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

Hiroki Katagiri, MD, PhD1,2 Yusuke Nakagawa, MD, PhD1,2 Kazumasa Miyatake, MD, PhD1,2 Toshiyuki Ohara, MD, PhD2 Mikio Shioda, MD, PhD2 Ichiro Sekiya, MD, PhD3 Hideyuki Koga, MD, PhD1,2

1 Department of Joint Surgery and Sports Medicine, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Bunkyo-ku, Tokyo, Japan
2 Department of Orthopaedic Surgery, Tokyo Medical and Dental University Hospital of Medicine, Bunkyo-ku, Tokyo, Japan
3 Center for Stem Cell and Regenerative Medicine, Tokyo Medical and Dental University, Tokyo, Bunkyo-ku, Tokyo, Japan

Address for correspondence: Hideyuki Koga, MD, PhD, Department of Joint Surgery and Sports Medicine, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8519, Japan (e-mail: koga.orj@tmd.ac.jp; koga-z@rg7.so-net.ne.jp).

Abstract

The study aimed to improve the 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 present study evaluated short-term patient-reported outcome measures; namely, the patient subjective satisfaction scores and Numeric Rating Scale (NRS) for walking pain after OWHTO aimed at neutral alignment with and without arthroscopic centralization for an extruded medial meniscus. A retrospective review of 50 primary OWHTO patients was conducted. Thirty-nine patients were included in the analysis after applying the exclusion criteria. The centralization group included 21 patients with knee osteoarthritis patients who underwent the OWHTO with arthroscopic meniscal centralization, while the control group included 18 patients who underwent OWHTO alone. The patient subjective satisfaction scores and NRS for walking pain were recorded at outpatient visits from before surgery to 3 years after surgery. In terms of the Lysholm knee scale, International Knee Documentation Committee subjective score, and Knee Osteoarthritis Outcome Score, the latest data (at least 2 years after surgery) were reviewed. Radiographic changes in joint space width and joint line congruence angle were measured 2 years postoperatively. Patient demographic data were also reviewed. One patient in the centralization group experienced a superficial surgical site infection. The patient subjective satisfaction and NRS scores for walking pain gradually improved by 1 year after surgery and were sustained until 3 years after surgery in both groups, with no significant difference between the groups. The course of patient-reported outcome measures from before surgery to 3 years after surgery for solely OWHTO aimed at neutral alignment and OWHTO aimed at neutral alignment with arthroscopic centralization showed the similar trends.

Keywords

- high tibial osteotomy
- meniscus
- arthroscopic centralization

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Two national registry-based studies reported 5- and 10-year conversion rates of high tibial osteotomy to total knee arthroplasty of approximately 10 and 30%, respectively.\textsuperscript{1,2} The clinical outcomes of open-wedge high tibial osteotomy (OWHTO) deteriorated over time with conversion to total knee arthroplasty.\textsuperscript{3} Therefore, further improvements in clinical results after OWHTO to decrease the conversion rate are required.

Medial meniscal extrusion commonly occurs in knee joint osteoarthritis and is strongly associated with osteoarthritis progression.\textsuperscript{4,5} Meniscal extrusion decreases the tibiofemoral contact area and increases the tibiofemoral contact pressure, leading to the worsening of knee osteoarthritis.\textsuperscript{6} Koga et al\textsuperscript{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 also resulted in good clinical outcomes of the Lysholm knee scale and Knee Osteoarthritis Outcome Score (KOOS) and radiographic outcomes with the lateral joint space widening at 2 years of follow-up.\textsuperscript{9} In a study using rats, the centralization technique of extruded medial meniscus successfully delayed cartilage degeneration.\textsuperscript{10} Therefore, the procedures combining OWHTO aimed at neutral alignment (weight-bearing line ratio goal of 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. However, the clinical and radiological outcomes of this technique are yet to be reported.

Thus, this study evaluated the short-term patient reported outcome measures, namely the patient subjective satisfaction scores and Numeric Rating Scale (NRS) for walking pain after the OWHTO aimed at neutral alignment, with and without an arthroscopic centralization for an extruded medial meniscus from before surgery to 3 years after surgery.

**Patients and Methods**

**Patients**

A retrospective review was conducted of physically active patients who had undergone primary OWHTO between December 2011 and May 2017 at our institution for unicompartmental knee osteoarthritis according to patient demand. The exclusion criteria were as follows: (1) patients who refused to provide consent; (2) patients who had joined a stem cell clinical trial; (3) incomplete questionnaire responses; and (4) loss to follow-up within 2 years. Until 2014, OWHTO alone was performed in five patients regardless of the condition of the medial meniscus. Since 2014, OWHTO with arthroscopic centralization of the medial meniscus was performed in 21 patients with medial meniscus extrusion, defined as an extension of the meniscal margin by at least 3 mm beyond the tibial margin on coronal magnetic resonance imaging (MRI) at the mid-point of the medial meniscus.\textsuperscript{11,12} Finally, OWHTO alone was performed in 13 patients without extrusion of the medial meniscus. This study was approved by the institutional review board. All patients provided full written informed consent for their participation in this clinical research before undergoing the operative procedure.

**Operative Procedures**

All surgeries were performed by and under the supervision of two senior surgeons with more than 15 years of experience in orthopedic surgery. Meniscal tears were repaired by the all-inside suture (Fast-Fix device, Smith & Nephew, MA) and/or the inside-out suture (Henning meniscal suture kit, Stryker, MI) techniques. If the torn meniscus could not be repaired, they were instead partially resected while trying to preserve as much volume as possible. Arthroscopic meniscal centralization was performed in the centralization group, as previously described.\textsuperscript{8} In brief, the extruded medial meniscus was observed before the procedure (\textsuperscript{1} Fig. 1A, B). Then, the meniscocapsular capsule under the medial meniscus was released from the medial tibial plateau. The rim of the medial tibial plateau was rasped for adhesion of the tibia and meniscocapsular capsule (\textsuperscript{1} Fig. 1D, E). A JuggerKnot Soft Anchor loaded with a No. 1 MaxBraid (Biomet, Warsaw, IN) suture was then inserted on the medial edge of the medial tibial plateau as posteriorly as possible (\textsuperscript{1} Fig. 1F, G). A single strand of sutures was pulled to pass the capsule from the inferior to the superior direction using a Micro Suture Lasso Small Curve with a nitinol wire loop (Arthrex, Naples, FL; \textsuperscript{1} Fig. 1H–J). The procedure was repeated with another strand of suture to create a mattress suture configuration. Another JuggerKnot Soft Anchor was inserted 1 cm anterior to the first anchor following the same procedure. The passed sutures were then tied by using a self-locking sliding knot (\textsuperscript{1} Fig. 2K, L).

The OWHTO procedure followed the method proposed by Staubli et al.\textsuperscript{13} 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 limb alignment was checked, as well as the position of the alignment rod at the knee, by intraoperative fluoroscopy. Wedge-shaped β-tricalcium phosphate blocks (Osferion 60; Olympus Terumo Biomaterials, Tokyo, Japan) were inserted into the opened osteotomy sites. Tris plates (Olympus Terumo Biomaterials, Tokyo, Japan) or Tomoxif plates (DePuy Synthes Johnson & Johnson, Tokyo, Japan) were used to fix the osteotomy site with locking screws. The postoperative rehabilitation did not vary with the meniscal procedure. The patients began to practice the range of motion and quadriiceps setting exercises a day after surgery. One-third, two-thirds, and full weight-bearing with crutches were initiated 3, 10, and 14 days, respectively, after surgery. The patients were allowed to start running exercises at 3 months after confirming bone union and progressed to full activity after 6 months postoperatively.

**Clinical Evaluations**

The NRS for walking pain and patient subjective satisfaction scores out of 100 points were determined based on the responses to questionnaires completed by the patients at
outpatient visits before surgery to 3 years after surgery. Passive knee extension and flexion angles were measured in a supine position with a goniometer and described in 1 and 5 degrees increments, respectively, preoperatively, and at the final follow-up. In terms of the Lysholm knee scale, the IKDC subjective score and KOOS, the latest data (at least 2 years after surgery) were collected. Passive knee extension and flexion angles and Lysholm knee scale scores were assessed by the attending surgeons who performed the surgery.

Fig. 1 Arthroscopic findings of the centralization technique. (A) Arthroscopic view of the medial meniscus from the anterolateral portal in the right knee joint. Displacement of the medial meniscus was confirmed arthroscopically. Full-thickness cartilage defects with exposed subchondral bone are visible (black arrowheads). (B) The extruded medial meniscus was easily moved 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) Release of the meniscotibial capsule with a rasp. (F, G) A JuggerKnot Soft Anchor is 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) is inserted and penetrates the capsule from the superior (H) to the inferior (I) direction at the margin between the meniscus and the capsule. (J) The retrieved suture passes the capsule from the inferior to the superior direction. (K) The sutures are tied by using a self-locking sliding knot (white arrows). (L) The extruded meniscus centralized after centralization of the mediobody of the medial meniscus. The tibial plateau and the exposed subchondral bone are covered (white arrowheads). MFC, medial femoral condyle; MM, medial meniscus; MTP, medial tibial plateau.

Radiological Evaluations
A single orthopedic doctor with more than 15 years of experience in orthopedic surgery and who did not perform any surgery in this series, reviewed the joint space width (JSW), joint line congruence angle (JLCA), femorotibial angle, hip–knee–ankle angle, weight-bearing line ratio, and Kellgren–Lawrence grade preoperatively and 2 years after surgery in a blinded manner. 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 intraobserver measurement reproducibility for JSW was assessed by intraclass correlation coefficients (ICCs). The observer was blinded to the previous results. The intraobserver ICC for JSW was 0.97. Therefore, the results were considered to be excellent.14 The minimal detectable change at the 95% confidence level (MDC95) for JSW was 0.43 mm.

Statistical Analysis
The statistical analyses were performed by using GraphPad Prism 5 (GraphPad Software, Inc., La Jolla, CA). The Kellgren–Lawrence grades, International Cartilage Repair Society (ICRS) grades for articular cartilage lesions, and postoperative follow-up periods were compared between the centralization and control groups by the Mann–Whitney tests. The remaining items were compared between the groups by t-tests, after confirming normality using a histogram, and equal variance by F-tests. JSW, JLCA, and range of knee joint motion in both groups were compared between preoperation and 2 years after operation by paired t-tests. The changes in NRS for walking pain and patient subjective satisfaction scores were compared between the centralization and control groups by mixed analysis of variance (ANOVA) with Tukey post hoc tests in IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY). A p-value <0.05 was considered statistically significant. Data were expressed as means with 95% confidence intervals (CIs) or median with minimum and maximum values. A post hoc power analysis revealed that, with an α value of 0.05, the current study achieved a power of 87.7% for the difference between preoperative and postoperative NRS scores.

Results
In this study, among the 39 total patients included in the analysis, 21 and 18 underwent OWHTO and arthroscopic meniscal centralization (centralization group) and OWHTO (control group), respectively (►Fig. 2). We observed no significant differences in patient characteristics except for postoperative weight-bearing line ratio between the treatment groups (►Table 1). The centralization group had a higher prevalence of medial meniscus root tear than to the control group, although the difference was not significant. All patients completed questionnaire responses of subjective satisfaction and NRS scores for walking pain until 3 years after surgery. The patient subjective satisfaction and NRS scores for walking pain gradually improved by 1 year after surgery and were sustained until 3 years after surgery.

Table 1

| Variable                        | Centralization (n = 21) | Control (n = 18) | p-value |
|--------------------------------|-------------------------|------------------|---------|
| Gender                         | Male 17 (80.9%)         | Male 14 (77.8%)  |         |
| Age at surgery (years)         | 70.6 ± 7.1              | 70.8 ± 8.1       |         |
| Preoperative body weight (kg)  | 67.5 ± 11.5             | 68.0 ± 11.2      |         |
| Preoperative body mass index   | 25.6 ± 1.9              | 25.4 ± 1.8       |         |
| Preoperative BMI               | 25.6 ± 1.9              | 25.4 ± 1.8       |         |
| Preoperative JSW (mm)          | 4.3 ± 0.3               | 4.3 ± 0.3        |         |
| Preoperative Lysholm score     | 58.8 ± 13.5             | 58.9 ± 13.4      |         |
| Preoperative KOOS              | 87.2 ± 11.6             | 87.2 ± 11.5      |         |
| Preoperative NRS               | 3.0 ± 2.3               | 3.1 ± 2.4        |         |

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surgery in both groups, with no significant differences between the groups (►Fig. 3). Postoperative patient subjective satisfaction scores and NRS scores for walking pain were significantly higher at all the time points compared with preoperative scores in both groups, except NRS scores at 3 months after surgery in the control group. The knee extension and flexion angles did not deteriorate after surgery in either group (►Table 2). Mean postoperative periods for the questionnaires were 40.7 months in the control group and 30.2 months in the centralization group (►Table 3). We observed no significant differences in IKDC subjective score, any KOOS subgroup scores, or Lysholm score between the groups. The change in JSW in the centralization group at 2 years after surgery (0.8 mm [0.3–1.4 mm] \( p < 0.05; \) ►Fig. 4) was larger than that in the control group (−0.1 mm [−0.6 to 0.5 mm]). In the centralization group, the JSW and JLCA were significantly improved 2 years after surgery compared with the preoperative values (►Table 4). One patient in the centralization group experienced a superficial surgical site infection.

**Discussion**

The most important finding of this study was that the course of patient subjective satisfaction and walking pain from preoperation to 3 years postoperation for OWHTO alone and OWHTO with arthroscopic centralization showed the same trends. The patient-reported outcome measures gradually improved by 1 year after surgery and were sustained until 3 years after surgery in both groups. OWHTO with arthroscopic centralization is a new procedure. This study is

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**Table 1 Patient characteristics**

|                          | Control group | Centralization group | \( p \)-Value |
|--------------------------|---------------|----------------------|--------------|
| Age (y)                  | 62 (47–71)    | 57 (44–73)           | 0.26         |
| Female                   | 11            | 12                   | 1.00         |
| Male                     | 7             | 9                    |              |
| Height (cm)              | 161.3 (151.2–185.0) | 161.6 (140.6–183.7) | 0.47         |
| Weight (kg)              | 61.9 (50.2–114.3) | 66.5 (43.0–83.0)     | 0.55         |
| BMI                      | 24.2 (18.5–36.7) | 23.5 (19.1–28.5)     | 0.13         |
| Preoperative patient satisfaction score | 50 (0–80) | 20 (0–70) | 0.10 |
| Preoperative FTA (degree) | 181.9 (177.5–187.3) | 181.9 (175.3–187.6) | 0.64 |
| Preoperative HKA angle (degree) | 7.7 (3.6–13.6) | 8.5 (2.7–11.8) | 0.37 |
| Preoperative weight bearing line ratio (%) | 10.9 (−11.9 to 30.9) | 13.4 (−17.2 to 36.4) | 0.37 |
| Preoperative KL grade (2/3/4) | 9/6/3 | 8/10/3 | 0.66 |
| ICRS grade: femoral cartilage (0/1/2/3/4) | (0/1/1/5/1) | (0/0/1/20/0) | 0.47 |
| ICRS grade: tibial cartilage (0/1/2/3/4) | (0/0/2/15/1) | (0/0/1/19/1) | 0.74 |
| Medial meniscus suture | 1             | 3                    | 0.61         |
| Medial meniscus partially resection | 4          | 8                    | 0.32         |
| Medial meniscal root tear | 0             | 5                    | 0.05         |
| Medial meniscal root pull-out repair | 0          | 3                    | 0.23         |
| Postoperative FTA (degree) | 174.2 (166.6–178.0) | 172.6 (167.9–177.1) | 0.24 |
| Postoperative HKA angle (degree) | −0.3 (−6.4 to 5.0) | −1.6 (−5.1 to 3.0) | 0.13 |
| Postoperative weight bearing line ratio (%) | 45.9 (26.1–69.8) | 55.3 (42.6–67.0) | 0.02 |
| Change of weight bearing line ratio (%) | 38.5 (13.2–55.9) | 39.3 (20.5–71.9) | 0.27 |

Abbreviations: BMI, body mass index; FTA, femorotibial angle; HKA angle, hip-knee-ankle angle; ICRS grade, International Cartilage Repair Society grade; KL grade, Kellgren–Lawrence grade.

Note: Values with brackets are expressed as median with minimum and maximum values.
**Fig. 3** (A) Line graph of patient subjective satisfaction scores in the control and centralization groups. ‡ Significant difference at the time point in compared with preoperative scores in both groups. (B) Line graph of Numeric Rating Scale scores for walking pain in the control and centralization groups. § Significant difference at the time point compared with the preoperative scores in the centralization group. **Fig. 4** (A) Scatterplot of the changes in joint space width in the control and centralization groups 2 years postoperatively. Control group: −0.1 mm (−0.6 to 0.5 mm), centralization group: 0.8 mm (0.3–1.4 mm); *p = 0.03. (B) Scatterplot of the change in joint line congruence angle in the control and centralization groups 2 years postoperatively. Control group: 0.4 (−0.5 to 1.3) degrees, centralization group: 0.9 (0.1–1.7) degrees, *p = 0.37.

**Table 2** Range of knee joint motion at the final follow-up

|                  | Preoperatively | 2 year after surgery | p-Value |
|------------------|----------------|----------------------|---------|
| **Control group** |                |                      |         |
| Extension        | 0 (−10 to 5)  | 0 (−3 to 5)         | 0.50    |
| Flexion          | 140 (100–150) | 145 (125–155)       | 0.06    |
| **Centralization group** |        |                      |         |
| Extension        | −2 (−10 to 3) | −1 (−3 to 2)        | 0.21    |
| Flexion          | 140 (130–155) | 145 (125–155)       | 0.23    |

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

**Table 3** Patient-reported outcome measures at the final follow-up

|                  | Control group | Centralization group | p-Value |
|------------------|---------------|----------------------|---------|
| **IKDC subjective score** | 65.2 (57.5–73.0) | 71.8 (63.9–79.7) | 0.22    |
| **KOOS**         |               |                      |         |
| Pain             | 79.9 (70.6–89.1) | 82.9 (75.8–90.1) | 0.58    |
| Symptoms         | 78.8 (69.6–88.0) | 81.8 (75.0–88.5) | 0.58    |
| ADL              | 90.8 (86.0–95.6) | 90.3 (84.9–95.7) | 0.89    |
| Sport/recreation | 63.3 (47.7–78.9) | 67.1 (56.0–78.3) | 0.67    |
| QOL              | 68.1 (56.5–79.7) | 67.9 (56.6–79.1) | 0.97    |
| Lysholm score    | 90.9 (86.0–95.8) | 94.1 (91.4–96.7) | 0.22    |
| **Postoperative periods for the questionnaires (mo)** | 40.7 (31.4–50.0) | 30.2 (26.4–34.0) | 0.03    |

Abbreviations: ADL, activities of daily living; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life.

Note: Values with brackets are expressed as mean with 95% confidence interval.
Table 4 Radiological evaluation of joint morphology

|                      | Preoperatively | 2 year after surgery | p-Value |
|----------------------|----------------|----------------------|---------|
| Control group        |                |                      |         |
| JSW (mm)             | 2.2 (1.5–2.9)  | 2.2 (1.5–3.0)        | 0.83    |
| JLCA (degrees)       | 3.9 (2.9–4.9)  | 3.5 (2.1–4.9)        | 0.17    |
| 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    |

Abbreviations: JLCA, joint line congruence angle; JSW, joint space width. Note: Values with brackets are expressed as mean with 95% confidence interval.

The first to evaluate its short-term clinical outcomes and the occurrence of early complications.

The meniscus plays a crucial role in load-bearing and shock absorption.15 Mapping of the contact forces on the medial meniscus in the human knee joint showed that the meniscus transmitted more than 50% of the total axial load to the joint.16 The meniscal extrusion in osteoarthritis patients extends beyond the outer margin of the tibial plateau and loses axial load distribution.17,18 The arthroscopic centralization technique was developed primarily to reduce meniscal extrusion. A biomechanical study of centralization for the extruded meniscus in pigs reported that the centralization technique increased the axial load distribution of the meniscus.19 Another study demonstrated that centralization for the extruded meniscus delayed cartilage degeneration in a rat model.10 Arthroscopic centralization in OWHTO has been proposed to restore meniscus function. However, the short-term clinical outcomes and the occurrence of early complications in this procedure had not previously been evaluated. The results of the current study showed that OWHTO with arthroscopic centralization for extruded medial meniscus did not deteriorate clinical outcomes up to 3 years after surgery. Long-term follow-up studies assessing the effectiveness of arthroscopic centralization in preventing osteoarthritis progression are essential.

The IKDC subjective scores after OWHTO ranged from 61 to 73 points in previous studies,20–23 comparable to the scores observed in both groups in our study. Similarly, the patient satisfaction subjective and Lysholm scores in both groups in the current study were not inferior to those in previous studies (75–81 points24–27 and 58–92 points,20,21,23,28–30 respectively).

Meniscus centralization surgeries may be associated with a risk of a deficit in knee range of motion by limiting the normal motion of the meniscus during knee extension–flexion31 due to suture of the capsule adjacent to the extruded meniscus. We found that the knee extension and flexion angles did not change in the centralization group at the final follow-up. Moreover, we observed no significant differences between the control and centralization groups in both the knee extension and flexion angles at the final follow-up.

Patients with meniscal root tears have a high prevalence of meniscal extrusion.11,32 Similarly, in the present study, all patients with meniscus root tear and all patients who underwent meniscus root repair were included in the centralization group. Meniscus root repair solely results in significantly satisfying clinical outcomes.33,34 However, at the present time, there is a paucity of studies comparing the outcomes of solely OWHTO and OWHTO concomitant with meniscus posterior root repair, while a few studies showed that significant differences of the clinical and radiologic outcomes were not found between the procedures.35,36 There is insufficient evidence to exclude the possibility that the meniscus root tear and meniscus root repair influenced the results of the present study.

The goal for the mechanical axis was a point 62% lateral on the transverse diameter of the tibial plateau to decrease the medial tibiofemoral contact pressure in traditional OWHTO.37 However, a valgus alignment after an HTO could cause lateral compartment osteoarthritis,38,39 cosmetic problems, or diminish sports performance levels, especially in active young patients. In addition, larger correction by correction target of 62% could result in joint line obliquity, inducing excessive tibiofemoral contact pressure in cases with severe varus alignment.40 Based on these considerations, the current study aimed for 57% of the weight-bearing line ratio as neutral alignment.

The conversion to total knee arthroplasty due to the progression of degenerative osteoarthritis is a major complication after an OWHTO. The results of the current study demonstrated that centralization increased the JSW by 0.9 mm in comparison to OWHTO alone. In distribution-based methods, the minimal clinically important difference value is defined as the upper value of the 95% CI for the average change in the control group.41 The minimal clinically important difference value for JSW in the present study was 0.5 mm, which was larger than the MDC95 for JSW. Twelve patients in the centralization group surpassed the minimal clinically important difference in JSW. A further observation study is required to assess the effect of the extra joint space on the progression of degeneration.

Limitations

This study has several limitations. First, although a significant difference between preoperative and postoperative NRS scores was detected, the present study included a small number of subjects; thus, these results should be considered preliminary. Second, this study was retrospective; thus, it had potential selection bias. Baseline potential influencing factors including body mass index (BMI), preoperative patient satisfaction score, meniscus root tear, meniscus root repair, partial meniscectomy, and postoperative weight-bearing line ratio were not controlled between the two groups. Patients who had meniscus root tear or meniscus root repair were only included in the centralization group. The centralization group had twice the number of patients.
with partial meniscectomy compared with the control group. Postoperative weight-bearing line ratio in the control group was smaller than that in the centralization group; under-correction with a smaller weight-bearing line ratio could negatively affect the short- and long-term clinical outcomes of OWHTO. These confounding factors potentially affected the results of the present study. Third, since the knee range of motion and Lysholm knee scale were evaluated by surgeons who performed the surgery, there was potential observer bias. Fourth, although the two senior surgeons participated in each other’s surgeries to equalize the operation methods, several surgeons performed surgeries under the two different senior surgeons and the operation techniques varied according to the attending surgeon. Thus, a randomized trial comparing OWHTO with or without centralization with larger numbers of participants under the stable operative procedure is required to draw a robust conclusion.

Conclusion

The courses of patient-reported outcome measures from before surgery to 3 years after surgery in OWHTO aimed at neutral alignment and OWHTO aimed at neutral alignment with arthroscopic centralization showed the similar trends.

Note

This study was conducted at Tokyo Medical and Dental University Hospital of Medicine.

Authors’ Contributions

H.K. conceived the study and performed all experiments and participated in its design. K.M. participated in its design and performed analysis. Y.N. acquired the data. T.O. and M.S. analyzed and calculated the data. I.S. participated in its design. H.K. 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 took responsibility for the integrity of the data and the accuracy of the data analysis.

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Conflict of Interest

None declared.

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References

1. Niinimäki TT, Eskelinen A, Mann BS, Jumnila M, Ohtonen P, Leppilähti J. Survivorship of high tibial osteotomy in the treatment of osteoarthritis of the knee: Finnish registry-based study of 3195 knees. J Bone Joint Surg Br 2012;94(11):1517–1521
2. W-Dahl A, Robertsson O, Lohmander LS. High tibial osteotomy in Sweden, 1998–2007: a population-based study of the use and rate of revision to knee arthroplasty. Acta Orthop 2012;83(03):244–248
3. Song SJ, Bae DK, Kim KL, Lee CH. Conversion total knee arthroplasty after failed high tibial osteotomy. Knee Surg Relat Res 2016;28(02):89–98
4. Berthiaume MJ, Raynauld JP, Martel-Pelletier J, et al. Meniscal tear and extrusion are strongly associated with progression of symptomatic knee osteoarthritis as assessed by quantitative magnetic resonance imaging. Ann Rheum Dis 2005;64(04):556–563
5. Roubille C, Martel-Pelletier J, Raynauld JP, et al. Meniscal extrusion promotes knee osteoarthritis structural progression: protective effect of strontium ranelate treatment in a phase III clinical trial. Arthritis Res Ther 2015;17:82
6. Luczkiwicz P, Daszkiewicz K, Witkowski W, Chróścielewski J, Ferenc T, Baczkowski B. The influence of a change in the meniscus cross-sectional shape on the medio-lateral translation of the knee joint and meniscal extrusion. PLoS One 2018;13(02):e0193020
7. Koga H, Watanabe T, Horie M, et al. Augmentation of the pullout repair of a meniscal meniscus posterior root tear by arthroscopic centralization. Arthroscopy Tech 2017;6(04):e1335–e1339
8. Koga H, Muneta T, Yagishita K, et al. Arthroscopic centralization of an extruded lateral meniscus. Arthroscopy Tech 2012;1(02):e209–e212
9. Koga H, Muneta T, Watanabe T, et al. Two-Year outcomes after arthroscopic lateral meniscal centralization. Arthroscopy 2016;32(10):2000–2008
10. Ozeki N, Muneta T, Kawabata K, et al. Centralization of extruded meniscal meniscus delays cartilage degeneration in rats. J Orthop Sci 2017;22(03):542–548
11. Costa CR, Morrison WB, Carrino JA. Medial meniscus extrusion on knee MRI: is extent associated with severity of degeneration or type of tear? AJR Am J Roentgenol 2004;183(01):17–23
12. Nguyen JC, De Smet AA, Graf BK, Rosas HG. MR imaging-based diagnosis and classification of meniscal tears. Radiographics 2014;34(04):981–999
13. Staubbli AE, De Simoni C, Babst R, Lobenhoffer P. TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia–early results in 92 cases. Injury 2003;34(Suppl 2):B55–B62
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(01):159–174
15. Rath E, Richmond JC. The menisci: basic science and advances in treatment. Br J Sports Med 2000;34(04):252–257
16. Fukubayashi T, Kurosawa H. The contact area and pressure distribution pattern of the knee. A study of normal and osteoarthritic knee joints. Acta Orthop Scand 1980;51(06):871–879
17. Hein CN, Deperio JG, Ehrensberger MT, Marzo JM. Effects of medial meniscal posterior horn avulsion and repair on meniscal displacement. Knee 2011;18(03):189–192
18. Hada S, Ishijima M, Kaneko H, et al. Association of medial meniscal extrusion with medial tibial osteophyte distance detected by T2 mapping MRI in patients with early-stage knee osteoarthritis. Arthritis Res Ther 2017;19(01):201
19. Ozeki N, Koga H, Matsuda J, et al. Biomechanical analysis of the centralization procedure for extruded lateral meniscus with posterior root deficiency in a porcine model. J Orthop Sci 2020;25(01):161–166
20. Bode G, von Heyden J, Pestka J, et al. Prospective 5-year survival rate data following open-wedge valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2015;23(07):1949–1955
21. Schröter S, Gonser CE, Konstantinidis L, Helwig P, Albrecht D. High complication rate after bipolar open wedge high tibial osteotomy stabilized with a new spacer plate (Position HTO plate) without bone substitute. Arthroscopy 2011;27(05):644–652
22. Niemeyer P, Schmal H, Hauschild O, von Heyden J, Südkamp NP, Köstler W. Open-wedge osteotomy using an internal plate fixator in patients with medial-compartment gonarthrosis and varus.
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malalignment: 3-year results with regard to preoperative arthroscopic and radiographic findings. Arthroscopy 2010;26(12): 1607–1616
23 Bastard C, Mirose G, Potage D, et al. Return to sports and quality of life after high tibial osteotomy in patients under 60 years of age. Orthop Traumatol Surg Res 2017;103(08):1189–1191
24 Tang WC, Henderson IJ. High tibial osteotomy: long term survival analysis and patients’ perspective. Knee 2005;12(06): 410–413
25 Sterett WI, Steadman JR, Huang MJ, Matheny LM, Briggs KK. Chondral resurfacing and high tibial osteotomy in the varus knee: survivorship analysis. Am J Sports Med 2010;38(07):1420–1424
26 Ozkaya U, Kabukçuoglu Y, Parmaksizoğlu AS, Yeniocak S, Ozkanli G. [Changes in patellar height and tibia inclination angle following open-wedge high tibial osteotomy]. Acta Orthop Traumatol Turc 2008;42(04):265–271
27 Miller BS, Joseph TA, Barry EM, Rich VJ, Sterett WI. Patient satisfaction after medial opening high tibial osteotomy and microfracture. J Knee Surg 2007;20(02):129–133
28 DeMeo PJ, Johnson EM, Chiang PP, Flamm AM, Miller MC. Midterm follow-up of opening-wedge high tibial osteotomy. Am J Sports Med 2010;38(10):2077–2084
29 Kohn L, Sauerschnig M, Iskansar S, et al. Age does not influence the clinical outcome after high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2013;21(01):146–151
30 Ribeiro CH, Severino NR, Moraes de Barros Fuchs PM. Opening wedge high tibial osteotomy: navigation system compared to the conventional technique in a controlled clinical study. Int Orthop 2014;38(08):1627–1631
31 Vedi V, Williams A, Tennant SJ, Spouse E, Hunt DM, Gedroyc WM. Meniscal movement. An in-vivo study using dynamic MRI. J Bone Joint Surg Br 1999;81(01):37–41
32 Lerer DB, Umans HR, Hu MX, Jones MH. The role of meniscal root pathology and radial meniscal tear in medial meniscal extrusion. Skeletal Radiol 2004;33(10):569–574
33 Edwards C, Goldman BH, Turley J, Richey B, Deal MJ, Kalbac D. Outcomes after surgical repair of meniscal meniscal root tears: a review. J Knee Surg 2020 (e-pub ahead of print). Doi: 10.1055/ s-0040-1710565
34 Bernard CD, Kennedy NI, Taglieri AJ, et al. Medial meniscus posterior root tear treatment: a matched cohort comparison of nonoperative management, partial meniscectomy, and repair. Am J Sports Med 2020;48(01):128–132
35 Lee OS, Lee SH, Lee YS. Comparison of the radiologic, arthroscopic, and clinical outcomes between repaired versus unrepairsd medial meniscus posterior horn root tear during open wedge high tibial osteotomy. J Knee Surg 2021;34(01):57–66
36 Ke X, Qiu J, Chen S, et al. Concurrent arthroscopic meniscal repair during open-wedge high tibial osteotomy is not clinically beneficial for medial meniscus posterior root tears. Knee Surg Sports Traumatol Arthrosc 2021;29(03):955–965
37 Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am 1979;10(03):585–608
38 Felson DT, Niu J, Gross KD, et al. Valgus malalignment is a risk factor for lateral knee osteoarthritis incidence and progression: findings from the multicenter osteoarthritis study and the osteoarthritis initiative. Arthritis Rheum 2013;65(02):355–362
39 Prakash J, Song EK, Lim HA, Shin YJ, Jin C, Seon JK. High tibial osteotomy accelerates lateral compartment osteoarthritis in discoid meniscus patients. Knee Surg Sports Traumatol Arthrosc 2018;26(06):1845–1850
40 Nakayama H, Schröter S, Yamamoto C, et al. Large correction in opening wedge high tibial osteotomy with resultant joint-line obliquity induces excessive shear stress on the articular cartilage. Knee Surg Sports Traumatol Arthrosc 2018;26(06):1873–1878
41 Harris JD, Brand JC, Cote MP, Faucett SC, Dhawan A. Research pearls: the significance of statistics and perils of pooling. part 1: clinical versus statistical significance. Arthroscopy 2017;33(06):1102–1112
42 Jin C, Song EK, Santoso A, Ingale PS, Choi IS, Seon JK. Survival and risk factor analysis of medial open wedge high tibial osteotomy for unicompartment knee osteoarthritis. Arthroscopy 2020;36(02):535–543
43 Lee SJ, Kim JH, Choi W. Factors related to the early outcome of medial open wedge high tibial osteotomy: coronal limb alignment affects more than cartilage degeneration state. Arch Orthop Trauma Surg 2021 (e-pub ahead of print). Doi: 10.1007/s00402-021-03769-4