7 Intraosseous Bioplasty of the Lateral Femoral Condyle of the Knee for Osteonecrosis

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Introduction

The subchondral bone plays a critical biomechanical role in knee homeostasis by providing structural support to the overlying articular cartilage. The presence of altered joint mechanics may cause both acute and chronic areas of increased focal stress and subsequent bone marrow edema (BME). Additional causes of BME may be acute or repetitive trauma, insufficiency fractures, osteoarthritis, and osteonecrosis. The pathophysiology of BME has been well-described, and the increased intraosseous pressure (IOP) results in subsequent decreased perfusion of subchondral bone [1]. The limited blood supply in these regions compromises the ability to heal. The subchondral ischemia coupled with increased focal stress results in high bone turnover and abnormal remodeling with subsequent attritional bone loss.

Osteonecrosis may be challenging to diagnose since standard knee radiographs often fail to demonstrate any signs of the subchondral bone pathology in the early stages (Fig. 7.1). In more advanced cases, subchondral sclerosis and collapse, along with joint space narrowing are more recognizable findings. Once the disease has progressed to the late stages, only osteochondral and arthroplasty reconstructive treatment options remain. Optimal treatment of osteonecrosis requires early recognition to allow for potential biologic restoration. Magnetic resonance imaging (MRI) is excellent for detecting the increased water content associated with marrow edema and is subsequently the imaging modality of choice for timely detection and detailed evaluation of osteonecrosis.

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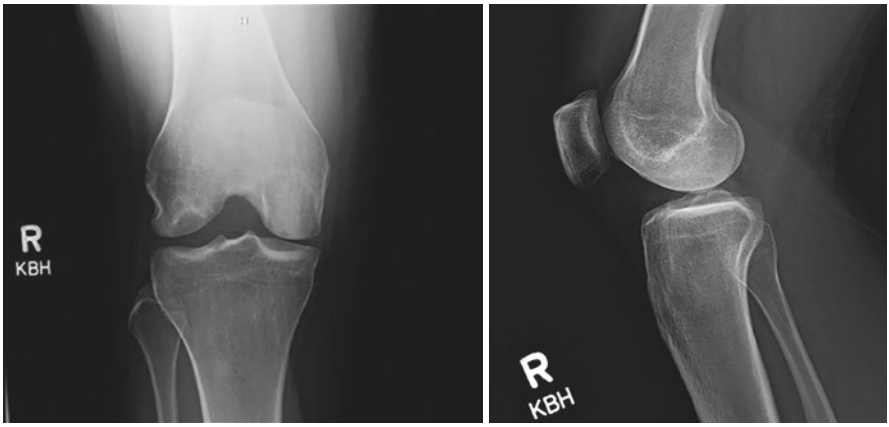

Fig. 7.1 AP and lateral radiograph of right knee demonstrating lytic lesion in lateral femoral condyle in a patient with secondary osteonecrosis

Patients with focal subchondral osteonecrotic lesions, without disruption of the articular cartilage or subchondral collapse, may be candidates for intraosseous bioplasty. The goal of this minimally invasive biologic treatment is to address the subchondral bone defects by reducing IOP, returning blood supply, and promoting bone remodeling. This technique utilizes fluoroscopic guidance to target the bone marrow lesion seen on MRI. Decompression of the lesion is followed by the injection of a combination of bone marrow aspirate concentrate (BMAC) and either autologous bone graft or allograft such as a demineralized bone matrix. This mixture delivers the osteoinductive, osteoconductive, and osteogenic factors necessary to promote bone healing and remodeling in an effort to diminish the patient's symptoms.

Indications/Contraindications

Bioplasty of the knee may be indicated for the treatment of numerous disorders of the knee, but the common finding in this diverse group of pathologies is BME. Although our description focuses on osteonecrosis of the knee, the intraosseous bioplasty technique may be applicable to other disorders of the knee that cause BME and the associated symptoms. The goal of this biologic treatment is to reduce symptoms of pain and ideally return patients to previous levels of function and allow them to lead an active lifestyle. This is especially important in younger, more active patients who wish to postpone joint arthroplasty.

Osteonecrosis of the knee was first described by Ahlback et al. in 1968 and can be a rapidly progressing disease that leads to end-stage arthritis [2]. The knee is the most common joint affected after the hip. Osteonecrosis of the knee is generally categorized into three types: primary or spontaneous osteonecrosis of the knee

(SONK), secondary (atraumatic, ischemic, or idiopathic osteonecrosis), and post-arthroscopic.

SONK is the most common form of osteonecrosis with the majority of patients being above 60 years of age. It is most often unilateral and affects women more than men. The prevalence is thought to be underestimated as many patients with end-stage osteoarthritis may have had undiagnosed SONK. It is believed to result from subchondral insufficiency fractures in osteopenic bone, leading to fluid accumulation, focal ischemia, and subsequent necrosis. The medial femoral condyle is most often affected due to the diminished extraosseous and intraosseous blood supply compared to the lateral femoral condyle [3].

Secondary osteonecrosis usually involves both condyles of the femur, and the opposite knee is involved 80% of the time [4]. Approximately 90% of cases are associated with alcohol abuse and corticosteroid use [5]. The pathophysiology is believed to be an increase in adipocyte size and number within the bone, leading to the displacement of the bone marrow. This increased pressure leads to vascular collapse and resultant ischemia [6]. The severity of osteonecrosis has been classified, and radiographs of Ficat stage I and II will have a normal joint space with no evidence of subchondral collapse. Stage II will show sclerosis in the trabeculae of the subchondral region. Stage III demonstrates a slightly narrowed joint space with some collapse of the subchondral bone and a crescent sign. Stage IV has a more significant joint-space narrowing, subchondral collapse, and further secondary degenerative changes [7] (Fig. 7.2). MRI is used to evaluate the progression of osteonecrosis and often demonstrates serpentine lesions with a well-demarcated border along with multiple foci of marrow involvement with extension into the metaphysis and diaphysis.

The reported incidence of post-arthroscopic osteonecrosis was found to be 4% by Cetik et al. with the medial femoral condyle comprising 82% of cases [8]. It has been proposed by Pape and colleagues that meniscectomized knee compartments undergo altered biomechanics and hoop stresses causing increased focal contact pressures which lead to insufficiency fractures with eventual necrosis [9].

Nonoperative treatment consists of medications, intra-articular injections, physical therapy, unloader braces, and activity modifications. Numerous surgical procedures have been proposed for patients that fail to improve after a trial of non-operative

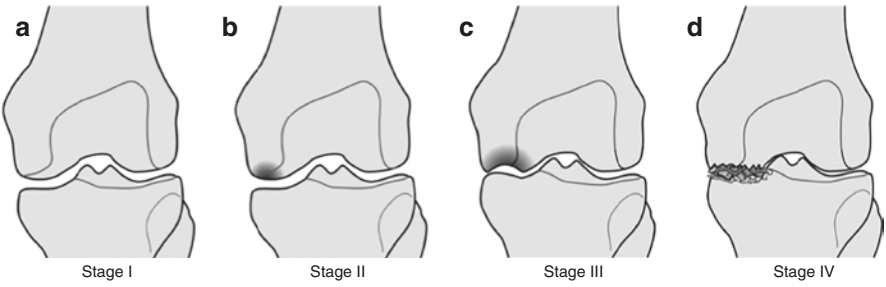

Fig. 7.2 (**a**–**d**) Ficat staging of osteonecrosis of the knee [7]

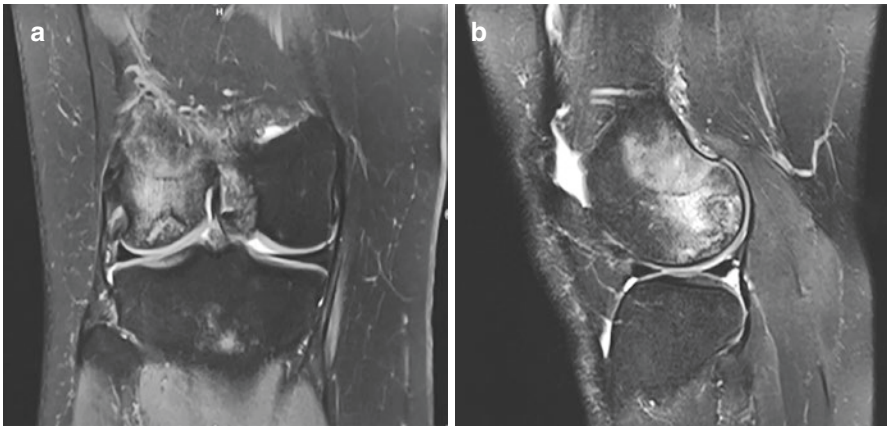

Fig. 7.3 Coronal (**a**) and sagittal (**b**) T2 fat-suppressed MRI image of the right knee demonstrating subchondral lesion with surrounding bone marrow edema in the lateral femoral condyle. As a result of increased water content, bone marrow edema on MRI demonstrates a hyperintense marrow signal on fluid sensitive, fat-suppressed sequences

treatment. Patients with radiographs and an MRI that demonstrate a focal lesion of subchondral BME without collapse are excellent candidates for intraosseous bioplasty (Fig. 7.3). This minimally invasive technique allows for concomitant arthroscopy to address intra-articular pathology such as meniscal tears or loose bodies. While a high tibial osteotomy alone has been advocated in the past to unload the affected condyle, bioplasty has the advantages of being a less-invasive and a less-morbid option. Patients with the collapse of the subchondral bone or cartilage loss are not indicated for bioplasty and may be more appropriate for osteochondral restoration or arthroplasty.

Technique

Positioning

The patient is positioned supine on the operating room table using the standard knee arthroscopy set-up. The operative leg is placed in a knee arthroscopy leg holder with a well-padded tourniquet proximally. The tourniquet is not initially inflated nor is the leg holder tightened to ensure adequate bone marrow aspirate.

Bone Marrow Aspiration

Bone marrow aspirate is initially harvested from the proximal tibia using a bone marrow trocar (Arthrex, Naples, FL). A stab incision is made just lateral to the tibial tubercle, and the trocar is advanced by hand approximately 3 cm past the cortex into

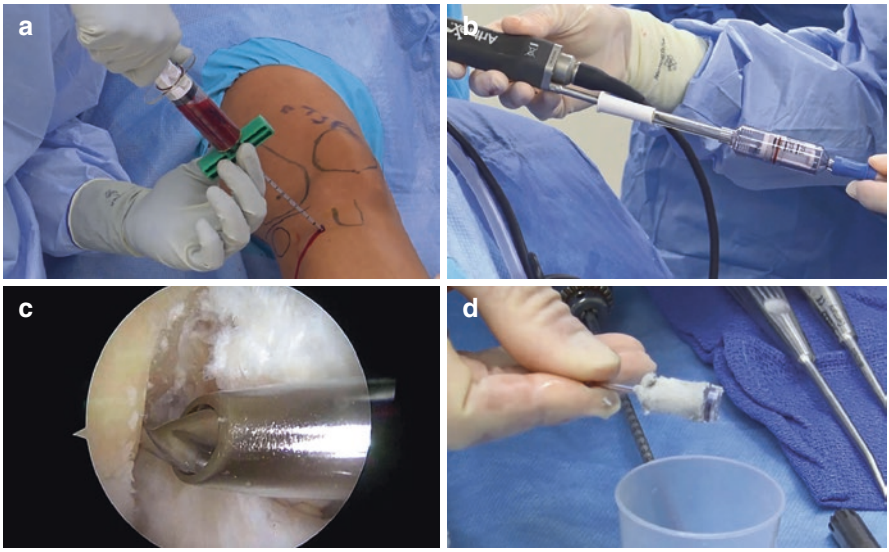

Fig. 7.4 (**a**) Bone marrow aspirate being obtained from the proximal tibia. (**b**) GraftNet autologous bone graft collection device attached to the arthroscopic shaver. (**c**) Arthroscopic image of bone being harvested from lateral femoral condyle. (**d**) Collected bone graft

the tibia. The trocar is calibrated so that distance from the cortex to the skin is recorded to ensure that the trocar is not advanced too deep. The stylus is removed, and a 30-cc syringe is secured on to the trocar and used to harvest the bone marrow aspirate. To aid in aspiration, the trocar may be periodically rotated 90° and slightly withdrawn to improve the harvest (Fig. 7.4a). The trocar may also be redirected through the same cortical hole to access additional bone marrow. Once the second syringe of bone marrow aspirate is obtained, the trocar is withdrawn and the aspirate is passed off the back table and prepared in the Angel bone marrow aspirate processing system (Arthrex).

Knee Arthroscopy and Bone Graft Harvest

Attention is then turned to arthroscopy of the knee. The leg is elevated and exsanguinated, the tourniquet is inflated, and the leg holder is tightened. A diagnostic arthroscopy is undertaken to evaluate the integrity of the articular cartilage covering the area of subchondral osteonecrosis as well as any concomitant pathology. Once the diagnostic portion of the arthroscopy has been completed and confirmation of healthy and stable cartilage is confirmed, attention is turned to the harvest of the autologous bone graft. Our preference is to harvest the bone graft arthroscopically from the lateral wall and roof of the notch of the knee using a burr (Arthrex) (Fig. 7.4c). The cartilage and soft tissue are removed from the harvest site, and care is taken to avoid iatrogenic injury to the insertion of the cruciate ligaments. Once the

bone is exposed, the GraftNet (Arthrex) is applied to the shaver to collect the morselized bone (Fig. 7.4b). We would recommend harvesting approximately 3–4 cc of bone graft to be mixed with the BMAC. The bone graft is removed from the GraftNet and placed into the delivery and mixing syringe (Arthrex) to be combined with the BMAC (Fig. 7.4d). In the case of insufficient bone graft harvest, a demineralized bone matrix may be added to increase volume. The BMAC is combined with the bone graft to create a mixture consistent with "slush" (Fig. 7.5a). We prefer a ratio of 5 cc of bone graft to 4 cc of BMAC to ensure adequate viscosity for injection. One milliliter of radiopaque dye may be added to the mix to aid in fluoroscopic visualization and confirmation of adequate fill.

Bioplasty Technique

The region of subchondral osteonecrosis is customarily approached from the corresponding side of the femoral condyle using a percutaneous approach. The preoperative MRI is useful to have available in the operating room, but fluoroscopy is always used to confirm localization. A spinal needle is utilized to place the tip on the cortex to localize the subchondral osteonecrotic lesion under fluoroscopy. This is followed by a percutaneous incision and subsequent drilling of a 2.4-mm guidewire (Arthex) into the lesion (Fig. 7.5c). Once the placement of the guidewire is confirmed with fluoroscopy, a 7-mm cannulated reamer (Arthrex) is used to complete the core

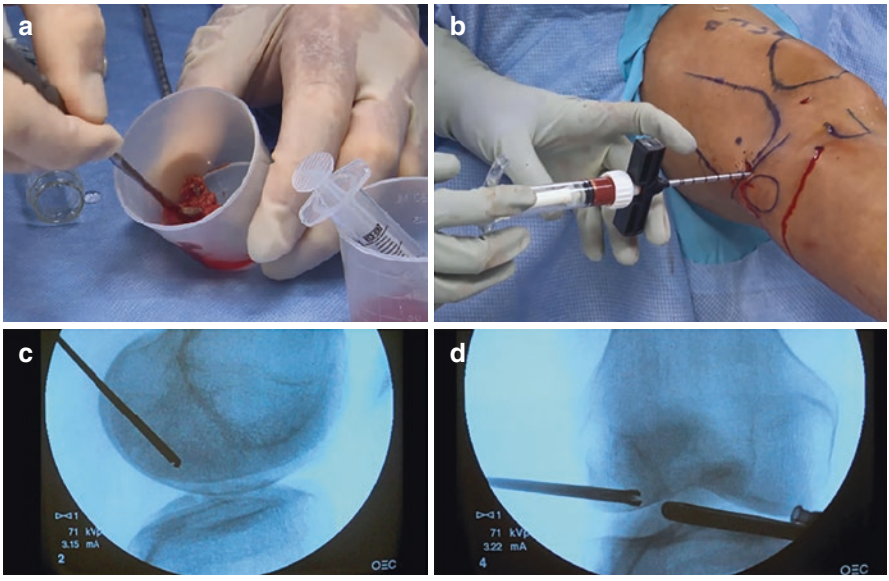

Fig. 7.5 (**a**) BMAC has been combined with bone autograft. (**b**) Biologic injection of BMAC and bone autograft placed in the lesion. Correct placement of injection is confirmed with the use of fluoroscopy (**c**, **d**)

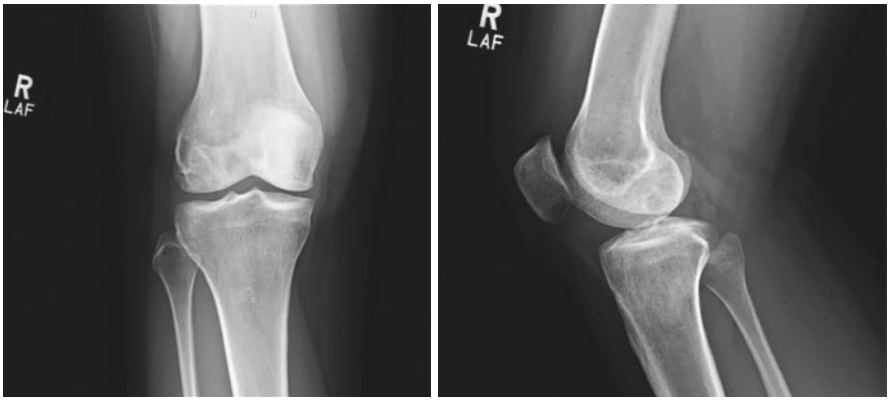

Fig. 7.6 AP and lateral radiograph of right knee demonstrating lesion in lateral femoral condyle approximately 4 months after bioplasty procedure for secondary osteonecrosis

decompression (Fig. 7.5d). Although fluoroscopic verification is essential, we recommend arthroscopic visualization of the cartilage surface during core decompression to ensure that the reamer does not violate the articular cartilage. The reamer is removed from the knee, leaving the guidewire in place. The inner style of the delivery cannula is removed, and the cannula is advanced over the guidewire. Once the delivery cannula position is confirmed under fluoroscopy, the guide wire is removed, and the mixing syringe is placed on to the back of the trocar (Fig. 7.5b). During injection, the trocar is slowly removed to ensure a complete fill of the core decompression void. Figure 7.6 demonstrates radiographs of the same lateral femoral condyle lesion as seen in Fig. 7.1 approximately 4 months after the bioplasty procedure.

We endorse the addition of radiopaque dye into the mixture to aid in fluoroscopic confirmation. If notable resistance is encountered with attempted injection, the BioXpress cannula (Arthrex) may be used to decrease resistance as it has a larger delivery diameter.

Discussion

Osteonecrosis of the hip in the young patient has been well studied, and current recommendations are for early diagnosis and treatment to avoid the catastrophic consequence of collapse of the articular cartilage and subsequent need for arthroplasty [10]. Similar to the hip, osteonecrosis of the knee is now more commonly recognized as a source of pain and disability. The pathophysiology is thought to be due to a decreased blood supply to the subchondral region of the bone and subsequent microfracture of trabecular bone. It is well documented that both the activity and number of mesenchymal stem cells in the hematopoietic and stromal compartments of the bone marrow are decreased in patients with osteonecrosis [10].

Historically, the gold standard surgical procedure for early-stage osteonecrosis of the femoral head was core decompression. More recently, core decompression

has been combined with injection of autologous bone marrow cells with good results [11, 12]. At a 5-year follow-up, 8 of 11 patients treated with decompression only went on to hip replacement compared to only 3 out of 13 treated with decompression and injection of bone marrow cells [13]. A randomized controlled trial performed by Ma et al. in 2014 demonstrated no progression of osteonecrosis in 100% of Ficat stage 1 and 2 patients in the treatment group and 66% in the control group treated without bone marrow cell implantation at 2-year follow-up [14]. Successful outcomes for the treatment of osteonecrosis in the hip have influenced the evolution of the development of the intraosseous bioplasty technique for the treatment of bone marrow lesions in the knee.

Core decompression for the treatment of osteonecrosis in the knee was first described in 1989 by Jacobs et al. They performed 28 core decompressions of the distal femur for avascular necrosis over a 7-year period and had a mean follow-up of 54 months. All 7 patients with Ficat stages I and II had good results. Of the 21 patients in stage III, 11 cases had good results, 4 had poor results, and 6 progressed to total knee replacement [15]. Even without the added benefit of BMAC and autograft bone, Marulanda et al. reported a 92% success rate with percutaneous decompression combined with limited weight-bearing for 4–6 weeks in secondary osteonecrosis [16]. Mont et al. presented their results of core decompression compared to protected weight bearing in 79 knees with osteonecrosis due to corticosteroid use. A subset of 26 knees from each group was matched for age, gender, diagnosis, Ficat and Arlet Stage, and length of follow-up. The matched protected weight-bearing group had 23% survival as compared with 74% survival in the core decompression group, and they concluded that surgical treatment may slow the rate of symptomatic progression of avascular necrosis of the knee and delay the need for more extensive procedures such as total knee arthroplasty [17].

Bone marrow edema in the knee has been strongly associated with pain, decreased function, cartilage damage, and progression to knee replacement [18, 19]. Previous studies have determined that IOP is approximately 97% higher in patients with BME versus those without and that increased IOP is associated with an increase in knee pain [20, 21]. In 2019, Kasik et al. initially published a case series of patients undergoing bioplasty in the knee for bone marrow edema [22]. They demonstrated statistically significant improvement in both visual analog scale (VAS) and International Knee Documentation Committee (IKDC) scores in 19 of 20 patients. They reported on 14 patients at 1-year follow-up, and only 1 required an arthroplasty procedure. Although all of these patients had concomitant pathology addressed at the time of the procedure (partial medial meniscectomy [70%], chondroplasty [25%], and partial lateral meniscectomy [20%]), short-term results are encouraging. Bioplasty has also been described in the treatment of subchondral cysts in both the lateral femoral condyle and lateral tibial plateau [23, 24]. Its use is also being studied in the capitellum, talus, patella, and proximal humerus. Additional long-term studies are necessary to provide affirmation of the efficacy of intraosseous bioplasty in the knee for the treatment of bone marrow lesions.

Utilizing intraosseous bioplasty in the treatment of focal subchondral osteonecrotic lesions of the knee has a distinct set of advantages over previously described more invasive techniques utilizing an arthrotomy or osteotomy. The entire procedure is performed through arthroscopic portals and percutaneous incisions. The bone marrow is aspirated from the proximal tibia, simplifying both prepping and draping, without the need to access the iliac crest. The use of BMAC provides osteoinductive factors and osteogenic stem cells, which are not found with simple decompression procedures. The ability to harvest the autologous bone graft arthroscopically using the burr and GraftNet is less invasive and morselizes the bone graft which allows easy delivery without the need for manual compression. Delivery of an osteoconductive scaffold along with osteoinductive factors into the previously decompressed lesion provides potential for more rapid incorporation compared to allograft or demineralized bone matrix.

Arthroscopic autograft harvest from the lateral femoral condyle has some distinct disadvantages. Graft harvest morbidity is always a concern, although our technique minimizes this risk by avoiding violation of the articular cartilage. The limited amount of graft that can be harvested arthroscopically may be problematic depending on the size of the lesion. We recommend augmentation with a demineralized bone matrix if the need arises. Special care should be taken to avoid iatrogenic damage to the cruciate ligament insertions during harvest and intermittently probing to monitor is recommended. Cost is also a concern, and the use of both the Arthrex GraftNet and Angel systems, in addition to the possible allograft, may be cost-prohibitive in an outpatient setting.

Editor's View

AVN and bone marrow lesions are difficult issues to treat because of poor biology. In this technique, we counteract that biology with the addition of the latest orthobiologics available. It is a straightforward technique for harvesting and delivery. It is a great option now to add in autograft tissue as seen here to perform the bioplasty in the hope we improve outcomes for this condition.

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