate synthetic bone-void filler into regions of painful SBME.^{10,23} The goal of the procedure is to improve the structural quality of the affected subchondral bone and promote local bone remodeling

while preventing subchondral bone collapse and subsequent progression of osteoarthritis.^{4,10,23,24} To date, PSF has been found to provide predictable pain relief through a minimally invasive approach, allowing patients to resume activity quickly with few known complications. A recent study followed patients for a 2-year period after PSF treatment of painful SBME and noted significant improvements in pain and function with a 30% conversion rate to total knee arthroplasty at 2 years postoperatively.⁴ To our knowledge, no current literature exists to illustrate the ability of PSF to prevent the need for any repeat intervention (i.e., injections, aspirations, arthroplasty) for knee pain over an extended follow-up period. The purposes of this study was to investigate the change in patient-reported pain after PSF and to determine the success rate of PSF in the prevention of additional intervention for the treatment of painful SBME of the knee over a 2-year postoperative period. We hypothesized that PSF would successfully prevent the need for additional treatment of knee pain in the majority of our patient population and would result in a decrease in subjective pain scores at 2-year follow-up.

Methods

Institutional review board approval (Lourdes/Virtua Health System institutional review board, no. 19-020) was obtained before commencement of this study. We retrospectively reviewed the medical records of all patients older than 18 years undergoing PSF from 2013 to 2016 at a single institution for treatment of atraumatic SBME of the knee. All patients had presented to the office of a single fellowship-trained sports medicine orthopaedic surgeon (S.M.) for evaluation of unilateral

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> • SBME identified on weight-bearing surface of medial/lateral femoral condyle and/or tibial plateau on preoperative MRI of affected knee • Pain on physical examination localized to same region of knee as identified SBME • Failure of nonoperative management of knee pain (physical therapy, NSAIDs) • Minimum of 2-year follow-up/documentation of VAS pain score and additional intervention for knee pain 	<ul style="list-style-type: none"> • Tricompartmental grade 4 Kellgren–Lawrence osteoarthritis in affected knee • Primary cause of knee pain attributable to additional knee pathology aside from SBME • SBME attributable to traumatic etiology • Gross knee instability in coronal or sagittal plane on preoperative examination under anesthesia

MRI, magnetic resonance imaging; NSAID, nonsteroidal anti-inflammatory drug; SBME, subchondral bone marrow edema.

knee pain present both with activity and at rest. Our cohort consisted of consecutive patients indicated for PSF as treatment for their knee pain having met the following specific criteria: identification of SBME on the weight-bearing surface of the femur and/or tibia confirmed on MRI of the knee, pain on physical examination localized to the identified region of edema, and failure of nonoperative management including a minimum of 4 weeks of physical therapy and a trial of nonsteroidal anti-inflammatory medications if tolerated (Table 1).

Preoperatively, all patients were recommended to be weight-bearing as tolerated on the affected limb to encourage self-regulation of activity in response to subjective pain level. Patients were excluded from this study if preoperative radiographs demonstrated tricompartmental Kellgren–Lawrence grade 4 osteoarthritis, the primary cause of knee pain could not be attributed to the knee SBME, a recent history of trauma to the ipsilateral knee was noted, or the patient was found to possess gross knee instability on preoperative examination under anesthesia that was not being addressed at the time of the procedure. Gross knee instability included a designation of grade 2 or greater noted with Lachman’s test, posterior drawer examination, valgus stress testing of the medial collateral ligament in 30° of knee flexion, or varus stress testing of the lateral collateral ligament in 30° of knee flexion. All radiographs were reviewed by the treating surgeon. Patient charts were retrospectively reviewed to determine patient age, sex, date of PSF, and location of SBME on preoperative MRI.

Patients meeting the inclusion and exclusion criteria were scheduled to undergo surgical arthroscopy of the affected knee, followed by PSF of the identified region of edema. Arthroscopy was performed before PSF in order to identify and address correctable intra-articular pathology (e.g., degenerative meniscus tears, loose bodies, chondromalacia, synovitis) as described by Cohen and Sharkey.⁴ Arthroscopy was also performed postinjection to confirm lack of intra-articular extravasation of calcium phosphate. The appearance of

articular cartilage graded by the Outerbridge classification and the presence of concurrent meniscal pathology were recorded at the time of arthroscopy. After the patient underwent a preoperative examination under anesthesia and surgical arthroscopy of the knee, PSF was performed using Subchondroplasty (Zimmer, Warsaw, IN) as previously described in the literature with specifications made according to recommendation by the manufacturer.²⁴ To ensure accuracy of the injection, the preoperative MRI with measurements locating the distance of the center of the region of edema to the surrounding cortices was available for review in the operating room. These images were cross-referenced with anteroposterior and lateral fluoroscopic images by the surgeon before drilling the Accuport delivery cannula (Zimmer) into the bone. Intraoperative fluoroscopy, as well as depth control measurement guides on the delivery cannula, were then used to confirm adequate placement of the delivery portion of the cannula(s) into the desired location as measured on MRI. In the event that the cannula was placed in the incorrect position, the cannula was kept in place and a second cannula was drilled into the appropriate location to minimize the risk of calcium phosphate extruding through the removed cannula’s track.

Once the appropriate cannula location was confirmed, calcium phosphate was injected into the lesion until a tactile sensation of pressure was noted and spread of radiopaque cement was seen on fluoroscopy. The precise volume of calcium phosphate used was recorded in each procedure. The surgeon’s preferred technique consisted of using a 3-hole side-delivery 11-gauge cannula for femoral lesions and a single-hole end-delivery 11-gauge cannula for tibial lesions. In patients with “kissing lesions” of the femur and tibia, 2 separate delivery cannulas were utilized to allow for simultaneous delivery of the calcium phosphate into each region of edema (Fig 2 A and B).

Patients were permitted to be weight-bearing as tolerated on the surgical extremity beginning immediately after surgery and encouraged to ambulate with

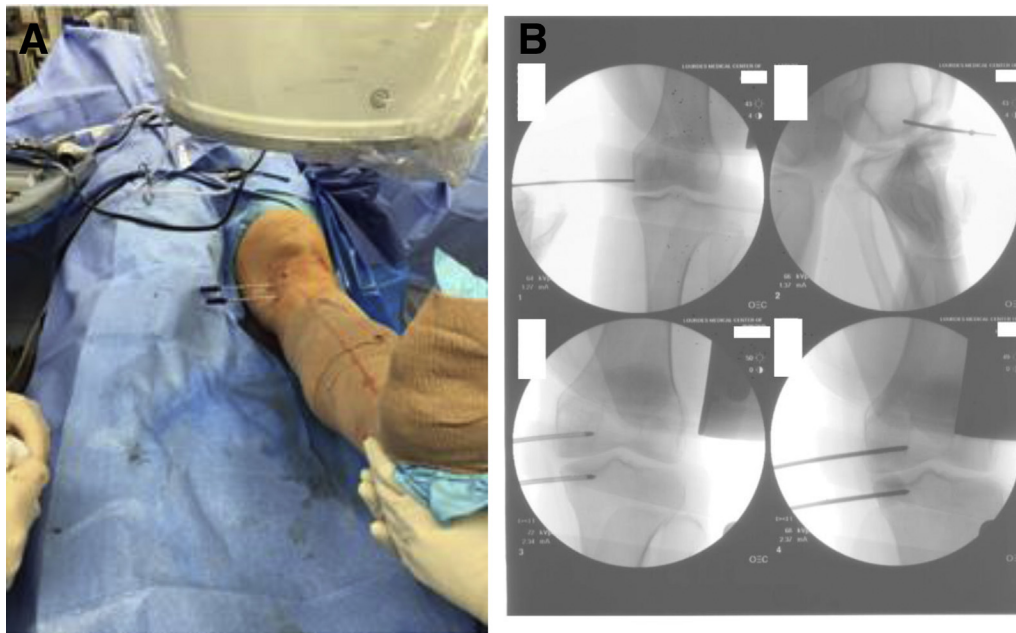


Fig 2. Pictured is a patient in the supine position possessing a left knee with “kissing” medial femoral condyle and tibial plateau subchondral bone marrow edema found on preoperative MRI. Two separate delivery cannulas are used for simultaneous injection of the regions of edema (A). Anteroposterior and lateral fluoroscopic views were used to locate the edema as identified on MRI before the calcium phosphate injection (B). (MRI, magnetic resonance imaging.)

the assistance of crutches as needed for 3 to 5 days. All patients were given a prescription for a nonsteroidal anti-inflammatory drug (celecoxib or naproxen) for 3 to 5 days postoperatively, as well as a prescription for 10 pills of 5- to 325-mg Percocet. Beginning 7 to 10 days postoperatively, patients began a structured physical therapy program for a minimum of 4 weeks. Patients were seen in the office for continued evaluation at 1 week, 6 weeks, 3 months, 6 months, 1 year, and 2 years postoperatively. Those patients who were found to have not followed up in-office at the 2-year postoperative interval were contacted via telephone to obtain information pertinent to this study. All individuals included in this study were followed for a minimum of 2 years after the date of surgery.

The primary outcome measure of this study was success of PSF treatment, defined as a lack of additional intervention for ipsilateral knee pain after surgery. This intervention included the administration of a corticosteroid injection, viscosupplementation, biologic injection, repeat PSF, or conversion of the affected knee to arthroplasty. Of note, all arthroplasty procedures were performed by the same surgeon who had performed the PSF procedure. Biologic injections included platelet-rich plasma and stem cell injections. Patients requiring additional intervention for knee pain were identified through examination of patient medical records or via questioning by telephone for those patients who had not presented to the clinic at the 2-year postoperative interval. Visual analog scale (VAS) scores were obtained at the final preoperative office visit and compared with those obtained at follow-up or via telephone 2-years postoperatively. To maintain uniformity at the time of

telephone conversation, all patients were questioned using a written script to calculate their 2-year postoperative VAS pain score and to determine whether they had presented to another institution to undergo intervention for recurrent knee pain in the ipsilateral knee. Statistical comparison of pre- and postoperative VAS scores was completed using the Mann–Whitney *U* test and performed using the R Studio program (Version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria). Comparison of the average body mass index (BMI) of those patients experiencing successful treatment with PSF to that of the patients who required additional intervention was carried out in similar fashion. The success rate of PSF treatment of subchondral bone marrow edema at 2 years was determined by calculating the proportion of patients in our cohort remaining free of additional intervention for recurrent knee pain during the postoperative period.

Results

A total of 74 patients were identified who had undergone PSF treatment of painful SBME of the knee during the study period with a minimum of 2-year follow-up. All patients had met the previously stated inclusion and exclusion criteria. The cohort consisted of 43 male (58.1%) and 31 female (41.9%) patients with an average age at the date of surgery of 47.0 years (range 24-75 years) and an average BMI of 28.93 (range 20.8-40.6). The average length of time from onset of symptoms to date of PSF procedure was 10.8 months (range 3-22 months). A total of 47 (64%) patients were found to have followed up in the office of the operative surgeon at 2 years postoperatively, and

Table 2. Cohort Distribution of SBME Location

Medial tibial plateau	16 (21.6%)
Lateral tibial plateau	5 (6.8%)
Medial femoral condyle	22 (29.7%)
Lateral femoral condyle	2 (2.7%)
Kissing lesion	29 (39.2%)

SBME, subchondral bone marrow edema.

the average length of follow-up of these patients was 38.9 months (range 24-61 months). Twenty-seven patients were noted in the medical records to have not presented to the surgeon's office at the 2-year postoperative interval and were called via telephone to obtain pertinent information.

Forty-five patients (60.8%) were noted to have a single region of SBME identified on preoperative MRI of the knee, located in either the medial femoral condyle, lateral femoral condyle, medial tibial plateau, or lateral tibial plateau (Table 2). Twenty-nine patients (39.2%) were noted to possess a "kissing lesion" on preoperative MRI, which is the designation given to the finding of SBME present in both the tibial plateau and femoral condyle on the same side (medial or lateral) of the knee. Eighty-four percent of patients were noted to possess Outerbridge classification grade 3 or 4 cartilage changes upon arthroscopic evaluation (Table 3). The average volume of calcium phosphate supplement injected into regions of SBME in the tibia was 1.8 cc and in the femur was 2.6 cc.

At 2-year follow-up from the date of surgery, it was found that 13 patients in the study cohort required additional intervention for knee pain. Three of these patients had undergone total knee arthroplasty and 2 had undergone unicompartmental knee arthroplasty, yielding a rate of conversion to arthroplasty of 6.8%. The average time to conversion to arthroplasty was 10.2 months (range 8-13 months) from the date of PSF. Eleven of the 13 patients had received viscosupplementation and 8 had received a corticosteroid injection in the surgical knee within the 2-year postoperative interval (Table 4). A total of 61 patients (82.4%) had not required any additional intervention for the treatment of recurrent knee pain during the study period and were considered to have experienced successful treatment with PSF. No significant complications related to this procedure were noted among patients in our cohort, including postoperative infection, fracture, deep-vein thrombosis (DVT), extravasation of calcium phosphate into the joint, or death. The average preoperative VAS pain score for this patient cohort was 7.55, which was found to be significantly greater than the average postoperative VAS score of 3.16 ($P < .001$). The average BMI of the 61 patients experiencing successful treatment was 28.2, which was found to be significantly lower than the

average BMI of 32.2 in the 13 patients experiencing failure ($P = .001$). The average BMI of the 5 patients converted to arthroplasty was 35.64.

Discussion

In this study, we found a decrease in knee pain and a low rate of additional intervention (17.6%) and conversion to arthroplasty (6.8%) after PSF as treatment of painful SBME of the knee. SBME has been proven to predict both the progression of joint surface degeneration and the imminent need for future total knee arthroplasty in patients with associated osteoarthritis.^{3,13,14} Alternative surgical options to treat this pathology include tibial or femoral osteotomies in young patients with knee malalignment and TKA in patients with associated osteoarthritis. High tibial osteotomies have a noted probability of survival of only 80% to 89% at 5 years and 56% to 73% at 10 years, with eventual recurrence of knee pain and conversion to TKA likely.^{25,26} TKA has been noted in one systematic review to result in dissatisfaction rates of up to 26.5% and has demonstrated greater rates of revision in patients younger than 60 for all causes of failure.^{18,21} Atraumatic, degenerative SBME of the knee has been found to present in patients as early as age 40 years, resulting in a need for a more reliable surgical option for management of this pathology in a younger patient population.⁵

In our study, patients undergoing PSF for treatment of painful SBME of the knee experienced an overall success rate of 82.4% in prevention of additional intervention. To our knowledge, this is the first study to evaluate the success of this procedure in the prevention of any additional invasive intervention for recurrent knee pain over a minimum 2-year postoperative follow-up. Davis et al.²⁷ followed 50 patients undergoing PSF treatment of SBME of the knee with an average follow-up of 14.6 months and found that 48% of patients required additional intervention for recurrent knee pain. Thirty-six percent of patients in that study cohort required corticosteroid or hyaluronic injections and 8% underwent TKA, which are greater than the 17.6% of patients receiving injections and 6.8% of patients converted to arthroplasty in our study over a 2-year period. Cohen and Sharkey⁴ published

Table 3. The cohort distribution of Outerbridge articular cartilage classification in the affected SBME-containing joint compartment.

Outerbridge 0	1 (1%)
Outerbridge 1	3 (4%)
Outerbridge 2	8 (11%)
Outerbridge 3	28 (38%)
Outerbridge 4	34 (46%)

SBME, subchondral bone marrow edema.

Table 4. An Overview of the 13 Patients Who Required Additional Intervention After PSF

Patient	BMI	Outerbridge Grade	Cortisone	Hyaluronic Acid	Arthroplasty	Time to Conversion, mo
1	30.6	3	X			
2	31.1	4	X	X	X TKA	13
3	34.7	4	X	X	X UKA	9
4	34.6	3		X		
5	29.3	2	X			
6	26.2	3	X	X		
7	27.8	3	X	X		
8	28.4	3		X		
9	38.4	4		X	X UKA	8
10	33.4	3		X	X TKA	12
11	40.6	4		X	X TKA	9
12	30.3	4	X	X		
13	32.7	3	X	X		

BMI, body mass index; PSF, percutaneous skeletal fixation; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

their findings evaluating outcomes after PSF treatment of painful SBME, noting a 30% conversion rate to TKA and mean improvement in VAS pain score of 4.5 points in patients with at least 2 years of follow-up. This is similar to the decrease in average VAS pain score of 4.39 points found in our study; however, Cohen and Sharkey noted a conversion rate to TKA much higher than the 6.8% found in our cohort. Of note, all patients in the study performed by Cohen and Sharkey⁴ had met indications for arthroplasty and presented to the authors' offices for the purpose of discussion of TKA or unicompartmental knee arthroplasty. This may have biased patients to be more willing to consider arthroplasty than those who had not been sent to a surgeon for the purpose of undergoing TKA or unicompartmental knee arthroplasty.

Arthroscopic evaluation of knee cartilage found at the time of surgery demonstrated a high average Outerbridge classification of 3.31 among the 13 patients who did not respond to PSF. It is somewhat intuitive that patients with a greater degree of chondromalacia as described by the Outerbridge classification may be more likely to be nonresponsive to PSF treatment of knee pain; however, this correlation was not proven statistically in this study. Interestingly, the only patient in our study with an Outerbridge classification of 0 was found to possess a large, atraumatic region of medial femoral condyle SBME upon initial presentation. This patient was treated with 6 months of conservative care as described earlier, followed by a repeat MRI for persistent symptoms that demonstrated an enlarged region of edema. Despite this increase in SBME size, the patient was subsequently treated with PSF and experienced successful relief of all symptoms.

PSF is a safe and effective surgical option for management of painful SBME of the knee with very few noted complications specific to this procedure. Evidence to support the safety of this procedure is reflected in our study in which no intraoperative or postoperative

complications were noted among all 74 patients over a 2-year postoperative interval. This low incidence of surgical complications is corroborated throughout current literature, including one study in which noted complications of 66 patients undergoing PSF for treatment of SBME of the knee included 1 patient with postoperative drainage and 1 patient with a DVT of the ipsilateral leg.⁴ Similarly, a study in 2018 using PubMed and Medline to evaluate current literature regarding PSF management of SBME found evidence of 2 patients experiencing intraarticular cement extravasation, 1 patient with a DVT of the affected limb, and no reports of infection across 8 different studies evaluated.²⁴ A direct statistical comparison of the incidence of postoperative complications after PSF and TKA was not performed, however, this evidence acknowledges the low risk of complications to which patients may be subjected when undergoing PSF.

Our study contributes to the current knowledge of PSF in the management of painful SBME of the knee. We followed patients for a total of 2 years to determine the success of PSF in the prevention of any additional intervention. We theorized that we were able to obtain outcomes superior to those in previously referenced studies due to a number of factors. Our patient cohort included a younger overall population than in previous reports. The average age of patients undergoing PSF in our study was 47.0 years at the date of surgery, as compared with the average age of 55.9 years in the study by Cohen and Sharkey.⁴ Younger patients may be more active and motivated to avoid the extended postoperative recovery time and limitations associated with arthroplasty in favor of a procedure with fewer postoperative restrictions and complications. This is especially relevant to the 11 patients in our study who were active-duty military, with only 1 requiring additional intervention at 2-year follow-up. Analysis of the 13 patients who required additional intervention demonstrated a significantly greater average BMI

compared with that of the success group ($P = .001$). This indicates the possibility of a correlation between increasing BMI and failure of PSF; however, this would require further statistical analysis to establish. Finally, the authors strongly believe that limiting the volume of calcium phosphate injected into the area of edema has an effect on clinical outcomes. In our patient cohort, regions of edema in the femur and tibia were filled with an average of 2.6 cc and 1.8 cc, respectively. The purpose of PSF is to fill the region of edema with enough calcium phosphate to support the deficient subchondral bone and allow for an environment of bone healing and remodeling.^{4,28} Care should be taken to avoid over-compression of calcium phosphate cement into the subchondral bone. As has been found in the lead surgeon's anecdotal experience, overfilling the defect may be associated with increased immediate postoperative pain and a theorized increased risk of fracture. For this reason, the lead surgeon firmly believes that avoidance of overfilling of the SBME is critical to the overall success of the procedure and filling of the lesions in our study was halted once tactile feedback of pressure was felt by the operative surgeon. Future studies evaluating the impact of the volume of calcium phosphate injected on the outcomes of PSF are required for validation of these anecdotal observations.

The current study acts to provide valuable insight into the success that may be afforded patients treated for painful SBME, as well as a future direction of research regarding the evaluation of PSF management for this pathology. This includes identification of patient-specific predictors of success via determination of the impact of patient age, sex, BMI, and SBME location on the success rate of PSF. It is important to identify these factors in order to better isolate which patients may expect acceptable outcomes after undergoing PSF treatment of painful SBME of the knee.

Limitations

Our study is not without limitations. First, it is limited by its retrospective design whereby important data are absent. Of note, we were not able to include the indications for the additional interventions even though these interventions were a focus of our study. Next, determination of preoperative indication for PSF and performance of all procedures by a single surgeon may subject our results to selection bias; however, following a single technique may help to make our results more reproducible. In addition, not all patients had followed up in the office 2 years after surgery. This necessitated a phone call at the 2-year postoperative mark to obtain VAS pain scores and inquire about additional intervention for knee pain, resulting in possible recall bias. Furthermore, we did not record the length of time from the date of PSF to the date at which patients underwent injection with viscosupplementation or corticosteroids.

In addition, during the time period in which this study took place neither the lead author nor his partners were performing joint surface unloading osteotomies. Further analysis of the 5 patients who went on to arthroplasty revealed that all 5 had varus malalignment, with an average of 9° (range 4° - 13°). Finally, without a control group or comparison group with which to compare our cohort, we can use our data only to report outcomes and are unable to state whether PSF provides superior results to other treatments for knee pain aimed at preventing arthroplasty.

Conclusions

Patients undergoing PSF for the treatment of painful SBME may expect a decrease in knee pain and low rates of additional intervention over a 2-year postoperative period.

References

1. Eriksen EF. Treatment of bone marrow lesions (bone marrow edema). *BoneKey Rep* 2015;4:755.
2. Beckwée D, Vaes P, Shahabpour M, Muylldermans R, Rommers N, Bautmans I. The influence of joint loading on bone marrow lesions in the knee: A systematic review with meta-analysis. *Am J Sports Med* 2015;43:3093-3107.
3. Scher C, Craig J, Nelson F. Bone marrow edema in the knee in osteoarthritis and association with total knee arthroplasty within a three-year follow-up. *Skeletal Radiol* 2008;37:609-617.
4. Cohen SB, Sharkey PF. Subchondroplasty for treating bone marrow lesions. *J Knee Surg* 2016;29:555-563.
5. Kon E, Ronga M, Filardo G, et al. Bone marrow lesions and subchondral bone pathology of the knee. *Knee Surg Sports Traumatol Arthrosc* 2016;24:1797-1814.
6. Thiryayi WA, Thiryayi SA, Freemont AJ. Histopathological perspective on bone marrow oedema, reactive bone change and haemorrhage. *Eur J Radiol* 2008;67:62-67.
7. Taljanovic MS, Graham AR, Benjamin JB, et al. Bone marrow edema pattern in advanced hip osteoarthritis: Quantitative assessment with magnetic resonance imaging and correlation with clinical examination, radiographic findings, and histopathology. *Skeletal Radiol* 2008;37:423-431.
8. Eriksen EF, Ringe JD. Bone marrow lesions: A universal bone response to injury? *Rheumatol Int* 2012;32:575-584.
9. 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.
10. Bonadio MB, Giglio PN, Helito CP, Pécora JR, Camanho GL, Demange MK. Subchondroplasty for treating bone marrow lesions in the knee—initial experience. *Rev Bras Ortop* 2017;52:325-330.
11. Roemer FW, Neogi T, Nevitt MC, et al. Subchondral bone marrow lesions are highly associated with, and predict subchondral bone attrition longitudinally: The MOST study. *Osteoarthritis Cartilage* 2010;18:47.
12. Sowers MF, Hayes C, Jamadar D, et al. Magnetic resonance-detected subchondral bone marrow and cartilage defect characteristics associated with pain

- and X-ray-defined knee osteoarthritis. *Osteoarthritis Cartilage* 2003;11:387-393.
13. Tanamas SK, Wluka AE, Pelletier J-P, et al. Bone marrow lesions in people with knee osteoarthritis predict progression of disease and joint replacement: A longitudinal study. *Rheumatology* 2010;49:2413-2419.
 14. Wluka AE, Wang Y, Davies-Tuck M, English DR, Giles GG, Cicuttini FM. Bone marrow lesions predict progression of cartilage defects and loss of cartilage volume in healthy middle-aged adults without knee pain over 2 yrs. *Rheumatology* 2008;47:1392-1396.
 15. Richmond J, Hunter D, Irrgang J, et al. Treatment of osteoarthritis of the knee (nonarthroplasty). *J Am Acad Orthop Surg* 2009;17:591-600.
 16. Nevalainen MT, Sharkey PF, Cohen SB, Roedl JB, Zoga AC, Morrison WB. MRI findings of subchondroplasty of the knee: A two-case report. *Clin Imaging* 2016;40:241-243.
 17. Nielsen FK, Boesen M, Jurik AG, et al. The effect of intra-articular glucocorticosteroids and exercise on symptoms and bone marrow lesions in knee osteoarthritis: A secondary analysis of results from a randomized controlled trial. *Osteoarthritis Cartilage* 2018;26:895-902.
 18. Beswick AD, Wylde V, Goberman-Hill R, Blom A, Dieppe P. What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. *BMJ Open* 2012;2.
 19. Franklin PD, Li W, Ayers DC. The Chitranjan Ranawat Award. *Clin Orthop* 2008;466:2597-2604.
 20. Mizner RL, Petterson SC, Clements KE, Zeni JA, Irrgang J, Snyder-Mackler L. Measuring functional improvement after total knee arthroplasty requires both performance-based and patient-report assessments: A longitudinal analysis of outcomes. *J Arthroplasty* 2011;26:728-737.
 21. Harrysson OLA, Robertsson O, Nayfeh JF. Higher cumulative revision rate of knee arthroplasties in younger patients with osteoarthritis. *Clin Orthop* 2004;421:162-168.
 22. Lonner JH, Hershman S, Mont M, Lotke PA. Total knee arthroplasty in patients 40 years of age and younger with osteoarthritis. *Clin Orthop* 2000;380:85-90.
 23. 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.
 24. Astur DC, de Freitas EV, Cabral PB, et al. Evaluation and management of subchondral calcium phosphate injection technique to treat bone marrow lesion. *Cartilage* 2019;10:395-401.
 25. Pannell WC, Heidari KS, Mayer EN, et al. High tibial osteotomy survivorship: A population-based study. *Orthop J Sports Med* 2019;7:2325967119890693.
 26. Niinimäki TT, Eskelinen A, Mann BS, Junnila M, Ohtonen P, Leppilahti J. Survivorship of high tibial osteotomy in the treatment of osteoarthritis of the knee: Finnish registry-based study of 3195 knees. *J Bone Joint Surg Br* 2012;94:1517-1521.
 27. Davis AT, Byrd JM, Zenner JA, Frank DA, DeMeo PJ, Akhavan S. Short-term outcomes of the subchondroplasty procedure for the treatment of bone marrow edema lesions in patients with knee osteoarthritis. *Orthop J Sports Med* 2015;3(7_suppl2):2325967115S00125.
 28. 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.