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Microfracture: A technique for repair of chondral defects

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Abstract
Articular cartilage damage resulting from traumatic injury, tumour or other diseases has poor healing capability due to its highly organised connective and low metabolic activity of the avascular tissue. Many techniques have been used in the past but repair of articular cartilage defects within synovial joints remains challenging. Microfracture is a marrow stimulation technique, to enhance chondral resurfacing by providing a suitable environment for tissue regeneration. Microfracture is a minimal invasive and cheap method with good short-term results especially in young active patients with small cartilage defects. It is becoming the first-line treatment most frequently used in clinic for articular cartilage repair. The current review provides helpful and comprehensive information about the indications, contraindications, surgical procedure of microfracture technique and its potential complications. The arthroscopic awls used in microfracture produces much less thermal necrosis of the bone than would a hand-driven or motorized drill and allow access to virtually the entire joint, whereas access is much more limited when using a drill. There are important future considerations for chondral resurfacing in human and veterinary medicine.

Keywords: Articular cartilage, awl, bone marrow, microfracture, veterinary

1. Introduction
Articular cartilage defects rarely heal spontaneously [1-8] regardless of whether the defects are acute, chronic, or degenerative. Joint injuries are a main cause of disability among human and equine athletes, and a common sequela of joint injury is the loss of articular cartilage [9]. Articular cartilage is a highly specialized skeletal tissue that is dependent on an intact matrix for its unique biochemical and physiologic properties [10, 11]. Articular cartilage damage resulting from traumatic injury, tumour or other diseases has poor healing capability due to its highly organised connective and little metabolic activity of the avascular tissue [12, 13]. The repair of articular cartilage defects within synovial joints remains challenging because cartilage has a limited capacity for intrinsic healing due to its avascular and hypocellular nature [14]. Although some patients do not have clinically severe problems from articular cartilage defects, with time most eventually will have degenerative changes associated with the cartilage damage [5, 6, 15]. These degenerative changes are progressive. They often become irreversible with development of intense arthritis if there is no adequate therapeutic intervention [16].

With seemingly sudden interest in chondral defects, physicians have attempted to heal damaged or degenerative articular cartilage for more than 250 years. Many techniques have been used including spongialization, abrasion, drilling, tissue autografts, allografts, and cell transplantation [1, 2, 5, 15, 17]. Recently, clinicians have taken a greater interest and a more aggressive approach toward articular cartilage problems because of better understanding of cartilage biology and pathophysiology and of advances in imaging techniques and arthroscopic surgery. Attitudes have changed towards articular cartilage resurfacing; greater emphasis now is placed on it [1, 2, 5, 6, 15]. Various therapies have been used to augment the healing of chondral defects in human [18] and equine patients [19], as well as rabbits including surgical modulation (full-thickness curettage, spongialization, sub- chondral bone drilling, and abrasion arthroplasty), and various grafting procedures (periosteal autografts, osteochondral grafts, sternal cartilage, autografts) and chondrocyte transplantation [1, 18, 19]. No single treatment has clearly shown favorable results when evaluated on the basis of functional outcome and practicality of the procedure. Full-thickness curettage of partial thickness equine articular

cartilage lesions resulted in inadequate healing [20]. Techniques that penetrate the subchondral bone plate (spongialization, subchondral bone drilling) in both full and partial thickness lesions have not resulted in better repair tissue than that in control lesions [21, 22]. Furthermore, disruptions of the subchondral bone plate have been associated with potential biomechanical changes leading to stresses that disrupt the new repair tissue [22]. Controversy has also surrounded the use of abrasion arthroplasty techniques; clinically positive results have been reported [23, 24], but other authors have questioned the case inclusion criteria [25, 26]. Experimental work using abrasion arthroplasty has also yielded variable results, partially because of the difficulty in achieving a consistent level of debridement of the subchondral bone plate [27, 28].

Microfracture is one among many methods available to treat articular cartilage lesions. Developed by Steadman in the 1980s, this widely used procedure is generally regarded as safe and effective [4, 16, 29] and has been developed to enhance chondral resurfacing by providing an enriched environment for tissue regeneration by taking advantage of the body's own healing abilities [30]. Microfracture, a marrow stimulation technique, stimulates a healing response by exposing the subchondral bone marrow and creating a blood clot that fills the defect and recruits connective tissue progenitors to repair cartilage lesions [31]. For this reason, microfracture has become the first-line treatment most frequently used in clinic for articular cartilage repair [32].

The microfracture technique often is considered the golden standard therapy for the treatment of cartilage defects [33]. There are some inherent advantages. In the clinic, microfracture is the predominant treatment method for joint injuries in symptomatic patients with grade III or IV cartilage damage because it is simple and cheap [34]. The microfracture technique is minimally invasive because it is arthroscopic through standard portals in most cases. In comparison to an abrasion chondroplasty the subchondral bone plate is not completely destructed but partially preserved between the microfracture holes improving load-bearing characteristics following healing [35]. In contrast to Pridie drilling no heat necrosis or polishing is introduced into the subchondral bone and marrow with microfracture [36, 37]. The equipment is standardized and the costs are minimal since expensive cell cultures are not necessary. Unlike osteochondral, perichondral, periosteal or chondral autograft procedures the problem of harvest site morbidity is excluded [38].

While microfracture can result to a positive outcome more quickly in younger populations with minor articular cartilage damage, this technique has limitations. Moreover, instead of using hyaline cartilage, the defect was filled with fibrocartilage derived from differentiation of pluripotent stem cells which resulted in an inconsistent composition and inferior biomechanical properties compared to native hyaline cartilage [39]. This technique, however, usually promotes regeneration of fibrocartilaginous tissue with inferior biomechanical properties to normal cartilage [40]. Both the low quality and insufficiency of mesenchymal stem cells bioactivity and retention as well as the abnormal articular cartilage microenvironment caused by the response from the release of inflammation factors and hyperplasia of synovial membrane mainly contribute to the plight of microfracture [41, 42]. Tissue engineering has the capacity to overcome these limitations due to the availability of seed cells and biomaterials.

2. The Microfracture Technique

2.1 Indications for Microfracture

Previous studies involving human and animal patients have reported beneficial effects of subchondral bone microfracture [4]. Steadman *et al*. described improved function in 95% of their study population with a mean follow-up of 11.3 years [43]. There was significant improvement in patients' ability to do activities of daily living, strenuous work and sports from preoperative scores to scores obtained during follow-up after surgery. These results were astonishing since microfracture (as well as Pridie drilling and abrasion arthroplasty) belongs to the classical marrow stimulation techniques that involve surgical access to the bone marrow spaces underlying regions of damaged articular cartilage and thus promote resurfacing with predominantly fibrocartilaginous repair tissue of inferior quality. In this context a fibrous type of cartilage tissue has been found in rabbits [35, 44, 45] and dogs [46] that underwent abrasion chondroplasty [47]. The histological findings were identical in laboratory experiments with rabbits that underwent Pridie drilling [48] or canines treated with microfracture [49]. This can also be seen in a recent sheep study with microfracture of created cartilage lesions. The initially well formed repair tissue degenerated over a stiff and hypertrophic subchondral bone plate after a period of 12 months [50]. Similar results could be detected in a recent prospective cohort study with microfracture of 48 isolated cartilage defects of the femur: MRI evaluation revealed osseous overgrowth in 25% of the patients and persistent gaps between the native and repair tissue in 92% of the microfracture repairs [51]. Recent histological studies in an equine model have shown the microfracture repair cartilage to be not only fibrous but a mixture of fibrocartilage (48%) and hyaline cartilage (20%) [52], however the aggrecan content was less than ideal.

The general indication for microfracture is full-thickness loss of articular cartilage in either a weight bearing area between the femur and tibia or in an area of contact between the patella and trochlear groove [2, 4, 7, 8]. Unstable cartilage that overlies the subchondral bone also is an indication for microfracture. Another indication is degenerative changes in a knee that has proper axial alignment. Although these changes may not be true osteochondral defects, they are in fact loss of articular cartilage at the bone-cartilage interface. General considerations for use of the microfracture procedure include patient age, acceptable biomechanical alignment of the knee, and activity level. If all of these criteria define a patient who may benefit from chondral resurfacing, then such a patient should be considered for microfracture [16].

2.2 Contraindications for Microfracture

Contraindications for microfracture include axial malalignment, a patient unwilling to follow a strict and rigorous rehabilitation protocol, partial-thickness defects, inability to use the opposite leg for weight bearing during the minimal weight bearing time, and a relative contraindication for patients older than 60 years [7]. Younger age resulted in better clinical outcome scores and better repair cartilage fill on MRI. The reported age threshold varied between 30 and 40 years [41, 51, 53]. The majority of the studies included only isolated chondral defects and a mean defect size <4 cm^2, which falls within the recommended lesion size for microfracture [29]. Other specific contraindications include any systemic immune-mediated disease, disease-induced arthritis, or cartilage disease [16].

2.3 The Surgical Procedure: Microfracture

Three portals are made for use of the inflow cannula, the arthroscope, and the working instruments. A tourniquet is not used routinely. An initial thorough diagnostic examination of the knee is done. In case of knee injury, the careful inspection is done routinely for the suprapatellar pouch, the medial and lateral gutters, the patellofemoral joint, the intercondylar notch and its contents, and the medial and lateral compartments including the posterior horns of both menisci. Typically, other necessary intraarticular procedures are done before doing microfracture, with the exception of ligament reconstruction. This routine helps prevent loss of visualization when the fat droplets and blood enter the knee from the microfracture holes. Additionally, particular attention is focused on soft tissues such as plicae and the lateral retinaculum that potentially could produce increased compression between cartilage surfaces [5]. After assessing the full-thickness articular cartilage lesion, the exposed bone is debrided of all remaining unstable cartilage. To debride the cartilage, a full radius resector, a hand-held curved curette, or both are used. All loose or marginally attached cartilage from the surrounding rim of articular cartilage also is debrided to form a stable perpendicular edge of healthy viable cartilage around the defect. This prepared lesion provides a pool that helps hold the marrow clot or "super clot", as it forms. The calcified cartilage layer that remains as a cap to many lesions then is removed by using a curette. Thorough and complete removal of the calcified cartilage layer is extremely important based on the authors' basic science research [52]. To avoid excessive damage to the subchondral bone, an arthroscopic awl then is used to make multiple holes, or microfractures, in the exposed subchondral bone plate. Awl is used with an angle that permits it to be perpendicular to the bone as it is advanced. The 90^0 awl is advanced only manually, not with a mallet. The 90^0 awl typically is used only on the patella or other soft bone. The holes are made as close together as possible, but not so close that one breaks into another and damages the subchondral plate between them. This technique usually results in microfracture holes that are approximately 3 to 4 mm apart. When fat droplets can be seen coming from the marrow cavity, the appropriate depth (approximately 2 to 4 mm) has been reached. The arthroscopic awls produce essentially no thermal necrosis of the bone compared with hand-driven or motorized drills. Generally, microfracture holes are made around the periphery of the defects first, immediately adjacent to the healthy stable cartilage rim. The microfracture holes then are made toward the center of the defect. When the arthroscopic irrigation fluid pump pressure is reduced, under direct visualization the release of marrow fat droplets and blood from the microfracture holes into the knee can be observed. When the quantity of marrow contents flowing into the joint appears adequate, all instruments are removed from the knee and the joint is evacuated of fluid. No intra-articular drains are placed because the goal is for the surgically induced marrow clot rich in marrow elements to form and to stabilize while covering the lesion. It is common for the chronic degenerative chondral lesions to have extensive eburnated bone and bony sclerosis with thickening of the subchondral plate [17], making it difficult to do an adequate microfracture procedure. In these instances and when the axial alignment and other indications for microfracture are met, a few microfracture holes are made with the awls to assess the thickness of the subchondral plate. A burr is used to remove the sclerotic bone until punctuate bleeding is seen. After the bleeding, a microfracture procedure can be done routinely. Results have improved noticeably for these patients with chronic chondral lesions since using this technique. If, however, the surrounding cartilage is so thin that it is not possible to establish a perpendicular rim to hold the marrow clot, then a microfracture procedure likely would not be done in patients with such advanced degenerative lesions. The microfracture technique produces a rough surface in the subchondral bone to which the marrow clot can adhere more easily, yet the integrity of the subchondral plate is maintained for joint surface shape. In addition to eliminating thermal necrosis and providing a roughened surface for blood clot adherence, the different angles of arthroscopic awls available provide easier access to difficult areas of the knee. The key to the entire procedure is to establish the marrow clot to provide the optimal environment for the body's own pluripotential marrow cells to differentiate into stable tissue within the lesion [3, 4, 7, 8]. The authors emphasize to their patients that they likely will not start to experience improvement in their knees for at least 6 months after microfracture.

3. Potential Complications of Microfracture

Complications after microfracture are generally rare. Steadman *et al* [4, 43] described no perioperative complications related to the surgical procedure in 1275 patients. Similarly, 3 randomized, controlled studies found no procedure-related serious adverse effects after microfracture [53]. One study reported adverse effects such as arthralgia (57%), effusion (5%), and crepitation (1.6%), with serious procedure-related adverse effects in 13% [2]. Local septic complications and deep vein thrombosis were observed in up to 2% [53, 54]. Arthrofibrosis requiring lysis of adhesions occurred in up to 16% of patients with degenerative defects treated with microfracture and high tibial osteotomy [55]. Failure after microfracture was variable and time-dependent. Some other case series reported lower revision rates of 2% to 7% at 4 to 11 years after microfracture [4, 54]. In degenerative defects, the early revision rate was 4% to 6% at 2 years and increased to 9% to 16% at 5 years [55, 56]. Most patients progress through the postoperative period with little or no difficulty. Cystic lesions have been described by others after surgical manipulation of the weight bearing region on the medial femoral condyle in horses [22, 57]. Trauma or disruption of the subchondral bone plate has been a factor defined by some authors as a possible cause for subchondral cyst formation [58, 59]. It has also been proposed that these changes occur in humans with advanced osteoarthritis because of synovial fluid intrusion through a damaged articular cartilage surface [60].

4. Future Considerations

There are important future considerations for chondral resurfacing in human and veterinary medicine. As the orthopaedic scientists continue to gain a better understanding of the biology of articular cartilage, it is the duty of orthopaedic surgeons to identify and understand endogenous biologic modulators of healing within the joint. Efforts have to continue to examine the exogenous application of various factors which could influence the cellular response and cartilage healing. The sciences of tissue engineering, stem cell therapy, gene therapy and the use of synthetic matrices are most likely to be critical to future success. Orthopaedic researchers must continue their attempt to gain a better understanding of the key role played by the calcified cartilage

layer and the subchondral bone in the formation of chondral defects and in cartilage healing.

The advantages of the microfracture include that less heat and therefore less necrosis, is produced than with drilling or other methods. The microfracture awls allow access to virtually the entire joint, whereas access is much more limited when using a drill. Furthermore, selection of the correctly angled awl permits the microfracture holes to be made perpendicular to the surface of the subchondral plate, whereas in most cases drilling is done at an angle not perpendicular to the bone. The roughened surfaces produced by the microfracture technique provide the anchoring surface to which the marrow clots can adhere firmly. Although the subchondral bone plate is penetrated, still its actual integrity as a structure is maintained. Perhaps most important, this technique provides access to biologic modulators of healing and to mesenchymal stem cells that have the ability to differentiate into cartilage like cells and produce a durable repair cartilage [16].

Maybe new developments like the scaffold augmented micro-fracture [61] will show more consistent clinical and biological results as well as faster rehabilitation for the treatment of small to medium sized cartilage defects in humans and animals.

5. Conclusion

This review shows that microfracture is a minimally invasive and safe technique for articular cartilage repair. This technique does not restore normal hyaline cartilage but primarily results in fibrous or hybrid repair cartilage tissue with variable repair tissue volume. Despite this shortcoming, excellent short-term functional improvement is consistently observed. This technique could be easily adopted in clinical treatment for osteoarthritic and articular cartilage injuries. Although the current review provides helpful and comprehensive clinical information for the clinician, it is important to recognize that the scientific level of evidence of the currently available literature on microfracture is still limited. Long term studies in human and animal patients are currently in progress.

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