The Subchondral Bone Condition During Microfracture Affects the Repair of the Osteochondral Unit in the Cartilage Defect in the Rat Model

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Introduction.

Bone marrow stimulation with microfracture (MF) is often performed for cartilage injuries because of its simplicity and the possibility of one-stage surgery. However, the results are not good because subchondral bone cysts and intraosseous ossification may be observed in the early postoperative period. When cartilage or the subchondral bone plate is injured, joint fluid flows into the subchondral bone, activating osteoclasts and causing osteolytic changes. Subsequently, osteoblasts are activated and bone formation occurs. Therefore, the state of subchondral bone after cartilage injury changes from osteolysis to osteosclerosis. Therefore, we hypothesized that MF at different times after cartilage injury would cause different subchondral bone changes. MF during the osteolytic phase may further activate osteoclasts and promote osteolysis. We also hypothesized that filling the MFhole with β-tricalcium phosphate (β-TCP), which is used as a bone graft substitute, could inhibit osteolysis by reducing the influx of joint fluid.

Objective.

To evaluate changes in the subchondral bone and cartilage repair in a rat model by performing MF at different times after creating a full-layer cartilage defect, and to evaluate the effect of filling the MFhole with β-TCP on suppressing the inflow of joint fluid into the subchondral bone.

Methods.

A 5 mm × 3 mm whole cartilage defect was created in the medial condyle loading area of the femur of both hindlimbs of 10-week-old SD rats.

Three groups (normal, resorption, and hardening phase) were set according to the condition of the subchondral bone, and MFhole was created 0 weeks (normal phase group), 2 weeks (resorption phase group), and 4 weeks (hardening phase group) after the cartilage defect was created. The right knee joint was left intact, and the MFhole of the left knee joint was filled with β-TCP.

The harvested knee joints were imaged using μCT to analyze the bone volume of the subchondral bone. Histological evaluation included HE staining and Safranin-O staining to score the status of cartilage and subchondral bone. The diameter of the MFhole was measured at each time point, osteoclasts were identified by TRAP staining, and the percentage of osteoclasts was measured at each time point.

Results.

In the case of MF only, in the normal group, the MFhole enlarged after 2 weeks and further enlarged after 4 weeks, but the depth became shallower. In the resorption group, the MFhole enlarged after 2 weeks, the beveled bone around the MFhole became thinner, and after 4 weeks, the MFhole enlarged and cyst formation was observed in the center. In the sclerotic group, the MFhole enlarged after 2 weeks, but the beveled bone around the MFhole became thicker, and after 4 weeks, the MFhole was covered with fibrous tissue and beveled bone was observed just below the covered tissue.

In the resorption group, the diameter of the MFhole was larger at 2 and 4 weeks than in the normal and sclerotic groups. Cartilage scores in the resorption group were worst at 2 and 4 weeks post-MF.

When filled with β-TCP, β-TCP was observed in the MFhole at 2 weeks post-MF and no subarticular bone cysts were observed. In each group, the surface of the MFhole was covered with fibrous tissue, with similar results at 4 weeks. In the normal group, the MFhole was significantly smaller than in the resorption group at 2 weeks after MF, but there was no significant difference between the resorption and sclerotic groups. In the resorption group, the MFhole was significantly greater than in the normal and sclerotic groups at 4 weeks post-MF. Cartilage scores were significantly lower with β-TCP filling than without β-TCP filling in all groups at 2 and 4 weeks post-MF.

The percentage of osteoclasts was significantly lower with β-TCP filling than without at 2 weeks post-MF; at 4 weeks post-MF, there was no significant difference between the groups with and without MF.

On CT images, no resorptive or osteosclerotic changes were observed around the MFhole in the normal group. In the resorptive group, resorptive bone changes around the MFhole were observed 2 weeks after MF; subchondral bone cysts developed 4 weeks later. In the sclerotic group, accelerated bone formation and intra-lesion osteophytes were observed after 4 weeks. Bone volume in the resorption and sclerotic groups was significantly higher with β-TCP filling than without filling at 2 weeks after MF.

Discussion.

This study showed that MF on subchondral bone during the resorption phase causes deterioration of the subchondral bone condition, including subchondral bone cysts, and that filling the MFhole with β-TCP can reduce the deterioration of the subchondral bone condition. This suggests that the clinical failure factor of MF is caused by the condition of the subchondral bone, which can be improved by filling the MFhole with β-TCP.

In an animal study examining the histological changes of subchondral bone after MF, osteoclasts accumulated around the MFhole within 2 weeks, and the diameter of the MFhole

subsequently expanded. Thus, MF to fragile subchondral bone with an accumulation of osteoclasts similar to the resorption phase may cause further enlargement of the MFhole. Since osteogenesis occurs as endochondral ossification after MFhole enlargement, MF to subchondral bone with activated osteogenesis as in the sclerotic phase may induce osteophytes within the lesion.

In the present study, filling the MFhole with β-TCP reduced the velocity of joint fluid flowing into the MFhole and inhibited the expansion of the MFhole. In addition, accumulation of osteoclasts around the MFhole promoted β-TCP resorption and endochondral ossification. Osteogenesis at the articular surface promoted coverage of cartilage defects by fibrocartilage and improved cartilage scores. For subchondral bone in the resorption phase, β-TCP filling may be an option for good clinical results.