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CURRENT CONCEPTS REVIEW

Management of Articular Cartilage Defects of the Knee

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- Articular cartilage has a poor intrinsic capacity for healing. The goal of surgical techniques to repair articular cartilage injuries is to achieve the regeneration of organized hyaline cartilage.
- Microfracture and other bone marrow stimulation techniques involve penetration of the subchondral plate in order to recruit mesenchymal stem cells into the chondral defect. The formation of a stable clot that fills the lesion is of paramount importance to achieve a successful outcome.
- Mosaicplasty is a viable option with which to address osteochondral lesions of the knee and offers the advantage of transplanting hyaline cartilage. However, limited graft availability and donor site morbidity are concerns.
- Transplantation of an osteochondral allograft consisting of intact, viable articular cartilage and its underlying subchondral bone offers the ability to address large osteochondral defects of the knee, including those involving an entire compartment.
- The primary theoretical advantage of autologous chondrocyte implantation is the development of hyaline-like cartilage rather than fibrocartilage in the defect, which presumably leads to better long-term outcomes and longevity of the healing tissue.
- Use of synthetic scaffolds is a potentially attractive alternative to traditional cartilage procedures as they are readily available and, unlike allogeneic tissue transplants, are associated with no risk of disease transmission. Their efficacy, however, has not been proven clinically.

The management of articular cartilage defects continues to be one of the most challenging clinical problems for orthopaedic surgeons. Articular cartilage is a highly organized tissue with complex biomechanical properties and substantial durability[1]. However, it has a poor intrinsic capacity for healing, and damage from trauma or degeneration can result in morbidity and functional impairment[2]. Untreated lesions can lead to debilitating joint pain, dysfunction, and degenerative arthritis.

Cartilage repair strategies include débridement; bone marrow stimulation; and cell-based, cell plus scaffold-based, and whole-tissue transplantation techniques[3]. In this review, we discuss the basic science, indications, advantages, shortcomings, and outcomes of each of these interventions in order to provide an evidence-based assessment for the treatment of these conditions.

Bone Marrow Stimulation: Microfracture

Bone marrow stimulation is the most frequently used technique for treating small symptomatic lesions of the articular cartilage in the knee. These procedures are technically straightforward, and the costs are low compared with those of other treatment modalities. Bone marrow stimulation techniques involve perforation of the subchondral plate in order to recruit mesenchymal stem cells from the bone marrow space into the lesion[4,5]. The mesenchymal stem cells are able to differentiate into fibrochondrocytes, which contribute to fibrocartilage repair of the lesion. However, the overall concentration of the mesenchymal stem cells is quite low and declines with age[6]. The formation of a stable blood clot that maximally fills the chondral defect is important, and it has been correlated with the success of bone marrow stimulation procedures[7]. Unstable

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clots that are only partially adherent to or fill only a portion of the defect will result in suboptimal repair[7].

Reparative fibrocartilage consists of type-I, type-II, and type-III collagen in varying amounts[8,9]. The fibrocartilage does not resemble the surrounding hyaline cartilage and has less type-II collagen. Unlike other cartilage restoration techniques, bone marrow stimulation does not involve transfer of chondrocytes into the lesion.

Creating a contained lesion is critical to achieving a stable base for filling the defect with a clot and adhesion of the clot. If the lesion is not shouldered by a stable rim of healthy cartilage, achieving a stable clot may be more difficult[10-12]. The calcified cartilage layer at the base of the lesion must be removed as well (Figs. 1-A through 1-D). Removal of this layer is important for clot adhesion and the ultimate success of the microfracture technique[13]. The prepared channels must be of sufficient depth to ensure penetration of the subchondral plate and communication with the marrow. Fatty droplets should be seen to emanate from the channel apertures to confirm that adequate depth has been achieved.

The postoperative regimen after bone marrow stimulation procedures is demanding and has been reported to be a critical aspect of the ultimate efficacy[14]. Patients with a femoral condylar lesion are initially treated with continuous passive motion with a 0° to 60° range of motion for six weeks postoperatively[15]. Studies have shown that continuous passive motion improves cartilage nutrition and stimulates mesenchymal stem-cell differentiation[16-19]. The patient typically remains non-weight-bearing with the use of crutches for six weeks. Patients who have undergone microfracture of a patellar or trochlear defect are allowed to bear weight as tolerated postoperatively, but knee motion is restricted from 0° to 40° in a brace[20,21]. Continuous passive motion is initiated immediately and used, within this arc of motion, for approximately six to eight hours daily. At two months, unrestricted motion is typically allowed and closed-chain exercises are initiated. Short-arc closed-chain concentric and eccentric muscle strengthening is effective and protects the patellofemoral articulation. Typically, a return to full activities is permitted at three months after a full, painless range of motion is achieved[20,21].

Outcomes (See Appendix)

Steadman et al. reported what we believe to be the first long-term follow-up study of microfracture, in which seventy-one knees were followed for an average of eleven years[20]. The patients all had a traumatic full-thickness chondral defect, had no meniscal or ligament injury, and were less than forty-five years of age. At the time of final follow-up, the patients had significant improvement in multiple clinical outcome measures ($p < 0.02$). The authors found that age was an independent predictor of functional improvement. Mithoefer et al. performed a prospective study of forty-eight patients (mean age, forty-two years) a mean of 3.6 years following the operation[22]. Most of the lesions (52%) were between 1 and 4 cm^2. Overall, knee function was good to excellent in thirty-two (67%) of the forty-eight patients, fair in twelve (25%), and poor in four (8%). The authors found that a lower body mass index correlated with better outcomes. Magnetic resonance imaging showed that 54% of the patients had good fill with repair tissue, 29% had moderate fill, and 17% had poor fill. The grade of fill on magnetic resonance imaging correlated with better clinical outcomes[12].

Microfracture has been compared with other cartilage restoration procedures in multiple well-designed, randomized studies. Knutsen et al. compared autologous chondrocyte implantation with microfracture in eighty patients with an average age of 32.2 years[23]. The average lesion size was 4.8 cm^2. After two years of follow-up, both groups had significant clinical improvement ($p < 0.05$). The Short Form-36 (SF-36) score, however, was significantly better in the microfracture group ($p = 0.004$). Histological assessment demonstrated hyaline-like or mixed hyaline/fibrocartilage-like tissue in 29% of the patients in the microfracture group and 50% of those in the group treated with autologous chondrocyte implantation. There was, however, a 23% failure rate with both procedures.

Gudas et al. compared the outcomes of osteochondral autologous transplantation with those of microfracture in young athletes in a randomized, controlled study[24]. Fifty-seven patients (twenty-eight treated with osteochondral autologous transplantation and twenty-nine treated with microfracture) were available at the time of final follow-up. The average age was 24.3 years, and the average lesion size was 2.8 cm^2 (range, 1 to 4 cm^2). At a mean of thirty-seven months postoperatively, both groups had substantial clinical improvement. However, on the basis of Hospital for Special Surgery (HSS) and International Cartilage Repair Society (ICRS) scores, 96% had a good-to-excellent result after the osteochondral autologous transplantation compared with 52% after the microfracture procedure. Biopsy specimens were obtained from 58% of the patients and histological evaluation of repair showed better ICRS scores for the group treated with osteochondral autologous transplantation. In addition, subjective evaluation of lesion fill, osseous incorporation, and surface congruency with magnetic resonance imaging showed good-to-excellent repair in 94% of the patients treated with osteochondral autologous transplantation compared with only 49% of those treated with microfracture. Twenty-six (93%) of the patients treated with osteochondral autologous transplantation and fifteen (52%) of those treated with microfracture returned to sports activities at their preinjury level at an average of 6.5 months. The authors concluded that osteochondral autologous transplantation was clinically superior to microfracture for the treatment of cartilage lesions in patients under the age of forty years.

Several recent studies have focused on the outcomes of microfracture in high-level athletes. Steadman et al. reviewed the outcomes in twenty-five active National Football League (NFL) players at an average 4.5 years after they underwent microfracture to treat a full-thickness chondral lesion[15]. Nineteen players (76%) returned to football the season following the microfracture. The athletes who returned to football played an average 4.6 seasons (range, one to thirteen seasons) and fifty-six games (range, two to 183 games) after the