Clinical and Radiological Outcomes of Medial Meniscal Allograft Transplantation Combined With Realignment Surgery

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Background: The outcomes of medial meniscal allograft transplantation (MMAT) combined with high tibial osteotomy (HTO) compared with isolated MMAT remain unclear.

Purpose: To compare the clinical and radiological results of MMAT combined with HTO and isolated MMAT.

Study Design: Cohort study; Level of evidence, 3.

Methods: This retrospective study included 42 consecutive patients, who were divided into group M (isolated MMAT; n = 22) and group H (MMAT combined with HTO with a varus angle >3°; n = 20). Group differences in subjective knee scores, isokinetic muscle strength test, and radiological outcomes (Kellgren-Lawrence grade, mechanical axis, graft extrusion, graft status, and articular cartilage loss) were compared.

Results: The mean follow-up period was 29.2 ± 4.9 months and 27.4 ± 5.3 months for groups M and H, respectively. The Lysholm score improved from 55.4 ± 9.5 to 81.3 ± 9.7 and from 52.6 ± 8.9 to 84.2 ± 10.2 in groups M and H, respectively (both $P < .001$). The International Knee Documentation Committee subjective score improved from 51.4 ± 10.3 to 79.6 ± 9.4 and from 49.3 ± 11.4 to 81.4 ± 8.3 in groups M and H, respectively (both $P < .001$). Both groups showed no significant differences in subjective knee scores and isokinetic extensor strength at the final follow-up. The rate of preoperative and postoperative high International Cartilage Regeneration & Joint Preservation Society grade (≥3) did not differ between the 2 groups. Group M showed greater coronal graft extrusion than did group H (3.3 ± 0.7 mm vs 2.7 ± 0.8 mm; $P = .014$); the rate of pathologic graft extrusion (≥3 mm) was not higher in group M (40.9%) than in group H (20%) with the number of patients available ($P = .143$). Both groups showed no significant difference in the graft status. Graft tears were observed in 2 patients (9%) in group M and 1 patient (5%) in group H ($P = .607$).

Conclusion: Clinical scores significantly improved after isolated MMAT and MMAT combined with HTO compared with preoperative values, and their short-term outcomes were similar. Postoperative graft extrusion was greater in patients who underwent isolated MMAT, implying that active correction of varus alignment during MMAT may help in intra-articular biomechanics.

Keywords: high tibial osteotomy; meniscal allograft transplantation; meniscal deficiency; varus malalignment

Meniscal allograft transplantation (MAT) is performed to alleviate pain, improve knee function, and potentially delay or prevent the development of osteoarthritis in the affected knee.[15,52-55] Long-term studies have shown favorable clinical and radiological results for MAT.[15,52-55] However, several factors, such as less meniscal mobility, more frequent degenerative change, and varus malalignment, are possible causes for the inferior outcomes of medial MAT (MMAT).[4,28,44,60,65] Among them, varus malalignment can be adequately corrected intraoperatively. Furthermore, the reasons for actively correcting malalignment are as follows: even in normal alignment, approximately 60% of the load is loaded on the medial compartment. If there is varus malalignment, >60% of the load is loaded medially, leading to unfavorable outcomes after performing MMAT.[5,60,62]

Addressing varus malalignment and medial meniscal deficiency ensures the proper realignment via a high tibial osteotomy (HTO), which helps the meniscal allograft to function optimally by reducing the shear and compressive forces on the medial side, promoting graft survival, and improving the overall stability and longevity of the procedure.[43,64] However, the criteria for performing HTO based on the mechanical tibiofemoral angle may vary between 1° and 5°.[24,43,64,65] The outcomes of MMAT combined with HTO compared with isolated MMAT have not been conclusively determined because patients with varus alignment undergoing MMAT often exhibit more advanced cartilage damage compared with those with good alignment. Previous studies have shown that the outcomes of MMAT

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combined with HTO are comparable with those of isolated MMAT in patients without malalignment.[24,64,65] However, these studies lack sufficient data on clinical outcomes and radiological results before and after MAT. They had relatively small sample sizes in concurrent HTO cases, warranting further systematic research.

Conversely, some authors have raised concerns about the negative effect of concomitant HTO.[16,61] Furthermore, whether the Fujisawa point is desirable during HTO has yet to be clarified. Overcorrection after targeting the Fujisawa point can increase joint line obliquity, exacerbate lateral osteoarthritis, and create an imbalance in the lower limbs, thereby reducing surgical satisfaction.[21,37] Recent studies have suggested avoiding overcorrection during meniscal repair or MAT to reduce the tibiofemoral contact pressure within the joint.[10,27,38,59,63] Cases of concomitant MMAT and HTO are rare in actual clinical practice, and clinical and radiological outcomes after them are lacking. The role of HTO during MMAT may be better elucidated if the status of preoperative osteoarthritis progression is similar between patients undergoing HTO and those not undergoing HTO and patients undergoing HTO have been set an appropriate target of about 55% for their correction angle to ensure it is not excessive by the same surgeon in a single institution.[27,38] Therefore, conducting a comprehensive study to overcome the limitations of previous research would be beneficial.

Consequently, this study aimed to compare the clinical and radiological results of MMAT combined with HTO and isolated MMAT. We hypothesized that the outcomes of MMAT combined with HTO would be equal to those of MMAT alone.

METHODS

We retrospectively reviewed the medical records of 51 patients who underwent MMAT between March 2017 and September 2021 by a single surgeon (J.G.K.). This study's inclusion criteria were as follows: (1) underwent magnetic resonance imaging (MRI) examination within 2 days postoperatively; (2) underwent a follow-up MRI 1 year after MMAT; and (3) had a minimum of 2-year follow-up. The exclusion criteria were as follows: (1) age >50 years; (2) multiple ligamentous injuries; (3) persistent excess ligamentous laxity; (4) joint obliteration on the Rosenberg view; (5) generalized cartilage loss classified as International Cartilage Regeneration & Joint Preservation Society (ICRS) grade 3 or 4; and (6) lateral compartment osteoarthritis of Kellgren-Lawrence (K-L) grade ≥2. However, localized articular cartilage loss classified as ICRS grade 3 or 4, which was confined to the area covered by the meniscal graft, was not an exclusion criterion. We included the combined ligament instability and malalignment restored via ligament reconstruction and osteotomy during MMAT as exclusion criteria.

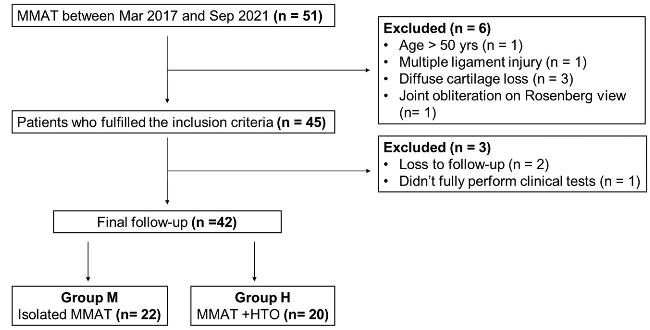

Figure 1. Flowchart of the included patients. HTO, high tibial osteotomy; Mar, March; MMAT, medial meniscal allograft transplantation; Sep, September; yrs, years.

A total of 42 patients were included in this retrospective study. The patients were divided into group M (isolated MMAT; n = 22) and group H (MMAT in combination with HTO; n = 20) (Figure 1). Our institution's ethics committee approved this study (KUMC 2023-11-001). As this was an observational study no informed consent was needed.

Surgical Technique and Postoperative Rehabilitation

Notably, all patients had undergone total or subtotal meniscectomy and experienced knee pain. A single experienced surgeon (J.G.K) performed MMAT using the modified bone bridge technique.[34] The graft was sized based on the anteroposterior and lateral radiographs with scanography for magnification correction using a modified Pollard method.[19,51] A fresh-frozen, nonirradiated meniscal allograft was prepared. After arthroscopic evaluation and resection of the remaining medial meniscus with peripheral preservation, a 4-cm longitudinal arthrotomy was performed just medial to the medial border of the patellar tendon. Superficial medial collateral ligament release was performed to widen the medial compartment space, providing better visualization and working space

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based on a previously published method.[7] The tip of an anterior cruciate ligament reconstruction tibial tunnel guide (ConMed Linvatec) was positioned in the native posterior root of the medial meniscus. After a 5 mm–diameter tunnel was created, retroreaming was performed to a depth of 5 mm using a FlipCutter of 10 mm (Arthrex). The footprint of the anterior root was visualized from the anterior arthrotomy site. The anterior bone tunnel was created under direct visualization using a guide pin, followed by a 10-mm reamer to a depth of 15 mm. The anterior bone plug and posterior bone shell were inserted into the bone tunnels under the traction of the posterior guide suture through the capsule, and the entire medial meniscal allograft was spread evenly. An inside-out repair was then used to secure the middle one-third. The posterior horn was secured using the Fast-Fix 360 system (Smith & Nephew Endoscopy), and the anterior third was secured with outside-in repair using 3 polydioxanone sutures (PDS II; Ethicon). Finally, we confirmed that the anterior and posterior roots were fixed and the entire meniscal allograft had the desired tension.

Patients underwent a weightbearing shifting procedure using a medial opening wedge HTO if they showed a varus alignment (absolute mechanical axis >3°) on a preoperative whole-leg weightbearing anteroposterior radiograph. The definition of varus alignment was based on that in previous studies.[11,42,47,49,58] A correction angle was planned to achieve a target alignment passing through a point at the lateral tibial intercondylar eminence.[20] Preoperatively, the picture archiving and communications system (PACS)–Photoshop (Photoshop CC 2017; Adobe) method was used to measure the height of the osteotomy gap, which shows high reliability.[39] Intraoperatively, the hip-knee-ankle angle was checked and adjusted to the preoperative templating (mechanical axis of the knee joint through the lateral tibial intercondylar eminence) using a Bovie line under fluoroscopy from the hip center to ankle center.[27,38] If the alignment target was not correct, the opening angle was adjusted. The osteotomy was stabilized using a locking plate system (Tomofix; DePuy Synthes) (Figure 2).

Notably, all the patients underwent the same protocol as in published research.[32] Partial weightbearing was allowed using a web brace (OA Reaction Web Knee Brace; DJO Global) during the first 6 weeks of full extension. Range of motion exercises were started 3 weeks, and the allowed range of motion at 3, 6, and 12 weeks postoperatively was 30°, 90°, and 120°, respectively. The patients were instructed to perform isometric muscle-strengthening and straight leg-raising exercises immediately after surgery, and isokinetic exercises were initiated at 12 weeks postoperatively. Light running and squatting were allowed 4 to 5 months postoperatively. Return to noncontact sports was permitted 7 to 9 months postoperatively; however, strenuous contact sports were prohibited.

Radiographic Evaluation

Radiographic evaluation was performed before and during the follow-up. Usually, follow-up radiological evaluations are conducted at 3, 6, and 12 months postoperatively and then annually. The K–L grade was used to assess medial compartment osteoarthritis progression on the Rosenberg view (45° posteroanterior flexion weightbearing radiograph), which is more reliable than a full extension weightbearing radiograph.[46] The Rosenberg method was used to measure the medial joint width from the center of the medial femoral condyle (MFC) to the center of the medial tibial plateau (MTP). The lower extremity alignment was measured using the mechanical axis of the hip-knee-ankle angle on a whole-leg weightbearing anteroposterior radiograph.[66] The joint line congruence angle was calculated as the angle between joint orientation lines on the distal femur and the tibial plateau, for which the lateral opening indicated the positive value. Measurements were performed using a PACS workstation (Centricity RA 1000; GE Healthcare). An experienced orthopaedic surgeon and a radiologist (S.J.K. and S.G.M., respectively) independently performed and measured radiographic measurements twice at 6-week intervals.

MRI Evaluation

MRI was performed on a 3.0-T system (Signa HD; GE Healthcare) preoperatively and at 2 days and 12 months postoperatively to assess the cartilage status of the medial compartment, graft extrusion, and signal intensity of the graft. All patients agreed to their radiological evaluation. Analysis was performed using the crosslink tool of the PACS workstation. The cartilage status of the medial compartment was assessed according to the ICRS grades (grade 0, intact; grade 1, normal cartilage contour with superficial lesions; grade 2, <50% loss of cartilage thickness; grade 3, >50% loss of cartilage thickness, as well as down to the calcified layer; and grade 4, full-thickness loss of cartilage).[48] The ICRS grade ≥3 was classified as a high grade.[57] The worst are as of the MFC and MTP cartilage loss were reported as the ICRS grade to determine the overall status of the corresponding articular cartilage.[33,35] Graft extrusion in the coronal plane at the posterior border level of the medial collateral ligament was measured as the distance between the medial margin of the graft and the superomedial aspect of the tibial plateau.[31] Pathologic extrusion was defined as graft extrusion of ≥3 mm.[1,6,25,36,41] Graft extrusions on postoperative MRI scans at 2 days and 12 months were assessed and compared using previously reported methods.[32,33] Our routine protocol involved evaluating whether the meniscal graft was close to its native anatomic position using a follow-up MRI scan after 2 days.[31-33] The graft status was graded according to the grading system used in previous studies—grade 0, normal; grade 1, globular increased signal intensity not extending to the articular surface; grade 2, linear intrameniscal hyperintense signal; and grade 3, increased signal intensity extending or communicating to the articular surface).[31,50] The graft was divided into 5 segments: anterior root, anterior one-third, midbody, posterior one-third, and posterior root.

An experienced orthopaedic surgeon and a radiologist (S.J.K. and S.G.M.) independently evaluated the MRI

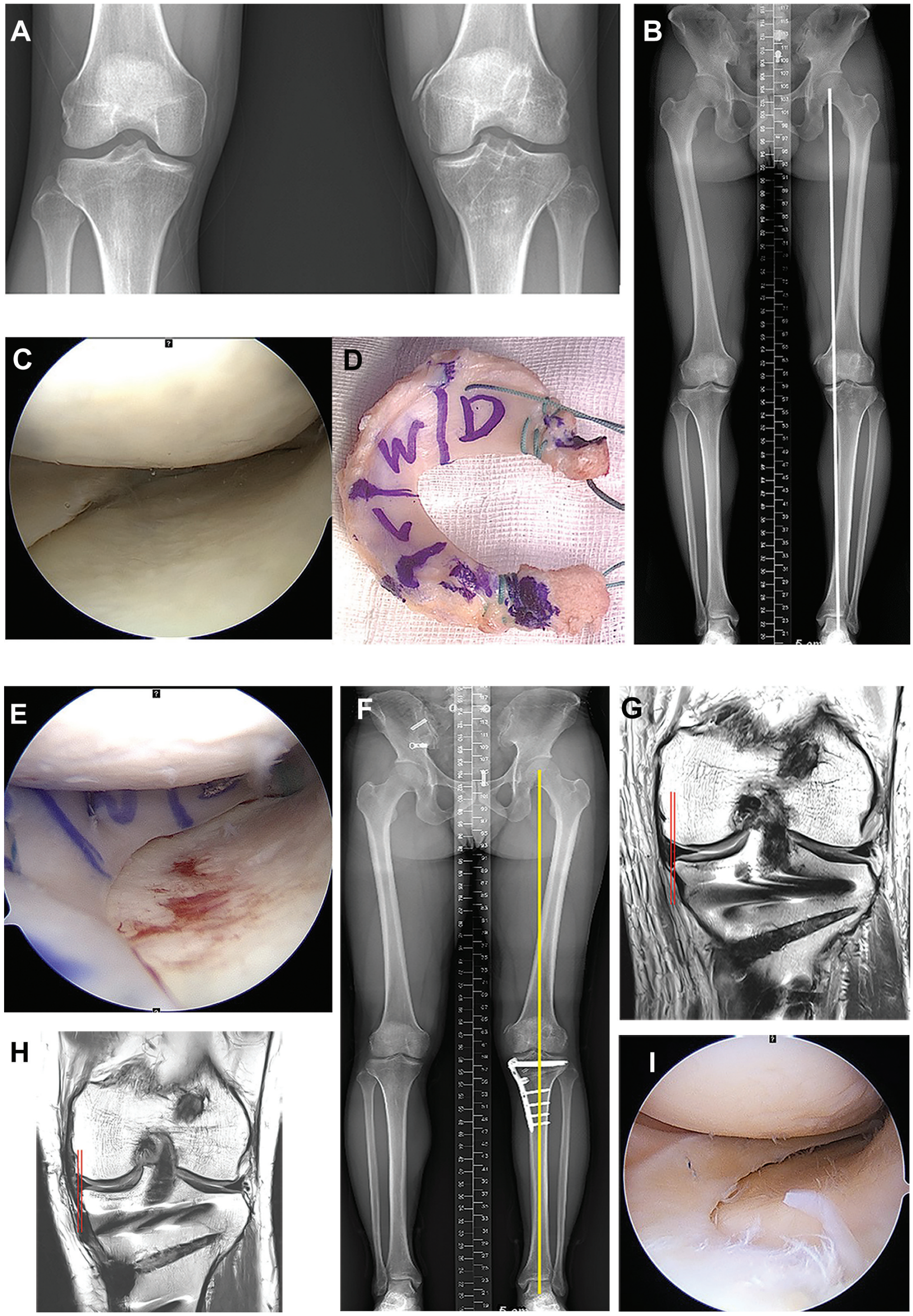

Figure 2. A 42-year-old male patient underwent concomitant MMAT and HTO on his left knee. (A) The preoperative K-L grade was grade 2. (B) The preoperative mechanical axis was varus 6.5°. (C) The MFC and MTP cartilage status were relatively intact during the surgery. (D) A freshly frozen, nonirradiated medial meniscal allograft was prepared. The anterior bone plug measured 8 mm in diameter and 8 mm in depth, whereas the posterior bone plug was 8 mm in diameter and 2 mm in depth. (E) The entire meniscal allograft was well fixed. (F) Simultaneously, HTO was performed to achieve a target alignment passing through a point at the lateral tibial intercondylar eminence. The postoperative mechanical axis was valgus 2° (G) Immediate postoperative MRI scan showed mild coronal graft extrusion (1.4 mm), indicated by red lines. (H) The postoperative MRI scan at 1 year also showed mild coronal graft extrusion (1.8 mm), indicated by red lines. (I) The medial meniscus was healed entirely during the second look arthroscopy. HTO, high tibial osteotomy; K-L, Kellgren-Lawrence; MFC, medial femoral condyle; MMAT, medial meniscal allograft transplantation; MRI, magnetic resonance imaging; MTP, medial tibial plateau.

TABLE 1
Descriptive Data for Groups M and H[a]

	Group M (n = 22)	Group H (n = 20)	P
Age, y	34.4 ± 5.2	37.7 ± 6.3	.074
BMI	22.7 ± 2.4	23.2 ± 3.1	.565
Sex, n, male/female	22/9	20/10	.719
Clinical follow-up period, mo	29.2 ± 4.9	27.4 ± 5.3	.262
MRI follow-up duration, mo	12.8 ± 1.9	12.4 ± 1.7	.476
Preop joint space width, mm	3.6 ± 1.1	2.9 ± 1	.037
Preop mechanical axis (hip-knee-ankle angle), deg	Varus 1.8 ± 1	Varus 4.2 ± 1.9	<.001
Preop joint congruence angle, deg	1.6 ± 1.1	2.8 ± 1.3	.002
Preop Kellgren-Lawrence grade, n, 1/2/3/4	10/11/1/0	4/12/4/0	.115
Preop ICRS grade on MFC ≥3	3 (13.6)	6 (30)	.269
Preop ICRS grade on MTP ≥3	1 (4.5)	3 (15)	.333
Coronal graft extrusion on MRI 2 d postoperatively, mm	0.5 ± 0.4	0.6 ± 0.4	.392
Preop Lysholm score	55.4 ± 9.5	52.6 ± 8.9	.331
Preop IKDC subjective score	51.4 ± 10.3	49.3 ± 11.4	.536
Concurrent cartilage repair (microfracture, ACI, or stem cell implantation)	2	4	.400
Concurrent cruciate ligament reconstruction			
Anterior cruciate ligament reconstruction	3	2	.637
Posterior cruciate ligament reconstruction	0	0	

[a]Data are presented as mean ± SD, n (%), or n. ACI, autologous chondrocyte implantation; BMI, body mass index; ICRS, International Cartilage Regeneration & Joint Preservation Society; IKDC, International Knee Documentation Committee; MFC, medial femoral condyle; MRI, magnetic resonance imaging; MTP; medial tibial plateau; Preop, preoperative.

scans. If there was a difference in the grading between the 2 observers, the grading was determined based on a consensus.

Clinical Assessments

The subjective functional tests included the Lysholm and International Knee Documentation Committee (IKDC) subjective knee scores. These tests were conducted preoperatively and at subsequent follow-ups. The present study used the patient-reported outcomes at a 2-year follow-up for the final assessment. Isokinetic muscle strength was measured using a Biodex System III dynamometer (Biodex Medical Systems) at an angular velocity of 60 deg/s. The peak torque of extension was measured. The results for the involved knee were compared with those for the uninvolved knee, and the side-to-side deficits (%) were calculated. The data at the 2-year follow-up were used for the final assessment.

Statistical Analysis

Statistical analysis was performed using the SPSS software (IBM SPSS Statistics 21; IBM Corp), and statistical significance was set at $P < .05$. The independent-samples *t* test was used to compare parametric variables such as joint space width, graft extrusion, and clinical scores. However, the Mann-Whitney *U* test was used to compare the 2 groups' nonparametric variables, such as the K-L, ICRS, and signal intensity grades. Pre- and postoperative parametric and nonparametric variables were compared using the paired *t* test and the Wilcoxon signed-rank test. The linear correlation was interpreted as follows: $|r|$ = 0.7 to 1 as strong; $|r|$ = 0.3 to 0.7 as moderate; and $|r|$ = 0.1 to 0.3 as weak.[2] Intra- and interobserver measurement reliabilities were assessed using intraclass correlation coefficient and classified as excellent (0.76-1), fair to good (0.40-0.75), and poor (0-0.40). Clinically meaningful differences in subjective functional tests were based on the minimal clinically important difference for the IKDC subjective score[17] of 11.5%. With α = .05 and power = 0.80, a minimum of 43 patients were needed to identify a meaningful difference in the IKDC subjective score. Therefore, we included 51 patients.

RESULTS

Table 1 presents the descriptive data. During MMAT, both groups showed statistically significant differences in preoperative joint space width, mechanical axis, and joint line congruence angle. However, the 2 groups showed no significant differences in other factors, such as age and body mass index. The mean follow-up period was 29.2 ± 4.9 months and 27.4 ± 5.3 months for groups M and H, respectively (P = .262). The Lysholm score improved from 55.4 ± 9.5 to 81.3 ± 9.7 and from 52.6 ± 8.9 to 84.2 ± 10.2 in groups M and H, respectively (both $P < .001$). The IKDC subjective score improved from 51.4 ± 10.3 to 79.6 ± 9.4 and from 49.3 ± 11.4 to 81.4 ± 8.3 in groups

TABLE 2
Clinical and Radiological Outcomes of Patients in Groups M and H[a]

	Group M (n = 22)	Group H (n = 20)	*P*
Lysholm score	81.3 ± 9.7	84.2 ± 10.2	.352
IKDC subjective score	79.6 ± 9.4	81.4 ± 8.3	.514
Isokinetic extensor strength at 60°, N·m/kg	155.8 ± 25.4	163.2 ± 28.1	.375
LSI for extensor strength, %	0.8 ± 0.2	0.9 ± 0.3	.207
Coronal graft extrusion, mm	3.3 ± 0.7	2.7 ± 0.8	.014
Pathologic graft extrusion	9 (40.9)	4 (20)	.143
Mechanical axis (hip-knee-ankle angle), deg	Varus 1.2 ± 2.2	Valgus 2.2 ± 0.7	<.001
Joint line congruence angle, deg	1.5 ± 1.3	1.8 ± 1.5	.492
K-L progression	4 (18.2)	2 (10)	.665
K-L grade ≥3	3 (13.6)	4 (20)	.691
ICRS grade on MFC ≥3	2 (9.1)	3 (15)	.656
ICRS grade on MTP ≥3	1 (4.5)	1 (5)	.945

[a]Data are presented as mean ± SD or n (%). ICRS, International Cartilage Regeneration & Joint Preservation Society; IKDC, International Knee Documentation Committee; K-L, Kellgren-Lawrence; LSI, leg symmetry index; MFC, medial femoral condyle; MTP, medial tibial plateau.

M and H, respectively (both *P* < .001). The 2 groups showed no significant differences in the Lysholm and IKDC subjective scores and isokinetic extensor strength at the final follow-up (Table 2). No specific osteotomy-related complications or adverse events were observed in group H (Figure 2). Concurrent cartilage repair was performed in 2 patients in group M and 4 patients in group H.

The intra- and interobserver agreements on the radiograph and MRI assessments were excellent (intraclass correlation coefficient, 0.788-0.851). During MMAT, K-L grade ≥3 was observed in 4.5% (n = 1) of patients in group M and 20% (n = 4) of patients in group H (*P* = .174). At 2 years postoperatively, K-L grade ≥3 was observed in 13.6% (n = 3) of patients in group M and 20% (n = 4) of patients in group H (*P* = .691). The K-L grade worsened in 18.2% (n = 4) and 10% (n = 2) of the patients in groups M and H, respectively (*P* = .665). Both groups showed no significant difference in postoperative joint line congruence angle (*P* = .492).

The 2 groups showed no significant difference in coronal graft extrusion on MRI scans at 2 days (*P* = .392); however, group M showed a greater coronal graft extrusion on MRI scans at 1 year postoperatively than did group H (3.3 ± 0.7 mm vs 2.7 ± 0.8 mm; *P* = .014). The rate of pathologic graft extrusion (≥3 mm) was not higher in group M (n = 9; 40.9%) than in group H (n = 4; 20%) (*P* = .143) (Table 2). The absolute value of graft extrusion showed a moderate correlation with the varus mechanical axis. The groups showed no significant differences in the pre- and postoperative cartilage statuses. Preoperatively, ICRS grade ≥3 cartilage loss was observed in the MFC in 13.6% (n = 3) and 30% (n = 6) of patients and the MTP in 4.5% (n = 1) and 15% (n = 3) of patients in groups M and H, respectively. Postoperatively, ICRS grade ≥3 cartilage loss was observed in the MFC in 9.1% (n = 2) and 15% (n = 3) of patients and the MTP in 4.5% (n = 1) and 5% (n = 1) of patients in groups M and H, respectively.

The 2 groups showed no significant difference in the graft status (Table 3). Graft tears were found in 2 patients (9.1%) and 1 patient (5%) in groups M and H, respectively (*P* = .607). None of the patients who had graft tears underwent surgery due to the absence of mechanical symptoms.

TABLE 3
Graft Status of Patients as Assessed Using MRI[a]

	Graft Status, 0/1/2/3, n		
	Group M (n = 22)	Group H (n = 20)	*P*
Anterior root	6/12/2/2	9/9/1/1	.238
Anterior one-third	11/9/2/0	9/10/1/0	.782
Midbody	8/10/3/1	5/13/2/0	.603
Posterior one-third	6/9/6/1	2/14/3/1	.253
Posterior root	6/9/3/4	6/8/3/3	.669
Graft tear, n (%)	2 (9)	1 (5)	.607
Tear site	1 midbody 1 posterior root	1 posterior root	

[a]Values are presented as n, unless otherwise indicated.The graft status is graded according to the grading system. Grade 0, normal; grade 1, globular increased signal intensity not extending to the articular surface; grade 2, linear intrameniscal hyperintense signal; and grade 3, increased signal intensity extending or communicating to the articular surface. MRI, magnetic resonance imaging.

DISCUSSION

The most crucial findings of this study were that clinical scores improved after both isolated MMAT and MMAT in combination with HTO and there were no significant differences in clinical outcomes between the 2 groups. Postoperative coronal graft extrusion was significantly greater in group M than in group H. The pathological graft extrusion rate was approximately twice as high in group M than in group H, although this was not a significant difference with the available numbers. The pre-and postoperative high ICRS grade rates did not differ between groups. The 2 groups showed postoperative improvements in ICRS grades, but no statistically significant difference was noted.

Varus malalignment is considered a contraindication for MMAT; however, outcomes would be comparable with those of MMAT in well-aligned lower limbs when the malalignment is corrected via a previous or concomitant bony realignment procedure at the time of MMAT.[52,53] Garrett and Steensen[14] reported that patients with varus malalignment had poorer Lysholm scores and higher failure rates compared with those with neutral alignment after cryopreserved MAT. Their follow-up was extended from 24 to 44 months. In contrast, some studies have indicated no significant clinical differences between using isolated MMAT in a well-aligned lower limb and MMAT combined with HTO to correct varus alignment. Vasta et al[64] reported no differences in patient-reported outcomes between isolated MMAT and MMAT combined with HTO; however, the absence of statistical information regarding the standard deviation and *P* values reduced the clarity of the results. Their mean follow-up was 4.8 years. Kazi et al[24] showed no differences in the IKDC subjective score, Tegner activity scale score, and median survival between isolated MMAT and MMAT combined with an osteotomy. Their mean follow-up was 180 months. The results of the present study are consistent with those of previous studies. There were no differences in the Lysholm and IKDC subjective scores or isokinetic muscle strength test results between the 2 groups at the minimum 2-year follow-up.

Meniscal extrusion is considered pathological when it exceeds 3 mm.[9,13,44] In a recent systematic review of clinical outcomes after MMAT,[40] absolute extrusion ranged from 2.6 to 4.4 mm, with the relative percentage of extrusion ranging from 24.8% to 53.7%, and the proportion of patients with major extrusions (>3 mm) varied from 0% to 78%. A direct correlation between graft extrusion and clinical outcomes after MAT has not been established; however, we have a theoretical concern that major extrusion may lead to a greater uncovered tibial surface area exposed to abnormal loads.[8,29] A meta-analysis performed by Lee[30] showed that absolute graft extrusion and the incidence of major extrusion were significantly greater after MMAT than after lateral MAT. Therefore, proper correction of the risk factors leading to graft extrusion during MMAT is crucial. Minimizing the pressure applied to the graft is the most critical strategy. The first risk factor is overstuffing the inherently thicker medial meniscal allograft into a relatively restricted joint space.[30] However, we attempted to resolve this problem by using a superficial medial collateral ligament release, which widened the medial compartment space in both groups. The second is its effect on the medial meniscotibial ligament. The meniscotibial ligament of the medial meniscus constrains the meniscus against extrusion; however, it is excised during MMAT. In situations where the medial compartment is under high pressure due to varus alignment, the absence of the meniscotibial ligament can exacerbate graft extrusion. The medial compartment bears approximately 60% of the load during walking, which increases when varus deformity is present.[5,60,62] Realignment procedures, such as medial opening wedge osteotomy, correct varus alignment and reduce the medial compartment load, with the advantage of a reduced medial meniscal extrusion. Astur et al[3] revealed that HTO decreased medial meniscal extrusion after 6 weeks and reported better outcomes for postoperative medial meniscal extrusion of <1.5 mm than >1.5 mm. Verdonk et al[65] showed that MMAT combined with HTO resulted in longer allograft survival and fewer failures than isolated MMAT with a well-aligned lower limb, suggesting that unloading the medial compartment could lead to better results. However, cartilage degeneration at the time of MMAT was more severe in patients who also underwent HTO. The present study performed HTO when the mechanical axis was >3° in varus based on the biomechanical rationale. There is still no clear consensus on the criteria for neutral alignment, and researchers define mild varus differently, ranging from 1° to 5°; therefore, the indications for HTO also vary among researchers.[11,18,42,49,58] This study adopted the criterion of ≤3° as neutral alignment, as suggested in previous studies.[11,42,47,49,58] Postoperative coronal graft extrusion was significantly greater in group M than in group H. The rate of pathological graft extrusion was twice as high in group M; however, this was not a significant difference with the available numbers. Group M was in mild varus, which was significantly different from the postoperative alignment in group H, and this may have contributed to the difference in the mean amount of graft extrusion. It is plausible to assume that HTO may have positively affected the intra-articular biomechanical environment in group H.

Conventionally, weightbearing lines would pass 60% to 70% laterally from the medial edge of the proximal tibia after medial opening wedge HTO, leading to a 3° to 5° valgus axis.[22] Notably, most authors perform HTO targeting a point known as the "Fujisawa point," although the Fujisawa point has never been confirmed biomechanically.[12,22,23,37,59] A recent biomechanical study demonstrated no benefit beyond the 3° valgus mechanical axis and reported that correcting the weightbearing line to 55% (1.7°-1.9° valgus axis) optimally distributed medial and lateral pressure.[45] Furthermore, several authors have reported that overcorrected postoperative lower limb alignment was associated with increased joint line obliquity, patellofemoral arthrosis, and decreased patient-reported outcomes.[27,37,56] Lee et al[38] revealed that HTO aimed at the lateral tibial spine showed clinical outcomes similar to those of HTO aimed at the Fujisawa point. Further progression of patellofemoral arthrosis was observed in patients targeting the Fujisawa point. Katagiri et al[23] showed that patients' reported outcome measures improved by 1 year postoperatively and were sustained until 3 years in HTO aimed at neutral alignment and HTO aimed at neutral alignment with arthroscopic meniscal centralization. In their study, weightbearing lines passed 57% laterally from the medial edge of the proximal tibia to avoid excessive joint line obliquity, lateral compartment osteoarthritis, and cosmetic problems. Lee et al[37] proved that less corrected HTO (weightbearing line ratios <57%) showed similar clinical results to those with appropriate correction (weightbearing line ratios within 57%-67%) and overcorrection (weightbearing line ratios >67%) correlated with inferior patient-reported outcomes. They suggested that less corrected HTO could be acceptable compared with targeting only the Fujisawa point with a high risk of overcorrection, as conventionally followed. In the present study, the mean mechanical axis difference between the 2 groups was within 3°, and there were no significant differences in the K-L grade and the ratio of the ICRS grades ≥3 between the 2 groups preoperatively. We targeted the lateral tibial spine to make a weightbearing line pass through 55% to 60% laterally, and the mean postoperative mechanical axis was 2.2° ± 0.7° valgus in group H; there was no overcorrection. However, we suggest that a conventional target point to induce a 3° to 5° valgus axis is not mandatory because intra-articular biomechanics can be somewhat normalized via a realignment procedure. Kim et al[26] reported that HTO with concomitant cartilage repair aimed at 50% to 55% lateral to the tibial plateau, leading to a neutral or valgus axis of <3°, showed clinical outcomes similar to those of 62% to 66% lateral to the tibial plateau. Therefore, proper correction can be an effective and safe technique for obtaining reliable clinical outcomes without complications.

Outcomes of MMAT in combination with HTO are lacking due to the rarity of simultaneous procedures; however, we tried to comprehensively compare MMAT combined with HTO and isolated MMAT in the present study. Preoperatively, group H showed slightly more advanced arthritis compared with group M without statistical significance. However, the postoperative results of group M were worse in graft extrusion and osteoarthritis progression. We assume that a synergistic relationship existed between improving the mechanical axis and meniscal restoration if the patients did not have advanced osteoarthritis. Our findings suggest that performing a realignment procedure in relatively young patients with medial meniscal deficiency and varus malalignment can yield clinical outcomes comparable with those of performing MMAT alone. Furthermore, the simultaneous realignment procedure indicates potential advantages in graft healing. The results of this study are expected to provide clinical guidance for future treatment decisions in similar patient populations.

The present study has some limitations. First, this was a retrospective study with a small sample size, and a selection bias could have occurred. MMAT is not frequently conducted according to strict criteria, and the procedure of concomitant MMAT and HTO is relatively rare. Therefore, our study might have lacked power for secondary outcomes, especially the percentage of patients with pathological meniscal extrusion. This point will require further study with larger numbers of patients. Second, the follow-up period was relatively short for determining K-L or ICRS grade progression. Therefore, the long-term radiological outcomes are limited. However, the follow-up period was sufficient to estimate patient-reported outcomes or complications. Third, there may be doubts about whether MMAT or realignment procedures are significant in intra-articular biomechanics. However, the mean mechanical axis difference between the 2 groups at the time of surgery was within 3°. Overcorrection was not performed during HTO in cases with varus deformity of ≥3°. Consequently, performing HTO and MMAT was associated with reduced graft extrusion, leading to the belief that it may not be necessary to question whether similar results could be achieved with HTO alone. A prospective study comparing an isolated realignment procedure with realignment combined with MMAT is required to answer this question fully. Finally, patients >50 years of age were excluded. Age >50 years and joint obliteration on the Rosenberg view are commonly known as contraindications for MAT. These patients undergo the operation only upon strong personal preference, regardless of the country's medical insurance benefits. However, as they are textbook contraindications for MAT, including these patients in the study could serve as outliers and potentially confound the interpretation of results.

CONCLUSION

Clinical scores significantly improved after isolated MMAT and MMAT combined with HTO compared with preoperative values, and their short-term outcomes were similar. Postoperative graft extrusion was greater in patients who underwent isolated MMAT, implying that active correction of varus alignment during MMAT may help in intra-articular biomechanics.

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