Decrease of Osteosclerosis in Subchondral Bone of Medial Compartmental Osteoarthritic Knee Seven to Nineteen Years after High Tibial Valgus Osteotomy

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Abstract
Osteosclerosis of the subchondral bone was measured by densitometer on plain radiographs in 55 medial compartmental osteoarthritic knees of 40 patients who were treated with high tibial valgus osteotomy for correction of varus deformity. The ratio of the osteosclerosis value of the medial side of the knee to that of the lateral side (Medial/Lateral ratio) was calculated and used as a parameter. The Medial/Lateral ratio of osteosclerosis decreased rapidly within three years after osteotomy at the reference points of the femur and the tibia. Even 7 to 19 years after osteotomy, a decrease of the ratio was noted in 16 knees with a standing femorotibial angle (FTA) less than 168° (12° of anatomical valgus angulation). This was interpreted to mean that osteosclerosis of the medial condyle decreased compared with that of the lateral condyle after over-correction of varus deformity. In the cases of more than 7 years after high tibial osteotomy, a positive straight regression line was drawn by calculation between Medial/Lateral ratio and postoperative limb alignment expressed by standing femorotibial angle, with coefficient of correlation ($\gamma$) of 0.295 ($p < 0.01$).

Medial compartmental osteoarthritic knees frequently show varus deformity with osteosclerosis in the subchondral areas of the medial joint surfaces of both the femur and tibia in radiographs. High tibial osteotomy has been attempted to correct the varus deformity of the knee, to give slightly valgus limb alignment, and to decrease compressive force loading on the medial compartment.

Osteoarthritic abnormalities such as osteosclerosis have been studied using contact microradiography and bone scintimetry, but there have been few reports using densitometry on simple radiographs. The purpose of this study was to study the long-term osteosclerotic changes in osteoarthritic knees following high tibial osteotomy.

Patients and Methods

Patients
Patients with a follow-up period of more than 7 years were the subjects of this study. Fifty-five knees of 40 patients with medial compartmental osteoarthritis (27 female, 13 male) were treated with high tibial osteotomy for correction of varus deformity. The age at operation ranged from 42 to 80 years, with a mean of 63.1 years. The follow-up period ranged from 7 to 19 years, with a mean of 10.3 years.

According to the grading system of knee osteoarthritis using standing radiographs, which was modified from Ahlbach, the radiographic findings of osteoarthritis of the knee were classified into 6 grades: Grade 0, normal joint; Grade 1, bone sclerosis or osteophyte formation; Grade 2, narrowing of the joint space of less than 3 mm; Grade 3, obliteration of joint space or subluxation; Grade 4, defect of the tibial plateau of less than 5 mm; and Grade 5, defect of tibial plateau of more than 5 mm. The preoperative osteoarthritic findings on radiographic examination were classified as Grade 2 in 33 knees, Grade 3 in 12, Grade 4 in 9, and Grade 5 in 1 out of 55 osteoarthritic knees in this series.

The Hospital for Special Surgery Knee Scoring System was employed for clinical evaluation, and the score ranged from 35 to 80 (mean ± SD: 62 ± 12) before osteotomy and from 45 to 100 (83 ± 14) at follow-up after osteotomy.

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Surgical Procedure

High tibial osteotomy was performed above the tibial tuberosity to remove a laterally based wedge in order to provide a postoperative standing femoro-tibial angle of 170° (10° of anatomical valgus angulation). The fragments were fixed with a Koshino’s blade plate from the lateral side. This blade plate was removed two years after the initial osteotomy.

Densitometry of Osteosclerosis of the Knees

Density of the sclerotic subchondral region in both femoral and tibial condyle was measured in plain radiographs taken before surgery and at follow-up examinations with a densitometer (Sakura PDA-65, Sakura Co. Ltd., Tokyo). This densitometer transmits single wavelength light through X-ray film and indicates film density within the range from 0.00 to 4.00 (the maximum density).

Reference Points of Densitometric Measurement in the Knee

Three parallel lines were drawn at the levels of 2, 7, and 12 mm from the tangential line at the distal ends of the medial and lateral femoral condyles. The contour of the posterior condyle was traced on the radiograph, and the longitudinal midline of the posterior condyle contour was drawn on the medial and lateral sides of the distal femur, respectively (Fig. 1). Then the five points were plotted at an interval of 3 mm along each transverse line with the point intersected by line A in the middle. The points were plotted on the tibial side in the same way after drawing a longitudinal midline of the tibial condyle. In cases with a blade plate in the upper tibia after osteotomy, the density of the tibial side was measured at 5 points only on the 2 mm line (Fig. 1). All of the blade plates and the other internal fixators were removed by two years after the initial osteotomy in this series.

The mean value of sclerosis at the five points was calculated on each line 2 mm, 7 mm, and 12 mm from the joint surface (Fig. 2).

The ratio of mean sclerosis of the five medial points to that of the 5 lateral points (Medial/Lateral ratio of osteosclerosis: M/L ratio) was calculated as a parameter of bone mineral content (Fig. 3). As a parameter of varus-valgus limb alignment, the femoro-tibial angle (FTA), the lateral angle between the femoral axis and the tibial axis (Fig. 4), was employed and measured in an anteroposterior radiograph taken with one leg standing.

The patients were classified into two groups: Group

Figure 1 Reference points in anteroposterior radiograph. A transverse line is drawn 2 cm proximal to the tangential line (C) at the distal ends of the medial and lateral femoral condyles, and a longitudinal line (A) is drawn at the midpoint of the line transecting the contour of the posterior condyles medially and laterally, respectively. Three parallel lines are drawn at the levels of 2, 7, and 12 mm from the tangential line at the distal ends of the medial and lateral femoral condyles. Then 5 points are plotted at intervals of 3 mm along each transverse line medially and laterally including the intersected point on line A (the third point). The points are plotted on the tibial side in the same way. A transverse line is drawn 2 cm distal to the tangential line (D) at the proximal ends of the medial and lateral tibial condyles, and a longitudinal line (B) is drawn through the midpoint of the line transecting the tibial joint surface (from the medial edge of the tibial plateau to the edge of the medial eminientia, and from the lateral edge of the tibial plateau to the edge of the lateral eminientia, excluding osteophytes) medially and laterally, respectively. Three parallel lines are drawn at the levels of 2, 7, and 12 mm from the tangential line at the distal ends of the medial and lateral femoral condyles. Then 5 points are plotted at intervals of 3 mm along each transverse line medially and laterally including the intersected point on line B (the third point).

Figure 2 Medial compartmental osteoarthritis of the knee before osteotomy (67-year-old female, Grade 3). The numbers on the medial and lateral sides in this figure indicate the mean value of the density at five points along each of the lines 2 mm, 7 mm, and 12 mm from the joint surface.
A with standing FTA of more than 168° and Group B with FTA equal to or less than 168° (12° or more of anatomical valgus angulation), and M/L ratios were compared between these two groups.

The Student’s t-test was used for statistical analysis, and p-values of less than 0.05 were considered to be significant.

Results

Distribution of Osteosclerosis

In cases of medial compartmental osteoarthritis, densitometry showed a higher osteosclerosis D value around the medial femoro-tibial articulation, with a markedly high value in the cases as the degeneration advanced. After correction of varus deformity by high tibial osteotomy, a gradual decrease of osteosclerosis was observed in most of the knees.

The M/L ratio decreased significantly in 55 knees of 40 patients within three years after osteotomy. M/L ratio was 1.03 ± 0.05 before operation, which decreased to 1.00 ± 0.05 within 3 years after operation (p < 0.01) at the points on the lines 2 mm and 7 mm line proximal to the distal femoral joint surface and on the line 2 mm distal to the proximal tibial joint surface. The M/L ratios at the same points in the knees were 1.01 ± 0.06 from 4 to 6 years and 1.02 ± 0.06 more than 7 years after osteotomy, which were significantly lower than the pre-operative ratios (p < 0.05 and p < 0.05, respectively).

Osteosclerosis of the medial femoral condyle decreased more markedly than that of the lateral condyle (Fig. 5).

Relationship Between Osteosclerosis and Postoperative Limb Alignment

High tibial osteotomy was performed with the aim of achieving a postoperative limb alignment of 10° (anatomical valgus angulation 170° femoro-tibial angle) on standing. In our series, the correction of varus deformity was not sufficient (under-correction) in 5 knees. The M/L ratio in these under-corrected cases decreased within three years after osteotomy in spite of no remarkable change in limb alignment, but increased again after seven years because of the gradual recurrence of varus deformity. We divided the cases into two groups according to postoperative standing FTA. Thirteen knees belonged to Group A with an angle of more than 168° (less than 12° of anatomical valgus angulation) and 14 knees to Group B with an angle equal to or less than 168° (more than 12° of anatomical valgus angulation).

The mean M/L ratio in Group B at follow-up was lower than the preoperative value (p < 0.01), and lower than that in Group A (Fig. 6). At the follow-up, the decrease of osteosclerosis in the medial condyle compared with that of the lateral was more significant in Group B.

There was a positive linear relationship between post-
operative standing femoro-tibial angle (X) and M/L ratio (Y) after more than 7 years after high tibial osteotomy. The formula of the regression line was \( Y = 0.593 + 2.47 \times 10^3 X \), with a coefficient correlation \( \gamma \) of 0.295 (p < 0.01) (Fig. 7). Osteosclerosis in the medial compartment decreased more in knees with greater valgus angulation even more than 7 years after osteotomy.

**Discussion**

Maquet demonstrated medially deviated weightbearing force as a cause of osteoarthritis of the knee and he reported that the resultant force on the knee had to pass through the center of gravity of the total load-bearing surface of the knee when the body was stationary. Johnson reported that in the varus-deformed knee the load on the medial plateau rapidly approached 100% of the total load on the joint. In the current study on bone density, it was concluded that the cause of osteosclerosis in the medial joint surface was due to this overload on the medial compartment. In a previous report, no significant osteoarthritic advancement was observed in the lateral joint surface in radiographs taken more than 9 years after high tibial osteotomy for correction of varus deformity in cases of medial compartmental osteoarthritis of the knee. Thus, the decrease of the M/L ratio means a decrease of film density in the medial condyle, which may be due to the decrease of osteosclerosis in the medial condyle.

The M/L ratio significantly decreased within 3 years after osteotomy, and then showed a gradual increase (Fig. 5). However, as varus-deformity occurred in 5 of the osteotomized knees with under-correction, the M/L ratio gradually increased again over more than seven years after operation. The high M/L ratio in these cases with varus recurrence was considered to be responsible for the increase in the mean value of the whole series.

Koshino and colleagues reported that there was a linear relationship between the deviation of the weightbearing axis from the knee center and the standing femoro-tibial angle (FTA), and the weightbearing axis passed through the center of the knee when its standing FTA

![Figure 5](image)

**Figure 5** Long-term postoperative changes of M/L ratio after high tibial osteotomy. The mean M/L ratio of all reference points including 2 mm and 7 mm proximal to the joint surface of the femur, and 2 mm distal to the joint surface of the tibia was investigated in 55 knees of 40 patients who were treated with high tibial osteotomy. It decreased from 1.03 ± 0.05 preoperatively to 1.00 ± 0.05 (p < 0.01) within 3 years, to 1.01 ± 0.06 (p < 0.05) from 4 to 6 years, and to 1.02 ± 0.06 (p < 0.05) after more than 7 years postoperatively. This is interpreted to mean that osteosclerosis of the medial femoral condyle decreased compared with that of the lateral femoral condyle.

![Figure 6](image)

**Figure 6** Postoperative valgus angulation and M/L ratio of more than 7 years after high tibial osteotomy. The postoperative mean M/L ratio in the group with standing femoro-tibial angle less than 168° was significantly smaller than that in the group with standing femoro-tibial angle of more than 168° (p < 0.01). After osteotomy, the mean M/L ratio showed a significant decrease in the group with standing FTA of less than 168° (14 knees) (p < 0.01), and no significant change in the group with standing FTA of more than 168° (30 knees). This is interpreted to mean that decrease of osteosclerosis in the medial condyle compared with that of the lateral condyle was significant in the group with the standing femoro-tibial angle of less than 168°.
Figure 7 Regression line between standing femoro-tibial angle and Medial/Lateral ratio. There is a positive linear relationship between standing femoro-tibial angle and Medial/Lateral ratio more than 7 years after high tibial osteotomy. The regression line has the equation: Y (degrees) = 0.593 + 2.47 x 10^{-3} X, with γ (coefficient correlation) 0.295 (p < 0.01). This is interpreted to mean that the greater the femoro-tibial angle, the greater the Medial/Lateral ratio.

was 172° (8° of anatomical valgus angulation), which was calculated by the formula of the regression line. As the passage of the weightbearing axis was changed from the medial to the lateral compartment by valgus osteotomy, the M/L ratio was decreased, which was interpreted to mean a decrease in osteosclerosis of the medial compartment. This phenomenon is explained by Wolff’s law of transformation in the bones of the knee.

In the current study, we succeeded in evaluating the relation between postoperative standing FTA and changes related to osteosclerosis. In the under-corrected knees, which had varus or only slight valgus limb alignment in spite of high tibial osteotomy, the osteosclerosis failed to show a decrease medially, while in the well-corrected or over-corrected cases, a decrease of osteosclerosis was observed. These results were compatible with the evidence that the uptake of strontium-85 on scintimetry decreased in the medial compartment of knees adequately corrected by high tibial osteotomy for osteoarthritis.

References