Change of Chondral Lesions and Predictive Factors After Medial Open-Wedge High Tibial Osteotomy With a Locked Plate System

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Background: Although cartilage regeneration after medial open-wedge high tibial osteotomy (HTO) has been described, there is a paucity of reports regarding which factors influence cartilage regeneration.

Purpose: To document whether cartilage regeneration occurs in the previously degenerated medial compartment of arthritic knees after medial open-wedge HTO without concomitant cartilage procedures and to assess which predictive factors influence regeneration after HTO.

Study Design: Case series; Level of evidence, 4

Methods: From February 2008 to January 2014, 104 consecutive knees were enrolled retrospectively that received medial open-wedge HTO with a medial locked plate system without any additional cartilage regeneration procedures and were followed by second-look arthroscopy for plate removal 2 years after surgery. The mean ± SD age at the time of index HTO was 56.3 ± 5.4 years. Cartilage status was graded at the time of initial HTO and second-look arthroscopy according to the International Cartilage Repair Society grading system, and regenerated articular cartilage was classified by the macroscopic staging system of Koshino et al at the time of second-look arthroscopy. Variables evaluated for possible association with regeneration of articular cartilage included age, sex, body mass index (BMI), American Knee Society score, mechanical tibiofemoral angle, medial proximal tibial angle, amount of correction angle, and degree of arthritis.

Results: Per the International Cartilage Repair Society grading system, the lesions in the medial femoral condyle and the medial tibial plateau were improved in 54 knees (51.9%) and 36 knees (34.6%), respectively, at the time of second-look arthroscopy. According to the macroscopic grading system, partial and total regeneration of articular cartilage in the medial femoral condyle and the medial tibial plateau was observed in 75 knees (72%) and 57 knees (55%), respectively. Based on univariable logistic regression tests, regeneration of articular cartilage was associated with a smaller mean preoperative varus mechanical tibiofemoral angle (odds ratio [OR], 0.7; $P = .023$) and lower BMI (OR, 0.8; $P = .026$) for the medial femoral condyle and younger age (OR, 0.9; $P = .048$) and a larger mean correction angle (OR, 1.1; $P = .023$) for the medial tibial plateau. The mean preoperative knee and function scores were significantly improved at the last follow-up, but no correlation was found between the clinical outcomes and cartilage regeneration. Multiple logistic regression analysis for regeneration of articular cartilage showed lower BMI (OR, 0.7; $P = .015$) to be a significant predictor for the medial femoral condyle.

Conclusion: Regeneration of degenerated articular cartilage in the medial compartment can be expected while correcting a varus deformity in arthritic knees after medial open-wedge HTO with a locked plate system without any additional cartilage regeneration procedures. Moreover, we suggest that medial open-wedge HTO in the medial arthritic knee with varus malalignment should be highly successful in terms of cartilage regeneration, especially for lower BMI patients.

Keywords: knee; arthritis; cartilage defect; open-wedge high tibial osteotomy; HTO; articular cartilage regeneration; medial locked plate system

High tibial osteotomy (HTO) is an established treatment for patients with unicompartmental knee arthritis combined with varus malalignment.[6-11,14,21] In recent years, medial open-wedge HTO has been popularized with the development of firm fixators, such as locked plates, as well as simplified surgical techniques that require less time.[10,16,17,20,27,31]

Decreased loading on a weightbearing medial compartment owing to lateral shifting of the weightbearing line and widening of the medial joint space are well-known

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reasons for regeneration after HTO.[9,19,32] Previous reports demonstrated that regeneration of articular cartilage in the medial compartment after lateral closed-wedge HTO was affected by preoperative cartilage degeneration grade, postoperative limb alignment, and differences between the medial femoral condyle (MFC) and medial tibial plateau (MTP).[1,9,14,22,34] Several reports recently assessed cartilage regeneration after medial open-wedge HTO,[7,8,25,26,30] but very little is known about which prognostic factors influence regeneration. This study sought to document whether cartilage regeneration occurs in the previously degenerated medial compartment of arthritic knees after medial open-wedge HTO without concomitant cartilage procedures and to assess which predictive factors could influence articular regeneration after HTO. We hypothesized that there would be cartilage regeneration after medial open-wedge HTO with a locked plate. We also hypothesized that the regeneration of articular cartilage would be affected by predictive factors, including preoperative cartilage degeneration grade and postoperative limb alignment.

METHODS

Patient Selection and Study Design

From February 2008 to January 2014, a total of 141 knees underwent medial open-wedge HTO for medial compartment osteoarthritis of the knee at our institution. All operations were performed by a single surgeon with the same materials and techniques with a medial locked plate system. All patients received a recommendation to undergo plate removal with second-look arthroscopy at 2 years after surgery. Inclusion criteria of this study were as follows: (1) patients with symptomatic isolated degenerative medial compartment joint disease of the knee associated with varus tibiofemoral malalignment, (2) range of motion in the knee joint maintained from $>100^\circ$ of flexion to $<10^\circ$ to 15° of flexion contracture, (3) second-look arthroscopy at 2 years after surgery concomitant with plate removal, and (4) no functional instability of the anterior cruciate ligament. Exclusion criteria were rheumatoid arthritis, hemophilia, posttraumatic osteoarthritis, active knee infection, lateral compartment degenerative disease and concomitant symptomatic, and moderate to severe patellofemoral joint disease. To evaluate possible factors affecting cartilage changes, correlation analyses were performed between cartilage status and other variables (age, body mass index [BMI], pre- and postoperative mechanical tibiofemoral angle, medial proximal tibial angle, clinical scores). Ethical approval for the current study was obtained from the review board of our institution.

Surgical Technique

Preoperative templating was conducted on a weightbearing lower limb orthogram with a cutout for operation planning.[10] Shifting the weightbearing line to 62% into the lateral tibial plateau was the objective of valgus osteotomy to create 3° to 5° of postoperative mechanical valgus.[6] The correction angle at the proximal tibia and the distance to the opening site of the osteotomy were calculated preoperatively.

All patients received an arthroscopic examination at the time of HTO. Arthroscopic procedures included irrigation of joint debris, meniscectomy of a flap tear, removal of large loose bodies, and resection of marked osteophytes in the intercondylar notch (Figure 1). However, no cartilage procedures were carried out.

After arthroscopy, a medial open-wedge HTO was performed with a TomoFix plate (DePuy Synthes). The horizontal osteotomy was performed first, parallel to the tibial slope, with a thin oscillating saw along with 2 guide pins and continuous irrigation cooling of the saw blade. The second osteotomy of the biplanar osteotomy sites started in the anterior one-third of the proximal tibia and proximal to the insertion of the patellar tendon at an angle of 130° to the first osteotomy plane. The mechanical axis was then adjusted according to preoperative planning under image intensification, and a long straight measuring rod was placed at the center of the femoral head and at the center of the ankle joint. After fixation of the plate with locking screws, a cancellous bone allograft (Korea Bone Bank) was performed if the gap width exceeded 10 mm. Active and passive range of motion was initiated on the first postoperative day. Partial weightbearing with crutch ambulation was then started when pain subsided. Patients were allowed to begin full weightbearing by 6 weeks postoperatively. Patients were also restricted for 6 months from sports that require jumping, cutting, or twisting maneuvers.

Evaluation Criteria

For radiologic evaluation, bilateral standing anteroposterior, lateral, and Merchant views of the knee and entire lower extremity orthograms were assessed preoperatively and at last follow-up with a digital measurement. The radiologic evaluation included mechanical hip-knee-ankle axis, medial proximal tibial angle, tibial slope, and Kellgren-Lawrence grade for preoperative planning.

Clinical examinations of the knee joints in our study were documented with the American Knee Society knee score and function score. All patients filled out a questionnaire for knee score and function score at the time of initial HTO and second-look arthroscopy. BMI was also measured on admission day.

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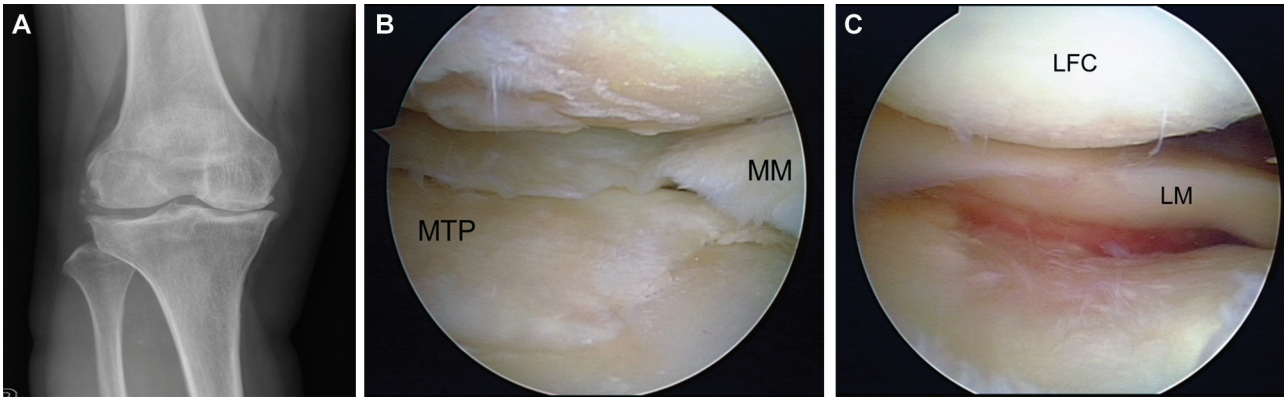

Figure 1. (A) Preoperative radiograph of a 49-year-old woman shows joint space narrowing and an osteophyte in the medial compartment. (B) Arthroscopic finding of the articular surface in the medial femoral condyle and medial tibial plateau (MTP) shows exposed subchondral bone at the time of high tibial osteotomy. (C) Arthroscopic finding of the articular surface in the lateral compartment shows superficial fissures and cracks that were considered grade 1 cartilage defects at the time of high tibial osteotomy. LFC, lateral femoral condyle; LM, lateral meniscus; MM, medial meniscus.

For evaluation of cartilage lesion, the MFC, MTP, lateral femoral condyle, and lateral tibial plateau articular cartilage were evaluated by arthroscopy at the time of initial HTO and second-look arthroscopy. Status of the articular cartilage was graded at the time of initial HTO and second-look arthroscopy according to the International Cartilage Repair Society (ICRS) grading system.[5] In this system, superficial lesions and superficial fissures and cracks are considered grade 1 cartilage defects, and lesions extending down to <50% of the cartilage depth are considered grade 2 defects. Grade 3 defects are defined as those extending down to >50% but not involving the subchondral bone, while those involving the subchondral bone are classified as grade 4 defects.

In addition, the status of the regenerated articular cartilage was classified according to the macroscopic staging system of Koshino et al[14] at the time of second-look arthroscopy. Cartilage with no regeneration was classified as stage A. Cartilage with regenerated pink fibrous tissue, whether or not partial white fibrocartilage was present, was classified as stage B. Cartilage with total regeneration was classified as stage C.

Statistical Analysis

Statistical analysis was carried out with SPSS 21.0 software (IBM Corp). The Wilcoxon signed-rank test was used to analyze significant differences between the initial and follow-up evaluations. Uni- and multivariable logistic regression was conducted to identify factors that affect regeneration of articular cartilage of the knee after HTO (age, sex, BMI, knee score, function score, mechanical hip-knee-ankle axis, medial proximal tibial angle, correction angle, and Kellgren-Lawrence grade). Continuous variables were compared by 1-way analysis of variance, and categorical variables were compared with a chi-square test or Fisher exact test. A P value <.05 was considered statistically significant.

TABLE 1
Patient Characteristics[a]

	Second-Look Arthroscopy		
	With (n = 104)	Without (n = 37)	P Value
Patients:knees	85:104	32:37	NA
Bilateral knee	16 (15.3)	5 (13.5)	.559[b]
Age at surgery, y	56.3 ± 5.4	53.7 ± 6.1	.051[c]
Male sex, knees	9 (8.7)	8 (21.6)	.072[b]
Body mass index, kg/m^2	26.1 ± 2.3	25.5 ± 2.5	.866[c]
Follow-up period, mo	25.0 ± 5.8	25.3 ± 4.9	.619[c]
Preoperative mechanical axis	–6.0 ± 2.2	–6.5 ± 2.9	.270[c]
Correction angle	7.8 ± 3.4	8.0 ± 2.2	.817[c]

[a]Values are presented as No. (%) or mean ± SD. NA, not applicable.
[b]Chi-square test.
[c]Student t test.

RESULTS

Among 141 knees, 104 knees that underwent second-look arthroscopy were included in this study. The mean ± SD patient age was 56.3 ± 5.4 years. The mean duration between HTO and second-look arthroscopy was 25.0 ± 5.8 months. Mean BMI was 26.1 ± 2.3 kg/m^2 (Table 1). There was no significant difference in demographic factors between those who had a second-look arthroscopy and those who did not.

The mean mechanical tibiofemoral angle was varus (6.0° ± 2.2°) before HTO and was corrected to valgus (1.8° ± 3.2°) at the final follow-up (P < .001). The mean amount of correction between the pre- and postoperative values of the mechanical angle was 7.8 ± 3.4. There were no cases of nonunion, malunion, infection, or intra-/postoperative fractures.

Regeneration of articular cartilage of the knee was evaluated with the ICRS grading system and the macroscopic

TABLE 2
International Cartilage Research Society Grade[a]

	Grade 4		Grade 3		Grade 2		Grade 1		Grade 0	
	Initial	Second Look	Initial	Second Look	Initial	Second Look	Initial	Second Look	Initial	Second Look
MFC	39 (37.5)	14 (13.5)	48 (46.2)	38 (36.5)	9 (8.7)	36 (34.6)	7 (6.7)	11 (10.6)	1 (1.0)	5 (4.8)
MTP	31 (29.8)	17 (16.3)	20 (19.2)	12 (11.5)	28 (26.9)	41 (39.4)	25 (24.0)	33 (31.7)		1 (1.0)
LFC			1 (1.0)			2 (1.9)	47 (45.2)	61 (58.7)	56 (53.8)	41 (39.4)
LTP			1 (1.0)		9 (8.7)	15 (14.4)	70 (67.3)	76 (73.1)	24 (23.1)	13 (12.5)

[a]Values are presented as No. (%). "Initial" and "second look" refer to arthroscopy. Significant differences were observed at the time of second-look arthroscopy in the medial and lateral compartments, $P < .001$. LFC, lateral femoral condyle; LTP, lateral tibial plateau; MFC, medial femoral condyle; MTP, medial tibial plateau.

TABLE 3
Change in International Cartilage Research Society Grade[a]

	Improved	Unchanged	Worse	*P* Value
Medial femoral condyle	54 (51.9)	47 (45.2)	3 (2.9)	.002
Medial tibial plateau	36 (34.6)	62 (59.6)	6 (5.8)	<.001

[a]Values are presented as No. (%).

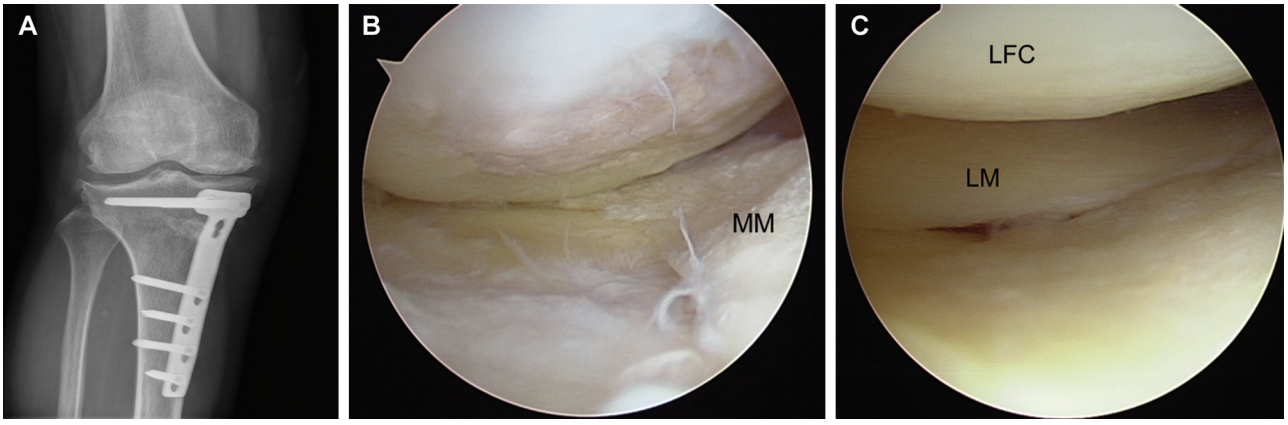

Figure 2. (A) Radiograph at 30-month follow-up just before implant removal shows solid union and good alignment with a locked plate for fixation. (B) Arthroscopic finding of the articular surface in the medial femoral condyle and medial tibial plateau shows total coverage with fibrous cartilage at 30 months after surgery without any additional cartilage regeneration procedures. (C) Arthroscopic finding of the articular surface in the lateral compartment at second-look arthroscopy shows no changes as compared with that before high tibial osteotomy. LFC, lateral femoral condyle; LM, lateral meniscus; MM, medial meniscus.

staging system of Koshino et al[14] at the time of second-look arthroscopy. Initial and second-look arthroscopic assessments of chondral lesions with the ICRS grading system are summarized in Tables 2 and 3. Significant differences were observed at the time of second-look arthroscopy in the medial and lateral compartments ($P < .001$) (Table 2, Figure 2).

As shown in Table 3, the lesions in the MFC were significantly improved in 54 knees (51.9%) at the time of second-look arthroscopy ($P < .001$), and the articular cartilage status of the MFC of 47 knees (45.2%) did not change. The lesions in the MTP were also significantly improved in 36 knees (34.6%) at the time of second-look arthroscopy ($P < .001$) (Table 3), and the articular cartilage status of the MTP of 62 knees (59.6%) did not change.

Table 4 summarizes evaluation of cartilage regeneration with the macroscopic staging system described by Koshino et al[14] at second-look arthroscopy. Partial and total regeneration of articular cartilage in the MFC was observed in 36 knees (34.6%) and 39 knees (37.5%), respectively. In the MTP, partial and total regeneration of articular cartilage was observed in 29 knees (27.9%) and 28 knees (26.9%), respectively. Full-thickness cartilage defects healed better when compared with partial-thickness cartilage defects.

American Knee Society scores (knee, 95.8 ± 7.3; function, 98.1 ± 4.9) were significantly improved at last

TABLE 4
Stage of Regeneration of Articular Cartilage on Second-Look Arthroscopy[a]

	Stage A: No Regeneration	Stage B: Partial Regeneration	Stage C: Total Regeneration
Medial femoral condyle	29 (27.9)	36 (34.6)	39 (37.5)
Medial tibial plateau	47 (45.2)	29 (27.9)	28 (26.9)

[a]Values are presented as No. (%).

TABLE 5
Univariable and Multivariable Analysis of the Medial Femoral Condyle[a]

	P Value		Odds Ratio (95% CI)	
Variable	Univariate Analysis	Multivariate Analysis	Univariate Analysis	Multivariate Analysis
Age	.788		1.0 (0.9-1.0)	
Sex	.122		0.1 (0.0-1.5)	
Body mass index	.026	.015	0.8 (0.6-0.9)	0.7 (0.6-0.9)
Preoperative				
Knee score	.105		0.9 (0.9-1.0)	
Function score	.228		0.9 (0.9-1.0)	
K-L grade	.474		0.6 (0.3-1.1)	
HKA axis	.023	.130	0.7 (0.6-0.9)	0.8 (0.4-0.9)
Correction angle	.115		1.1 (0.9-1.2)	
Last				
Knee score	.988		1.0 (0.9-1.0)	
Function score	.474		0.9 (0.8-1.0)	
K-L grade	.983		0.6 (0.5-1.4)	

[a]HKA, hip-knee-ankle; K-L, Kellgren-Lawrence.

follow-up as compared with preoperative clinical scores (knee, 60.8 ± 10.4; function, 63.1 ± 7.3; $P < .001$). In univariable logistic regression tests of the changes in the MFC, significant differences were observed at the time of second-look arthroscopy in terms of smaller mean preoperative varus mechanical tibiofemoral angle (odd ratio [OR], 0.7; 95% CI, 0.6-0.9; $P = .023$) and patients with lower BMI (OR, 0.8; 95% CI, 0.6-0.9; $P = .026$) (Table 5). In univariable logistic regression of changes in the MTP, significant differences were observed among patients of younger age (OR, 0.9; 95% CI, 0.8-0.9; $P = .048$) and with greater mean correction angle (OR, 1.1; 95% CI, 1.0-1.3; $P = .023$) (Table 6). In the multivariable logistic regression modeling, only lower BMI (OR, 0.7; 95% CI, 0.6-0.9; $P = .015$) remained predictive for regeneration of articular cartilage in the MFC of the knee (Table 5).

DISCUSSION

This study revealed a high rate of improvement of degenerated articular cartilage in the medial compartment at second-look arthroscopy after HTO with a medial locked plate system. Full-thickness defects of the medial compartment were improved among patients with younger age, low BMI, larger mean correction angle, and smaller mean preoperative varus mechanical tibiofemoral angle at 2 years after HTO. Therefore, medial open-wedge HTO can be recommended as a viable treatment option for relatively young and low BMI patients with medial compartment osteoarthritis accompanied with degenerated articular cartilage, if the proper correction angle is applied.

Remodeling of the articular cartilage after HTO has already been reported, and the theoretical basis is decreased stress on the load-bearing cartilage in the medial compartment.[1,6,7,9,14,19,22,32] Additional cartilage regeneration procedures along with HTO have been applied on degenerated articular cartilage of the knee, including arthroscopic debridement, drilling, shaving, and microfracture.[1,3,12,35] The role of additional cartilage-specific procedures has been debated. Akizuki et al[1] compared combined HTO and abrasion arthroplasty versus HTO alone and found no difference in clinical and histologic examinations between groups, although better morphologic scores were seen in the abrasion arthroplasty group. A recent study[8] analyzed the effect of subchondral drilling among patients with HTO, finding no difference in the formation of fibrocartilage with or without subchondral drilling. In the current study, partial or total regeneration of cartilage was achieved in the MFC in 72% of knees and in the MTP in 55% of knees without cartilage regeneration procedures. However, because of the lack of a control group in our study, the effect of chondral resurfacing procedures remains unclear.

Ideal postoperative limb alignment after HTO has been proven to have a significant influence on cartilage regeneration.[9,13,14,21] Recently, Jung et al[7] found that cartilage regeneration occurred more frequently in cases with postoperative limb alignment (mechanical tibiofemoral angle

TABLE 6
Univariable and Multivariable Analysis of the Medial Tibial Plateau[a]

	P Value		Odds Ratio (95% CI)	
Variable	Univariate Analysis	Multivariate Analysis	Univariate Analysis	Multivariate Analysis
Age	.048	.116	0.9 (0.8-0.9)	0.9 (0.8-1.0)
Sex	.740		1.3 (0.2-6.7)	
Body mass index	.909		0.9 (0.8-1.1)	
Preoperative				
Knee score	.581		0.9 (0.9-1.0)	
Function score	.242		0.9 (0.9-1.0)	
K-L grade	.364		0.7 (0.4-1.4)	
HKA axis	.065		0.8 (0.6-1.0)	
Correction angle	.023	.152	1.1 (1.0-1.3)	1.1 (0.9-1.3)
Last				
Knee score	.348		0.9 (0.8-1.0)	
Function score	.426		0.9 (0.8-1.0)	
K-L grade	.970		0.9 (0.5-1.5)	

[a]HKA, hip-knee-ankle; K-L, Kellgren-Lawrence.

>0° and valgus <6°) than in those with revarization (<0°) and overcorrection (valgus >6°). We also observed that a greater correction angle was a predictive factor for regeneration of articular cartilage in the MTP after HTO. However, Tsukada and Wakui[33] found no significant differences in the ratio of cartilage repair between overcorrected and moderately corrected knees after open-wedge HTO. It remains unclear whether overcorrected knees could obtain a higher ratio of cartilage repair than moderately corrected knees.

Several articles have investigated the extent to which the success of HTO depends on the angle of correction, the operation technique, and the rate of complications.[2,28] However, it is unclear which individual factors, such as age, sex, and obesity, affect the outcome of HTO. Spahn et al[29] evaluated prognostic factors that influence the outcome of HTO at midterm follow-up and found no significant differences with respect to sex or patient age in the frequency of poor results after HTO. However, their results indicated that being overweight was a significant factor predicting poor outcome after HTO. Another study[4] found that the risk of unsuccessful surgery after HTO was 10 times higher when the BMI was >30 kg/m^2 and 5 times higher with age >56 years. In a recent study, Kumagai et al[15] demonstrated that the incidence of cartilage regeneration after open-wedge valgus HTO was significantly higher in lower BMI cases, but age and sex did not affect regeneration. Similarly, the current study revealed that lower BMI was the only positive predictive factor in the multivariable logistic regression modeling for regeneration of articular cartilage in the medial compartment after medial open-wedge HTO. Therefore, higher BMI should be considered a negative factor in terms of cartilage regeneration when selecting patients for HTO.

There is controversy in the literature about the association between cartilage regeneration and clinical results after HTO. Koshino et al[14] reported that knee score among patients with immature regeneration was lower than that in those with mature regeneration. However, many studies have shown no correlation between clinical outcome and cartilage regeneration.[1,14,19] Similarly, in the current study, clinical scores from the pre- and postoperative periods were not significantly correlated with the status of the regenerated articular cartilage in the MFC and MTP at the time of second-look arthroscopy.

There have been debates on the evaluation for the regenerative cartilage that was quite different from the surrounding degenerative cartilage in osteoarthritis.[14,18,23] Thus, previous studies used 1 or 2 different grading systems to classify the repair findings.[7-9,14,15,33] Our study utilized ICRS grading and a modified staging system of Koshino's classification[14] at the time of second-look arthroscopy. ICRS grading can be useful to compare initial and follow-up chondral lesions. Modified Koshino's classification is necessary to assess the regenerative cartilage. It would be helpful to compare our results and previous or further reports.

This study had some limitations. First, this was a retrospective study without a control group. Second, since this study was based on second-look arthroscopic findings at the time of plate removal after medial open-wedge HTO, the follow-up period was only 2 years after surgery. A long-term prospective study with correlated clinical results is needed. Third, intrinsic reasons for regeneration of degenerated articular cartilage in the medial compartment of the knee after HTO were not yet identified. The size of the intraoperative cartilage defect and histologic findings at second-look arthroscopy were not investigated. Correlations between the results of second-look arthroscopy and other related factors should be studied in the future, such as cartilage regeneration strategies, postoperative muscle strength, patient activity score, and expression of fibrogenic cytokines in the synovium. Finally, this study did not assess the use of dGEMRIC technologies (delayed gadolinium-enhanced magnetic resonance imaging of cartilage).[24] Such methods of assessment would have improved the analysis of cartilage quality after HTO.

CONCLUSION

The regeneration of degenerated articular cartilage in the medial compartment can be expected while correcting a varus deformity in arthritic knees after medial open-wedge HTO with a locked plate system without any additional cartilage regeneration procedures. Moreover, we suggest that medial open-wedge HTO in a medial arthritic knee with varus malalignment should be highly successful in terms of cartilage regeneration, especially for lower BMI patients.

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