Short-term Outcomes after High Tibial Osteotomy Aimed at Neutral Alignment Combined with Arthroscopic Centralization of Medial Meniscus in Osteoarthritis Patients

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Abstract

Purpose To improve long-term outcomes of open-wedge high tibial osteotomy (OWHTO), procedures combining OWHTO aimed at neutral alignment and arthroscopic centralization for meniscal extrusion have been introduced. The purpose of the present study was to compare short-term clinical and radiological outcomes of medial joint space width (JSW) after the OWHTO aimed at neutral alignment with and without arthroscopic centralization for an extruded medial meniscus.

Methods A retrospective review of 50 primary OWHTO patients was conducted. Thirty-five patients included for analysis after exclusion criteria was applied. Twenty-one knee osteoarthritis patients, who underwent the OWHTO with arthroscopic meniscal centralization, were included in the centralization group. Fourteen patients, who underwent solely OWHTO, were included in the control group. Lysholm knee scale, International Knee Documentation Committee (IKDC) subjective score, Knee Osteoarthritis Outcome Score (KOOS), and patient subjective satisfaction scores were recorded at the final follow-up. Radiographic changes of JSW and joint line congruence angle (JLCA) were measured 2 years postoperatively. Patient demographic data were also reviewed.

Results IKDC subjective scores, KOOS subgroup scores, patient subjective satisfaction scores, and Lysholm score did not show significant differences between the two groups at the final follow-up. Change of the JSW in the centralization group was significantly greater than that in the control group 2 years postoperatively (Control group: -0.1 mm, Centralization group: 0.8 mm P =0.03).

Conclusion Change of JSW after OWHTO aimed at neutral alignment with arthroscopic centralization for extruded medial meniscus was greater than solely OWHTO, and there was no significant difference in the short-term clinical outcomes between the 2 procedures at the final follow-up.

Introduction

Two national registry-based studies reported that the 5-year conversion rate of open-wedge high tibial osteotomy (OWHTO) to total knee arthroplasty was approximately 10% and the 10-year conversion rate to total knee arthroplasty reached approximately 30%.[1, 2] Clinical outcomes of OWHTO had deteriorated over time with conversion to total knee arthroplasty.[3] Therefore, further improvement of clinical results after OWHTO to decrease the conversion rate is required.

Medial meniscal extrusion commonly occurs in knee joint osteoarthritis and is strongly associated with the progression of osteoarthritis.[4, 5] Meniscal extrusion decreased the tibiofemoral contact area and increased tibiofemoral contact pressure, leading to the worsening of knee osteoarthritis.[6] Koga et al. [7, 8] reported that arthroscopic centralization of the extruded meniscus, where the capsule adjacent to the meniscus was sutured to the edge of the tibial plateau, decreased meniscal extrusion. Arthroscopic centralization for an extruded lateral meniscus results in good clinical outcomes of the Lysholm knee scale and the Knee Osteoarthritis Outcome Score (KOOS) and radiographic outcomes with the lateral joint space widening at 2-years follow-up.[9] In a study using rats, the centralization technique of extruded medial meniscus successfully delayed cartilage degeneration.[10] Therefore, procedures combining OWHTO aimed at neutral alignment (weight bearing line ratio aimed at 57%) and arthroscopic centralization of the medial meniscus for medial unicompartmental knee osteoarthritis with an extruded medial meniscus have been developed to decrease tibiofemoral contact pressure and achieve superior long-term results. Its clinical and radiological outcomes are yet to be reported.

The purpose of this study was to compare short-term clinical outcomes, namely the IKDC subjective score, all KOOS subgroup scores, the patient subjective satisfaction scores, and the Lysholm score, and radiological outcomes of medial joint space width (JSW) after the OWHTO aimed at neutral alignment, with and without an arthroscopic centralization for an extruded medial meniscus. The underlying hypothesis for this study was that OWHTO with arthroscopic centralization would lead to similar short-term clinical outcomes in comparison to solely OWHTO, and that change of JSW after OWHTO with arthroscopic centralization would be greater than solely OWHTO.

Methods

Subjects

A retrospective review of 50 patients who had undergone primary OWHTO between December 2011 to May 2017 at Tokyo Medical and Dental University Hospital of Medicine was conducted. The OWHTO had been undergone for younger and/or physically active unicompartmental knee osteoarthritis patients with patient demand. Patients were excluded during the course of the study if patients refused of consent or joined stem cell clinical trial, postoperative infection occurred, procedure was inadequate with the weight bearing line passed at less than 40% of the width of the tibial plateau postoperatively, questionnaire was incomplete, or follow-up lost in within 2 years. All patients gave their full written informed consent for participation in this clinical research prior to the operative procedure. Three patients were enrolled stem cell clinical trial (Figure 1). Four patients did not fill completely questionnaire before surgery. Four patients were excluded due to the weight bearing line passed at less than 40% of the width of the tibial plateau postoperatively. All the patients were followed up for 2 years or more, except for 3 who were lost to follow-up within 2 years. One patient did not fill completely questionnaire at 2 year after surgery. Consequently, a total of 35 patients were included in this study. Until 2014, OWHTO solely had been performed for 5 patients regardless of the condition of the medial meniscus. However, since 2014, OWHTO with arthroscopic centralization of the medial meniscus have been performed for 21 patients where extrusion of the midbody of the medial meniscus was confirmed preoperatively; and solely OWHTO have been performed for 9 patients without extrusion of the medial meniscus. The extrusion of the medial meniscus was defined as extension of the meniscal margin by at least 3 mm beyond the tibial margin, on a coronal magnetic resonance imaging (MRI) at the mid-point of the medial meniscus. Consequently, this study included 21 patients that underwent OWHTO and arthroscopic meniscal centralization (centralization group) and 14 patients that underwent only OWHTO (control group). Demographic data including age, sex, height, weight, and body mass index (BMI) had been recorded preoperatively. This study was approved by the institutional review board.

Operative procedures

All surgeries were performed by/under the supervision of two senior surgeons (more than 15 years of experience in orthopedic surgery). A standard arthroscopic evaluation was performed before OWHTO. Articular cartilage lesions were assessed by International Cartilage Repair Society (ICRS) grade. Any unstable meniscal tears were repaired if possible, by the all-inside suture technique using the Fast-Fix device (Smith & Nephew, Andover, MA, USA) and/or the inside-out suture technique using the Henning meniscal suture kit (Stryker, Kalamazoo, Michigan, USA). Three patients in centralization group and one patient in control group were undergone meniscus suture. If the torn menisci were difficult to repair, they were partially resected while trying to preserve as much volume as possible. Eight patients in centralization group and four patients in control group were undergone partially meniscus resection.

Arthroscopic meniscal centralization, as previously described, was performed for the extrusion of the medial meniscus in the centralization group (Figure 2).[8] In brief, extrusion of the medial meniscus was confirmed by pushing the midbody of the meniscus out of the rim of the medial tibial plateau using a probe (Figure 2A, B). A mid-medial portal was made with an arthroscopic view from the anterolateral portal, 1 cm proximal to the medial meniscus and anterior to the medial femoral condyle. Any osteophytes were resected (if they existed) using a chisel. The meniscotibial capsule under the medial meniscus was then released from the medial tibial plateau for mobilization of the meniscus in order to ease reduction of the meniscal extrusion. The rim and distal part of the medial tibial plateau were rasped to prepare for adhesion of the tibia and meniscotibial capsule (Figure 2D, E). A JuggerKnot Soft Anchor loaded with a No. 1 MaxBraid (Biomet, Warsaw, IN) suture was inserted on to the medial edge of the medial tibial plateau as posterior as possible (Figure 2F, G). The tip of the Micro Suture Lasso Small Curve with nitinol wire loop (Arthrex, Naples, FL) penetrated the capsule from a superior to an inferior direction at the margin between the meniscus and the capsule (Figure 2H, I). A single strand of sutures was passed into the wire loop, and the other limb of the wire loop was pulled to pass the suture from an inferior to a superior direction (Figure 2J). The same procedure was repeated with another strand of the suture to create a mattress suture configuration. Another JuggerKnot Soft Anchor was inserted on to the medial edge of the medial tibial plateau, 1 cm anterior to the first anchor, and the same procedure was repeated. The passed sutures were then tied using a self-locking sliding knot (Figure 2K). The displaced meniscus was centralized after centralization of the midbody of the medial meniscus (Figure 2L).

The OWHTO procedure followed the method proposed by Staubli et al.[11] In brief, the preoperative plan involved, shifting the mechanical axis to a point 57% lateral on the transverse diameter of the tibial plateau. The correction angle and opening width were measured. The osteotomy site was opened by a spreader while the limb alignment was simultaneously monitored by fluoroscopy to check the position of the alignment rod at the knee. Once the desired alignment (weight bearing line ratio at 57%) was obtained, wedge-shaped β- tricalcium phosphates (Osferion 60; Olympus Terumo Biomaterials, Tokyo, Japan) were inserted between the opened osteotomy site. Tris plate (Olympus Terumo Biomaterials, Tokyo, Japan) or Tomofix plates (DePuy Synthes Johnson & Johnson, Tokyo, Japan) were used to fix the osteotomy site with locking screws.

The postoperative rehabilitation followed our standard protocol, which did not vary with the meniscal procedure. The patients began to practice the range of motion and quadriceps setting exercises a day after surgery. One-third, two-third, and full weight-bearing with crutches were initiated 3, 10, and, 14 days respectively after surgery. Patients were allowed to start running exercises at 3 months after confirming bone union and patients progressed to full activity after six months postoperatively.

Clinical evaluations

Clinical evaluations for all patients were assessed by orthopedic doctors who were qualified by Japanese Board of Orthopaedic Surgery and were more than 10 years of experience in orthopedics.

Passive knee extension and flexion angles were measured in a supine position with a goniometer and described in 1° and 5° increments, respectively, pre-operatively and at the final follow-up. The Lysholm knee scale was used to determine the knee functional score at the final follow-up. The International Knee Documentation Committee (IKDC) subjective score, and KOOS were used to measure patient-reported outcomes at the final follow-up.[12] Patient subjective satisfaction scores out of 100 points were also evaluated pre-operatively and at the final follow-up. Post-operative complications needing an additional surgery, such as loss of knee motion, infection at the operation site, a tear of the sutured meniscus, and conversion to total knee arthroplasty were recorded.

Radiological evaluations

A single orthopedic surgeon (HK), who had more than fifteen years of experience in orthopedic surgery and did not perform any surgery in this series, retrospectively reviewed the JSW and joint line congruence angle (JLCA) at pre-operative, 1 year, and 2 years after surgery intervals in a blinded manner. The medial joint space of the affected knee was measured on the Rosenberg view (standing, 45° flexion, posteroanterior view), since this is more sensitive and accurate to view narrowing of the joint space than the conventional extension weight bearing anteroposterior view.[13] The JSW was measured at the narrowest point in the medial compartment. The JLCA was measured as the angle between joint orientation lines at the distal femur and the proximal tibia. The femoro-tibial angle (FTA), hip-knee-ankle angle (HKA angle), weight bearing line ratio, and Kellgren-Lawrence grade were also described using an anteroposterior long-leg weight-bearing radiograph preoperatively and 2 years after surgery. Intra-observer measurement reproducibility for JSW was assessed with the Intra-class correlation coefficient (ICC). The observer was blinded to the previous results. The intra-observer ICC for JSW was 0.97. Therefore, the results were considered to be excellent.[14] Minimal detectable change at the 95% confidence level (MDC95) was 0.43mm for JSW.

Statistical analysis

Statistical analyses were performed using the GraphPad Prism 5 (GraphPad Software, Inc., La Jolla, CA, USA). Kellgren-Lawrence grade, ICRS grade for articular cartilage lesions, and postoperative follow up periods were compared between centralization group and control group using a Mann-Whitney test. Rest of items were compared between the two groups using a *t*-test, after confirming normality using a histogram, and equal variance using the F test. JSW, JLCA, and range of knee joint motion in both groups were compared between at pre-operation and at 2 year after operation by a paired *t*-test. *P*-values <0.05 were considered statistically significant. Data were expressed as mean with 95% CI or median with minimum and maximum values. A post hoc power analysis revealed that, with an alpha value of 0.05, the current study achieved a power of 66.4% for the difference in change of JSW between the groups.

Results

Patient characteristics

Age, gender, height, weight, BMI, preoperative FTA, preoperative HKA angle, preoperative weight bearing line ratio, the Kellgren-Lawrence grade, and ICRS grade for articular cartilage lesions did not show significant differences between the two groups (Table 1). Postoperative FTA, postoperative HKA angle, postoperative weight bearing line ratio, and change of weight bearing line ratio also did not show significant differences between the groups 2 years after surgery.

Clinical outcomes at the final follow-up

Postoperative follow-up periods did not show significant differences between the groups. The knee extension and flexion angles did not deteriorate at the final follow-up in both groups, and there were no significant differences between the 2 groups at the final follow-up (Table 2). All patients in both groups did not have any complication or obvious residual pain. Moreover, there were no cases of early failure that were converted to total knee arthroplasty. There were no significant differences in the IKDC subjective score or any KOOS subgroup scores at the final follow-up between the 2 groups (Table 3). The patient subjective satisfaction scores significantly improved at the final follow-up in both groups, and there was no significant difference between the groups. There were no significant differences in the Lysholm score between the 2 groups at the final follow-up.

Effects of Meniscal Centralization on Joint Morphology

In control group, there was no significance difference between preoperative and 2 year after surgery in JSW and JLCA (Table 4). In centralization group, the JSW and JLCA 2 year after surgery were significantly improved in comparison to the preoperative JSW and JLCA, respectively. Change of JSW 2 years after surgery in the centralization group was significantly greater than that in the control group (Control group: -0.1 mm [-0.6-0.5 mm], Centralization group: 0.8 mm [0.3 - 1.4 mm] *P*=0.03, Figure 3). There was no significance difference between change of JLCA 2 years after surgery in control group and centralization group (Change of the JLCA: Control group: 0.4°[-0.5 - 1.3°], Centralization group: 0.9° [0.1-1.7°] *P*=0.37).

Discussion

The most important finding of this study was that change of JSW after OWHTO aimed at neutral alignment with arthroscopic centralization for extruded medial meniscus was greater than after solely OWHTO. Moreover, there was no significant difference in the IKDC subjective score, any KOOS subgroup scores, the patient subjective satisfaction scores, or the Lysholm score between the 2 groups at the final follow-up. First, medial joint spaces were significantly increased in the centralization group. Joint space widening might delay the progression of degenerative osteoarthritis to prolong the conversion to total knee arthroplasty. Second, since OWHTO aimed at neutral alignment with arthroscopic centralization were new procedure, this study was the first for this new procedure to be evaluated short-term clinical outcomes and occurrence of early complication. Clinical outcomes at the final follow-up for the centralization group were similar to those for the control group and were not inferior compared to previous studies.[15–17]

The conversion to total knee arthroplasty due to the progression of degenerative osteoarthritis is a major complication after an OWHTO. The current study demonstrates that centralization increased JSW by 0.9 mm in comparison to an OWHTO solely. In distribution-based methods, the minimal clinically important difference value is defined as the upper value of the 95% confidence interval for the average change in control group.[18] The upper value of the 95% confidence interval for the average change in control group was 0.5 mm in JSW, which was larger than MDC95 for JSW. Twelve patients in the centralization group surpassed the minimal clinically important difference in JSW. A previous review has reported that the annual joint space narrowing rate was 0.13 mm / year in osteoarthritis patients.[19] A prospective cohort study that analyzed 298 patients who underwent OWHTO also found that the annual joint space narrowing rate was 0.02 mm /year.[20] Based on these data, it can be presumed that a centralized meniscus occupying the joint space is 6.9 times as high as the annual joint space narrowing (0.9 mm divided by 0.13 mm) and the extra mm of joint space might prolong the conversion to total knee arthroplasty.

IKDC subjective scores after an OWHTO were reported from 61 points to 73 points in previous studies.[21–24] IKDC subjective scores in both groups in our study were within the range of previous studies. Similarly, patient satisfaction subjective scores and the Lysholm score in both groups in the current study were not inferior to those from previous studies (75 to 81 points [17, 25–27] and 58 to 92 points, [16, 21, 22, 24, 28, 29] respectively).

Meniscus plays a crucial role in load-bearing and shock absorption.[30] In a previous study, contact forces on the medial meniscus in the human knee joint were mapped, which showed that the meniscus transmitted more than 50% of the total axial load in the joint.[31] The medial meniscus in osteoarthritis patients extrudes beyond the outer margin of the tibial plateau and loses axial load distribution.[32, 33] A biomechanical study of centralization for an extruded meniscus on pigs revealed that the centralization technique was able to increase axial load distribution of a meniscus.[34] Therefore, additional procedures to decrease meniscal extrusion could be a possible solution to improve survival rates of the OWHTO. The current study indicated that an OWHTO with arthroscopic centralization for an extruded medial meniscus did not deteriorate clinical outcomes, and notably improved radiological outcomes with medial joint space widening up to 2 year after surgery. Longer follow-up studies to assess the effectiveness of arthroscopic centralization in preventing the progression of osteoarthritis and the conversion to total knee arthroplasty was essential.

Meniscus centralization surgeries might associate with a risk of deficit of knee range of motion by limiting normal motion of the meniscus during knee extension-flexion due to suture of the capsule adjacent to the extruded meniscus. We found that the knee extension angle and the knee flexion angle did not change in the centralization group at the final follow-up. There were no significant differences between the control group and the centralization group in both the knee extension and flexion angle at the final follow-up. No case had a limited range of motion in this series.

The mechanical axis has been aimed to a point 62% lateral on the transverse diameter of the tibial plateau to decrease the medial tibiofemoral contact pressure in traditional OWHTO.[35] However, there could be several complications due to a valgus alignment after OWHTO. A cohort study including approximately 10,000 knees revealed that valgus malalignment increases the risk of radiographic lateral knee osteoarthritis progression when compared to neutral knee alignment.[36] In addition, OWHTO could cause a worsening of lateral compartment osteoarthritis in patients with complete discoid meniscus.[37] A valgus alignment after an HTO could also cause cosmetic problems or diminish sports performance levels especially in young active patients. From a biomechanical perspective, if the correction target were aimed at 62% in weight bearing line ration, a large correction with a joint-line obliquity could induce excessive tibiofemoral contact pressure in cases with severe varus alignment.[38] Based on these considerations, the current study aimed at 57% in weight bearing line ratio as neutral alignment.

Limitations

This study has several limitations. First, the present study included a small number of subjects, although the sample size was still large enough to detect differences in JSW and the post hoc power analysis showed enough power for JSW. Second, surgeries were performed by/under the two different senior surgeons. However, the two senior surgeons took part in each other surgeon surgeries and equalized the operation methods. Third, since this study was conducted in a retrospective manner, there might be a selection bias. The centralization group had twice the number of partial meniscectomy than the control group. Partial meniscectomy generally decreases the JSW. Different number of partial meniscectomy would not weaken the results of this study. Thus, a further randomized trial comparing OWHTO with or without centralization is warranted.

Conclusions

In conclusion, change of JSW after OWHTO aimed at neutral alignment with arthroscopic centralization for extruded medial meniscus was greater than solely OWHTO, and there was no significant difference in the short-term clinical outcomes between the 2 procedures at the final follow-up.

Abbreviations

Open-wedge high tibial osteotomy
OWHTO
Joint space width
JSW
International Knee Documentation Committee
IKDC
Knee Osteoarthritis Outcome Score
KOOS
Joint line congruence angle
JLCA
Magnetic resonance imaging
MRI
Body mass index
BMI
International Cartilage Repair Society
ICRS
Femoro-tibial angle
FTA
The hip-knee-ankle angle
HKA angle
Intra-class correlation coefficient
ICC
Minimal detectable change at the 95% confidence level
MDC95

Declarations

Ethics approval and consent to participate:

This study was approved by the institutional ethical review board. All patients provided their full written informed consent for participation in this clinical research prior to the operative procedure.

Consent for publication:

All authors and all participants consented for publication this study on this journal. All authors read, approved the final manuscript and takes responsibility for the integrity of the data and the accuracy of the data analysis

Availability of data and materials:

The datasets during the current study available from the corresponding author on reasonable request.

Competing interests:

Hiroki Katagiri, Yusuke Nakagawa, Kazumasa Miyatake, Koji Otabe, Toshiyuki Ohara, Mikio Shioda, Ichiro Sekiya, and Hideyuki Koga declare that they have no competing interests.

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Authors' contributions:

HK conceived the study and performed all experiments and participated in its design. KM participated in its design and performed analysis. YN and KO acquired the data. TO and MS analyzed and calculated the data. IS participated in its design. HK had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

All authors read, approved the final manuscript and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Tables

Table 1. Patients' characteristics

	Control group	Centralization group	P Value
Age (y)	62 [47 - 71]	59 [44 - 73]	0.23
Female	11	12	0.19
Male	3	9	
Height (cm)	160.2 [151.2-176.5]	165.0 [140.6 - 183.7]	0.19
Weight (kg)	66.7 [50.2–114.3]	65.1 [43.0 - 83.0]	0.77
BMI	25.7 [18.5 - 36.7]	23.7 [19.1 - 28.5]	0.14
Preoperative patient satisfaction score	38.3 [0 - 80]	28.6 [0 - 70]	0.29
Preoperative FTA (degree)	181.3 [177.5 – 186.3]	181.5 [175.3 - 187.6]	0.79
Preoperative HKA angle (degree)	7.4 [3.6 – 10.5]	7.5 [2.7 - 11.8]	0.98
Preoperative weight bearing line ratio (%)	14.0 [2.6 - 30.9]	14.1 [-17.2 - 36.4]	0.97
Preoperative KL grade (2/3/4)	8/4/2	8/10/3	0.39
ICRS grade: femoral cartilage (0/1/2/3/4)	(0/1/0/12/1)	(0/0/1/20/0)	0.70
ICRS grade: tibial cartilage (0/1/2/3/4)	(0/0/1/12/1)	(0/0/1/19/1)	0.98
Postoperative FTA (degree)	172.8 [166.6 – 177.5]	172.6 [167.9 - 177.1]	0.80
Postoperative HKA angle (degree)	-1.5 [-6.4 – 1.5]	-1.7 [-5.1 - 3.0]	0.77
Postoperative weight bearing line ratio (%)	52.4 [41.1 – 69.8]	55.6 [42.6 – 67.0]	0.27
Change of weight bearing line ratio (%)	38.5 [13.2 – 55.9]	41.5 [20.5 – 71.9]	0.45
Postoperative follow up periods (month)	36.1 [24 - 87]	29.1 [24-36]	0.50

Values with brackets are expressed as median with minimum and maximum values. body mass index, (BM)I; femoro-tibial angle (FTA); hip-knee-ankle angle (HKA angle); Kellgren-Lawrence grade (KL grade); International Cartilage Repair Society grade (ICRS grade)

Table 2. Range of knee joint motion

	pre-operatively	2 year after surgery	P Value
Control group			
Extension	0 [-10-5]	0 [-2-5]	0.16
Flexion	140 [100-150]	145 [125-155]	0.04
Centralization group			
Extension	-2 [-10-3]	-1 [-3-2]	0.16
Flexion	140 [130-155]	145 [125-155]	0.25

Values with brackets are expressed as median with minimum and maximum values.

Table 3. Patient-reported outcome measures

	Control group	Centralization group	P Value
IKDC subjective score	65.5 (55.6-75.5)	71.8 (63.9-79.7)	0.29
KOOS			
Pain	82.7 (71.8-93.5)	82.9 (75.8-90.1)	0.96
Symptoms	82.2 (72.1-92.3)	81.8 (75.0-88.5)	0.93
ADL	93.2 (88.1-98.2)	90.3 (84.9-95.7)	0.44
Sport/Recreation	67.9 (50.2-85.5)	67.1 (56.0-78.3)	0.94
QOL	73.7 (60.4-86.9)	67.9 (56.6-79.1)	0.49
Patient subjective satisfaction score	84.6 (76.8-92.5)	79.7 (70.0-89.3)	0.44
Lysholm score	93.3 (88.4-98.1)	94.1 (91.4-96.7)	0.75

Values with parentheses are expressed as mean with 95% CI. International Knee Documentation Committee (IKDC); Knee Injury and Osteoarthritis Outcome Score (KOOS)

Table 4. Radiological evaluation of joint morphology

	pre-operatively	2 year after surgery	P Value
Control group			
JSW (mm)	2.2 (1.4-3.1)	2.2 (1.7-3.0)	0.82
JLCA (degrees)	3.8 (2.6-5.0)	3.4 (1.7-5.2)	0.36
Centralization group			
JSW (mm)	1.9 (1.4-2.4)	2.7 (2.3-3.2)	<0.01
JLCA (degrees)	4.2 (3.3-5.1)	3.3 (2.6-3.9)	0.03

Values with parentheses are expressed as mean with 95% CI

joint space width (JSW); joint line congruence angle (JLCA)

Figures

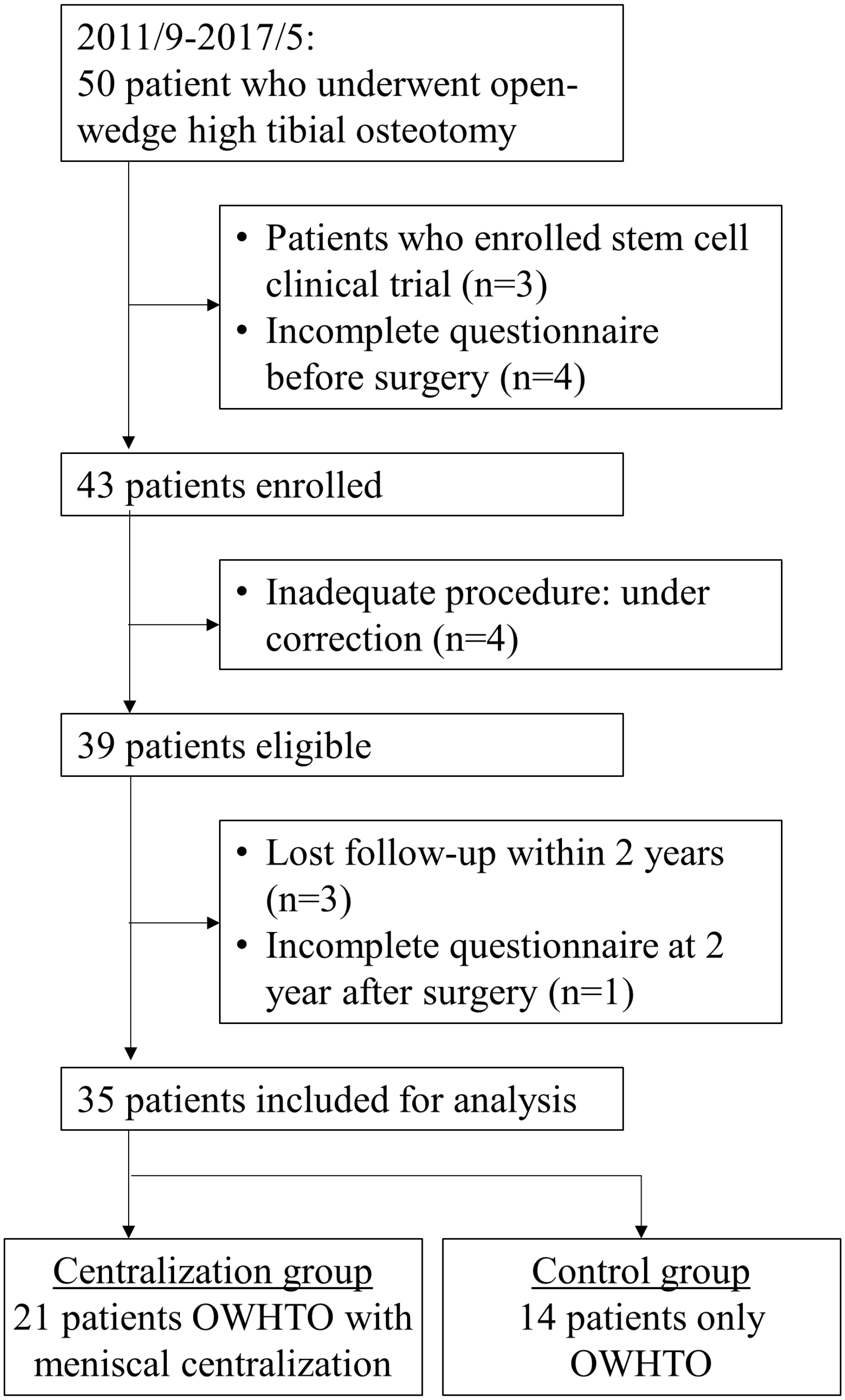

Figure 1

Flow chart of inclusion and exclusion

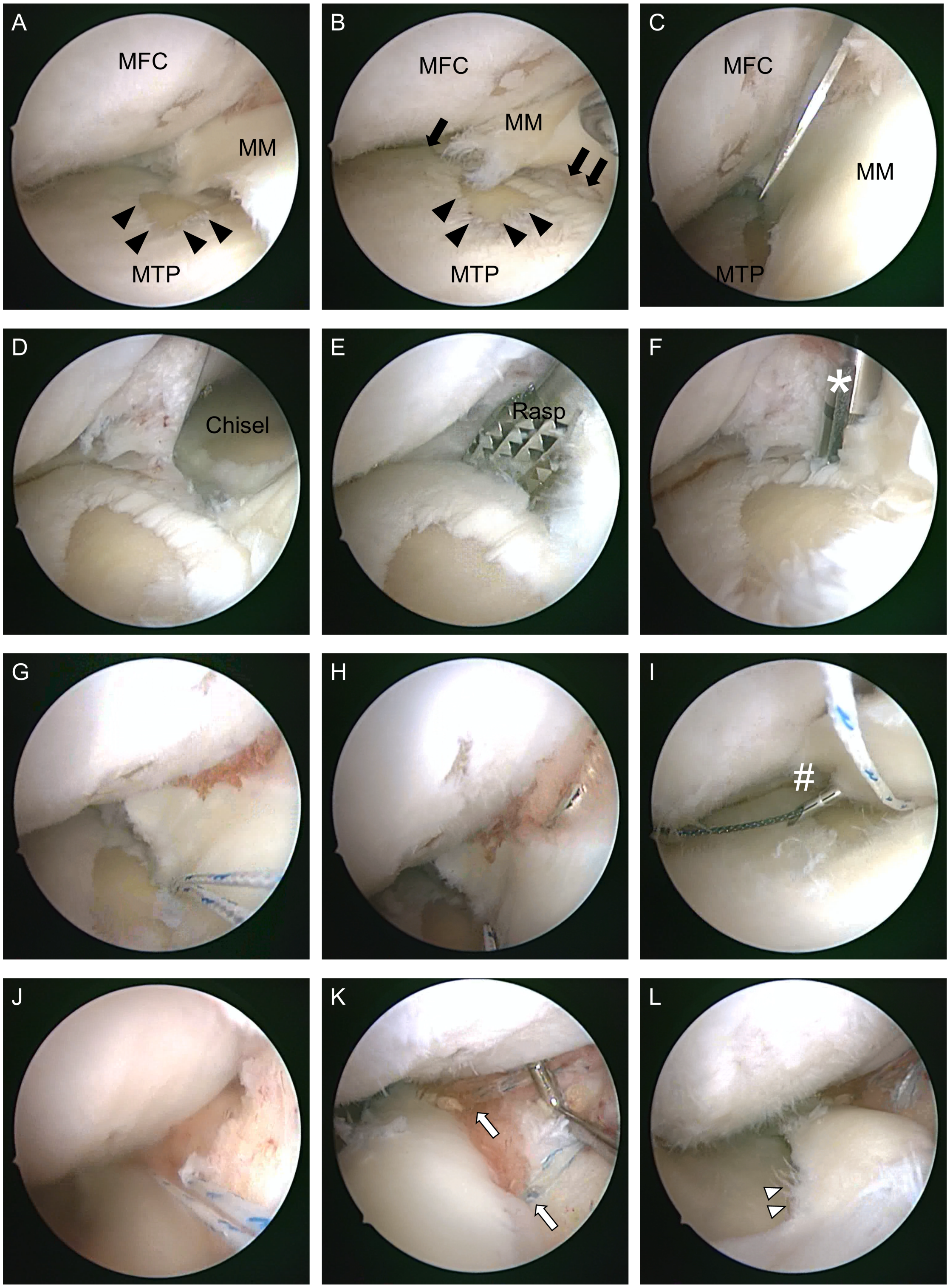

Figure 2

Arthroscopic findings of the centralization technique. (A) Arthroscopic view of the medial meniscus from the anterolateral portal in right knee joint. Displacement of the medial meniscus was confirmed arthroscopically. Full thickness cartilage defects with exposed subchondral bone was observed (black arrowheads). (B) The extruded medial meniscus was easily moved away beyond the rim of the medial tibial plateau (black arrows) with a probe. (C) A mid medial portal 1 cm proximal to the medial meniscus anterior to the medial femoral condyle. (D) Spur resection with a chisel. (E) Meniscotibial capsule released with a rasp. (F, G) A JuggerKnot Soft Anchor inserted on the medial edge of the medial tibial plateau (a sleeve of the JuggerKnot Soft Anchor; white asterisk). (H, I) A Micro SutureLasso Small Curve with a nitinol wire loop (white pound sign) inserted and penetrated the capsule from superior (H) to inferior (I) direction at the margin between the meniscus and the capsule. (J) Retrieved suture passed the capsule from inferior to superior. (K) The sutures tied using a self-locking sliding knot (white arrows). (L)The extruded meniscus centralized after centralization of the midbody of the medial meniscus. Tibial plateau and the exposed subchondral bone covered (white arrowheads). (MFC: medial femoral condyle. MM: medial meniscus. MTP: medial tibial plateau.)

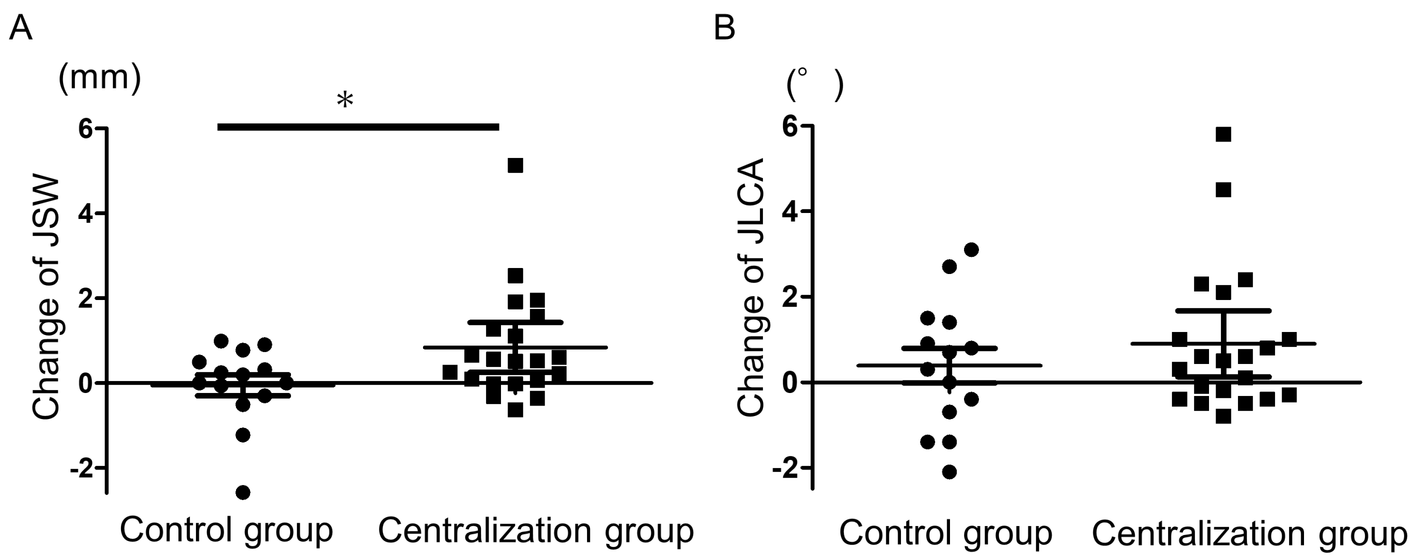

Figure 3

(A) Scatter plot of change of JSW in the control group and the centralization group 2-years postoperatively. (B) Scatter plot of change of JLCA in the control group and the centralization group 2-years postoperatively. *<0.05