Knee articular cartilage injury in leg lengthening

Histological studies in rabbits

Eiichi Nakamura, Hiroshi Mizuta, Akira Sei and Katsumasa Takagi

The effect of lengthening the tibia, by callotasis on the articular cartilage in the knee, was investigated histologically in 18 rabbits. The distraction rate was 1 mm per day. On the right tibia, the distraction frequency was in 2 steps (0.5mm/12 hours), while on the left it was in 120 steps (0.0083 mm/12 minutes). The 18 animals were divided into 3 subgroups based on length gain. Cartilage and subchondral bone samples were examined by light and fluorescent microscopy. The incidence of cartilage degeneration on the 2-step side was 2/5, 5/6, and 6/7 at 10, 20, and 30 percent length increases. On the 120-step side it was 0/5, 1/6, and 1/7 at the same length increases. The intensity of tetracycline fluorescence of the subchondral plate on the 2-step side was higher than that on the 120-step side, showing 1.7, 2.0, and 2.3-fold increases at 10, 20, and 30 percent length increases. Our study suggests that increasing the frequency of distraction in callotasis can help to prevent damage to articular cartilage in adjacent joints.

Department of Orthopedic Surgery, Kumamoto University School of Medicine, 1-1-1 Honjo, Kumamoto 860, Japan
Tel +81-96 3442111. Fax -96 3620532
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Although callus distraction is widely used for limb lengthening, there are still unsolved problems in this technique. One of them is possible damage to the articular cartilage in adjacent joints of an elongated bone (Paley 1988). Hiroshima et al. (1992) reported some cases with narrowing of the hip joint space in femoral lengthening. However, the incidence of this damage and the factors affecting the articular cartilage are as yet unknown. We report changes in the articular cartilage and subchondral bone of the knee joint in rabbits due to tibial lengthening by callus distraction, based on 2 distraction rates and three categories of length gain.

Material and methods

21 adult New Zealand white rabbits (3600 ± 200 g) were used. Under Nembutal® anesthesia, a longitudinal skin incision was made on the medial aspect of the tibia. The periosteum was incised longitudinally and carefully retracted. 4 threaded 2.4-mm pins were inserted at right angles to the diaphysis using a drill guide. A transverse hand-saw osteotomy was performed just below the tibiofibular junction between the second and third pins. The pins were then clamped to a unilateral external fixator. Both tibiae were operated on in the same manner.

Distraction at a rate of 1 mm per day was started the day after the operation. On the right tibia the frequency of distraction was 2 steps per day (0.5 mm every 12 hours) by hand, while on the left it was 120 steps per day (0.0083 mm every 12 minutes) by autodistractor; this miniature device had been checked for performance and accuracy in the laboratory and in pilot animal studies.

The 21 animals were divided into 3 subgroups of 7 each based on length gain. 3 animals were excluded because of fracture of the tibia. Thus, the first subgroup (5 animals) had a 10 percent increase in length. In the second subgroup (6 animals) and the third (7 animals) increases were 20 and 30 percent, respectively.

At the end of the distraction period in each subgroup, the animals were killed with Nembutal®. 3 days before that, tetracycline (30 mg/kg body weight) was given as a single intramuscular injection. Both tibiae were dissected and the articular surfaces of the tibial condyle were examined grossly. For light and fluorescent microscopy examinations, osteochondral specimens were taken from the area not covered by the meniscus on the medial tibial condyle; 2 serial samples were cut sagittally to a thickness of about 2 mm under cooling irrigation.

After fixation in 10 percent formalin and decalcification, 1 sample was embedded in paraffin, sectioned, and stained with hematoxylin and eosin (HE) and safranin-O and fast green. Each section was evaluated using the histological and histochemical grading system of Mankin et al. (1971). After fixation and dehy-

Table 1. Changes in medial tibial articular cartilage and subchondral bone by increments of lengthening

A	B		C		D	
	2 steps	120 steps	2 steps	120 steps	2 steps	120 steps
10 (n 5)	2 (40)	0	5.4[c] *1*	2.0 *1*	176[c] *47*	105 *32*
20 (n 6)	4 (67)	1 (17)	6.0[c] *2*	2.2 *2*	256[d] *42*	126 *14*
30 (n 7)	6 (87)	1 (14)	8.1[ad] *2*	2.7 *2*	269[bd] *21*	118 16

A percent increase in length.
B number of rabbits with fibrillation of medial tibial cartilage (percentages).
C Mankin's score. Mean *SD*.
D intensity of tetracycline fluorescence on subchondral plate in medial tibial condyle. Mean *SD* (arbitrary unit).
Differs [a]($P < 0.05$), [b]($P < 0.01$) from value for 10 percent increase in length.
Differs [c]($P < 0.05$), [d]($P < 0.01$) from value for 120-step side.

dration, the other sample was embedded in glycolmethacrylate (Kashimoto et al. 1991). Undecalcified sections were then cut and ground by the EXACT-cutting-grinding system to 150 μm thickness. The intensity of tetracycline fluorescence of the subchondral plate from the tidemark to 750 μm inferior to it was measured with an OLYMPUS OSP-1 microfluorometer (Miyata et al. 1984). The digitized data were analyzed as the intensity per unit area.

ANOVA was used to evaluate the influence of length gain and the daily frequency of distraction. The nonparametric Kruskall-Wallis test was used to compare the 3 subgroups in the same step. When significant differences were found, the Mann-Whitney U-test was used. To evaluate differences between both sides in the same length gain, the Mann-Whitney U-test was used. $P < 0.05$ was considered significant.

Results

The lateral condyle of both tibiae in all animals showed no macroscopic changes. In contrast, the medial condyle exhibited surface changes mainly on the 2-step side. At 10 percent increase in length, 2 of 5 rabbits on the 2-step side showed a slight fibrillation, but no rabbits on the 120-step side showed any changes. At 20 and 30 percent increases, 4 out of 6 and 6 out of 7 on the 2-step side had a fibrillated cartilage. On the 120-step side, only 1 of 6 and 1 of 7 showed the same medial changes at 20 and 30 percent lengthenings (Table 1).

Microscopically, a cleft in the tangential zone and fissuring chiefly in the transitional zone were found on the medial condyle exhibiting the macroscopic changes. With increasing length, there was increased cartilage degeneration accompanied by hypocellularity, disarrangement of the cartilage cell columns, empty lacunae, and small-sized chondrocytes on the 2-step side (Figure 1). On the 120-step side, no rabbits showed any histological changes in the matrix, except for the 2 rabbits manifesting fibrillated cartilage. Although a loss of Safranin-O staining had already been found on the medial tibial cartilage at the point of 10 percent lengthening on the 2-step side, no loss at all was seen on the 120-step side even at 30 percent lengthening. For all length gains, cartilage on the 2-step side had significantly higher Mankin scores than those on the 120-step side (Table 1).

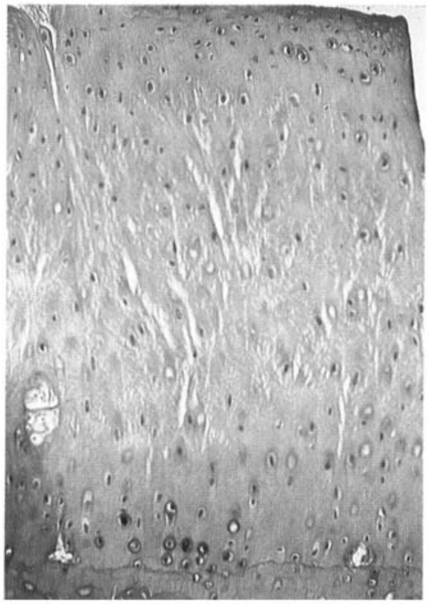
The intensity of tetracycline fluorescence on the subchondral plate on the 2-step side was higher than that on the 120-step side for all length gains. The fluorescence intensity on the 2-step side showed 1.7, 2.0, and 2.3-fold increases at 10, 20, and 30 percent increases in length (Table 1 and Figure 2).

Discussion

In limb lengthening by callotasis, tension is generated on the soft tissues adjacent to an elongated bone. These include blood vessels, nerves, and muscles. Tension on the surrounding muscles may cause axial deviation and contracture of the adjacent joints. Elevated tension on the muscles crossing a joint also generates increased pressure on its articular cartilage, which may lead to cartilage breakdown (Paley 1990).

Radin et al. (1984) demonstrated subchondral stiffening and the consequent cartilage degeneration in rabbits whose knees were subjected to repetitive impact-loading. Our histological findings for the medial tibial condyle on the 2-step side were very

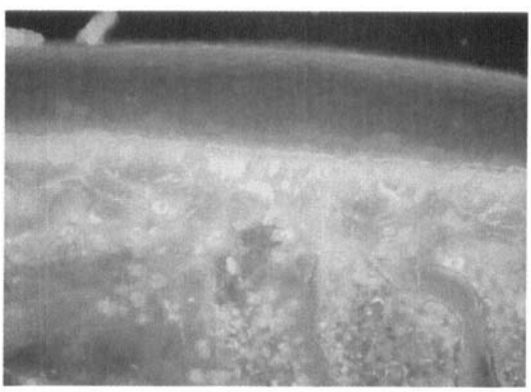
Figure 1. Articular cartilage from medial tibial condyles at 30 percent lengthening. HE stain, ×500.



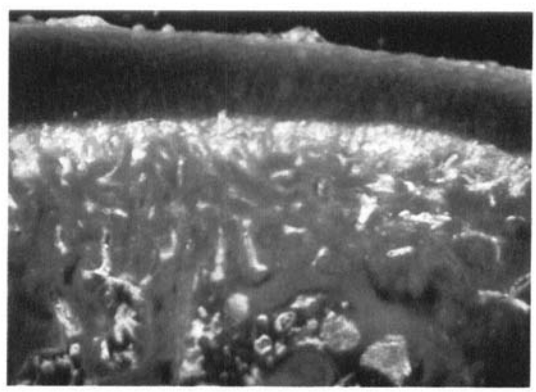
The 2-step side. Surface cleft, fissuring, and hypocellularity in cartilage. In addition, loss of normal columnar arrangement, empty lacunae, and small-sized chondrocytes are seen.

The 120-step side. Surface and cell architecture are intact.

Figure 2. Fluorescence photomicrograph of the subchondral plate from the medial tibial condyle at 30 percent lengthening, using identical exposure times and lighting. ×177.



The 2-step side. Fluorescence intensity of tetracycline on the 2-step side is significantly higher than on the 120-step side for all length gains.



The 120-step side.

much in agreement with their results. Therefore, our data suggest that these alterations on the 2-step side may be due to increased mechanical stress on articular cartilage.

Ohnishi et al. (1992) measured the resistance to distraction on the fixator in tibial lengthening at a rate of 1 mm per day, with a frequency of distraction between 2 steps per day by hand (0.5 mm every 12 hours) and 1440 steps per day by autodistractor (0.7 μm every minute). They found that in 2-step distraction, an acute increase in resistance took place simultaneously with each step of lengthening and that the baseline of the resistance time-course was similar to the stress relaxation curve of a viscoelastic material. Conversely, it was found that in 1440-step distraction, the baseline of this resistance time-course changed very little and was lower than in 2-step distraction.

In lengthening the tibia, the triceps surae muscles offer the greatest resistance to distraction (Paley 1990), which suggests that resistance on the fixator is due mainly to the tension on the triceps surae muscles. Since this muscle attaches to the femoral condyles, the elevated tension may lead to an increase in mechanical compressive stress on the knee joint. This indicates that the difference in the histological changes between both sides is attributable to the magnitude of the tension of the triceps surae muscle, which is due to the difference in the frequency of distraction.

From the viewpoint of recovery of axial deviation and joint stiffness, several authors suggested that about 30 percent may be the maximum lengthening that can be safely achieved (Dal Monte and Donzelli 1987, Price 1989). However, our results showed that at a 30 percent gain in length on the 2-step side, 87 percent of the rabbits suffered moderate cartilage degeneration. At present, it is not known to what degree these changes develop into arthrosis.

In limb lengthening, Ilizarov (1989) demonstrated that a greater frequency of distraction provided better osteogenesis. Our results suggest that increasing the frequency of distraction in callotasis may also prevent damage to the articular cartilage in adjacent joints.

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