Archives of Orthopaedic and Trauma Surgery (2020) 140:161–169
https://doi.org/10.1007/s00402-019-03237-0

ORTHOPAEDIC SURGERY

Early experience of lateral hinge fracture during medial opening-wedge high tibial osteotomy: incidence and clinical outcomes

Kwang Yun Song[1] · In Jun Koh[2] · Man Soo Kim[3] · Nam Yong Choi[3] · Ji Hwan Jeong[3] · Yong In[3]

Received: 23 August 2018 / Published online: 4 July 2019

Abstract

Purpose Lateral hinge fracture (LHF) during a medial opening-wedge high tibial osteotomy (MOWHTO) is considered to be the main cause of instability, further displacement, loss of correction, malunion, and nonunion. The purposes of this study were to evaluate whether the incidence of LHFs during MOWHTOs has decreased as the number of cases performed over time has increased, and whether the radiographic and clinical outcomes of patients with LHFs were worse than those of patients without LHFs.

Materials and methods During the period of July 2013 to January 2017, 132 MOWHTOs were performed by a single surgeon using a locking plate (TomoFix®, DePuySynthes, Solothurn, Switzerland) for the treatment of medial compartment osteoarthritis, with LHFs postoperatively detected in 32 knees (24.2%). To evaluate trends in the incidence of LHFs occurring during MOWHTOs over time, all 132 cases were divided chronologically into four groups of 33 cases and compared. The time for bony union and loss of correction were compared between the LHF group and the non-LHF group using an osteotomy filling index, hip–knee–ankle (HKA) angles, medial proximal tibial angles (MPTA), weight-bearing line (WBL) ratios, and posterior tibial slope (PTS) angles on radiographs. Clinical outcomes were also compared using the Knee Society Scores (KSS) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores 1 year post-surgery.

Results The incidence of LHFs in each group of 33 cases did not decrease over time (21.2%, 27.3%, 24.2%, and 24.2%, respectively, $p = 0.954$). The time to union was significantly different between the non-LHF group (5.0 months) and the LHF group (7.3 months) ($p < 0.001$). However, there were no immediate or 1-year postoperative differences in the HKA angles, MPTAs, WBL ratios, or PTS angles between the non-LHF and LHF groups (all $p > 0.05$). The KSS and WOMAC scores were significantly improved in both groups (all $p < 0.001$) 1 year post-surgery, without any differences between the groups ($p = 0.997$ and $p = 0.122$, respectively).

Conclusions LHFs during MOWHTO procedures occurred consistently, with a similar incidence over time. Although patients with LHFs required more time to bony union, they showed similarly favorable radiographic and clinical results as the patients without LHFs 1 year after surgery.

Keywords Osteoarthritis · High tibial osteotomy · Opening-wedge · Lateral hinge fracture

✉ Yong In
iy1000@catholic.ac.kr

Kwang Yun Song
skyer1020@gmail.com

In Jun Koh
oskoh74@gmail.com

Man Soo Kim
kms3779@naver.com

Nam Yong Choi
nychoimay@yahoo.co.kr

Ji Hwan Jeong
a06jjh16z@naver.com

[1] Department of Orthopaedic Surgery, Incheon St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

[2] Department of Orthopaedic Surgery, St. Paul's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

[3] Department of Orthopaedic Surgery, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, 222 Banpo-daero, Seocho-gu, Seoul 06591, Korea

Introduction

Medial opening-wedge high tibial osteotomy (MOWHTO) is a well-established treatment option for medial compartment osteoarthritis (OA) or osteonecrosis with varus malalignment [1–5]. In properly indicated patients, clinical evidence shows that decreased pain and elevated function scores can be achieved by shifting the mechanical axis to a position lateral to the midpoint of the tibial plateau [6, 7]. Nevertheless, previous studies have reported complications, including lateral hinge fractures (LHF), increase in posterior tibial slopes and patellofemoral joint pressure, and alteration of patella heights following otherwise successful MOWHTO procedure [8–16]. Among the complications of MOWHTO procedures, LHFs are reported to be the main cause of instability, further displacement (which leads to serious further complications, such as malunion or nonunion), and loss of correction [17–21].

The incidence of LHFs has been correlated with the osteotomy aiming point and sufficiency of the osteotomy [22, 23]. However, a correlation between the opening distance of the osteotomy and the occurrence of LHFs is controversial [22, 24, 25]. Takeuchi et al. [21] introduced a system to classify three types of lateral hinge fractures according to the position of the fracture relative to the proximal tibiofibular joint. Among the three types of fractures, type II and III were considered unstable and were most related to nonunion or malunion of the fracture [21, 26].

Acknowledging the importance of LHFs in patients' clinical courses, many researchers have focused on surgical tips to prevent such complications and have suggested using techniques, such as optimal aiming point of the osteotomy and sufficiency of the osteotomy, to reduce LHFs [21–23, 26, 27]. However, the incidence of LHFs following these previously suggested surgical tips has not been reported. Furthermore, there are only limited reports regarding the clinical outcomes of LHFs occurring during MOWHTO procedures, compared to those without LHFs, using locking compression plates.

Therefore, the aim of this study was to assess the incidence of LHFs during MOWHTO procedures and to further analyze any decrease in the incidence using previously suggested surgical tips and accumulating surgical experience. We also compared whether patients with LHFs had radiographically and clinically inferior outcomes compared to patients with no LHFs after 1 year. We hypothesized that the incidence of LHFs would be reduced over every 30 cases as surgeons became accustomed to the procedure and that patients with LHFs would show radiographic and clinical outcomes similar to those of patients without LHFs.

Methods

This retrospective cohort study was approved by the Institutional Review Board of our hospital. All patients provided written informed consent. Between July 2013 and January 2017, a total of 143 MOWHTOs were performed in 129 patients by a single surgeon at our institution. The indication for MOWHTO was symptomatic medial unicompartmental knee OA with varus malalignment in patients less than 65 years of age. Varus malalignment of 5° or more in the femorotibial angle induced by an abnormal mechanical medial proximal tibial angle (MPTA) was considered an optimal indication. Patients with symptomatic lateral compartments; patellofemoral OA; active inflammatory arthritis, such as rheumatoid arthritis; flexion contractures of more than 15°; or range of motions below 120° did not meet our indication criteria for MOWHTO. Patients who underwent MOWHTOs due to post-traumatic arthritis, had fixating devices other than locking plates used, or had concomitant ligament surgery were excluded from the study. Retrospective data were collected from patients with a minimum follow-up period of 1 year. Eight patients had MOWHTOs for reasons other than primary OA, such as osteonecrosis (one patient) and post-traumatic arthritis (seven patients). A total of three patients were lost to follow-up. Ultimately, 132 MOWHTOs in 121 patients were retrospectively included in the study. To evaluate the trends of incidence of LHFs over time, all 132 MOWHTO cases were chronologically divided into four groups. Each group consisted of an equal 33 cases. The cases were further divided into two groups depending on the presence or absence of LHFs during the MOWHTO procedures.

Patient demographics and comorbidities were evaluated preoperatively, including body mass index (BMI), hypertension, diabetes mellitus, anemia (Hb < 12.0 g/dL), and smoking and drinking statuses. Radiographic evaluations, including hip–knee–ankle angles (HKA angle), MPTAs, weight-bearing line (WBL) ratios, and posterior tibial slope (PTS) angles were performed preoperatively, immediately postoperatively, and at 3 months, 6 months, and 1 year postoperatively, as well as annually thereafter. The HKA angle was assessed on a weight-bearing full-length hip-to-ankle anterior–posterior (AP) radiograph, by drawing the femoral mechanical axis from the center of the femoral head to the midpoint of the tibial spines, and the tibial mechanical axis from the midpoint of the tibial spines to the center of the talar dome [28]. If the HKA angle pointed to varus, the value was described as negative, if the angle pointed to valgus, the value was described as a positive value. The MPTA was also measured on a weight-bearing full-length hip-to-ankle AP radiograph using the tibial mechanical axis and the medial articular surface of the proximal tibia [28]. Radiologic measurement of the WBL ratio was conducted by calculating the proportion of the contact points, starting from the medial edge of the tibial plateau, using the mechanical axis from the femoral head center to the ankle joint center [29]. The PTS was measured using a posterior tibial inclination and a right angle of the tibia anatomical axis bisecting the tibia shaft on true lateral view of the knee.

The osteotomy angle, defined as the angle measured in the knee AP radiograph by lines between the perpendicular line of the tibial long axis bisecting line and the Kirschner wire as a guide for the primary osteotomy, was compared between the groups (Fig. 1). Additionally, the rates of achieving the so-called "safe zone" at the tip of the Kirschner wire, between the fibular head tip and the circumference line of the fibular head, were compared between the groups [22]. Postoperative computed tomography (CT) scans were routinely performed 2 days post-surgery to detect LHFs missing on the immediate postoperative simple radiographs. Clinical evaluations were done using the Knee Society Scores (KSS) [30] and the Western Ontario and McMaster Universities Osteoarthritis Index(WOMAC) scores [31] preoperatively, at 3 months, 6 months, and 1 year postoperatively, as well as annually thereafter.

LHFs were confirmed by definite cortical disruptions seen on postoperative simple radiographs or CT scans. Every case of a confirmed LHF was then classified using the criteria of Takeuchi et al. [21]. A type I fracture had a fracture line that extended just proximal or within the tibiofibular joint, type II was defined as a fracture with a fracture line that extended distally to the tibiofibular joint, and type III was defined as a fracture with a fracture line that extended to the lateral plateau of the proximal tibia.

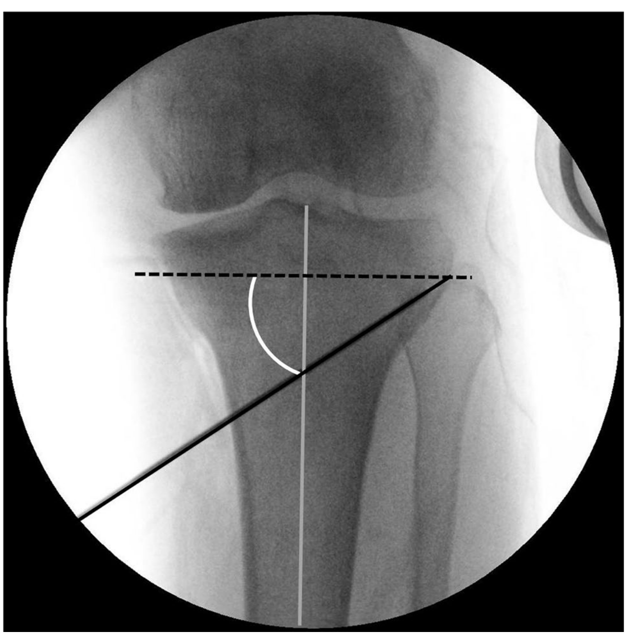

Fig. 1 Osteotomy angle was measured on knee anterior–posterior view using perpendicular line of tibia shaft bisecting line and Kirschner wire as a guide for primary osteotome

Evidence of bony union at the osteotomy site was confirmed by an increase in density due to bone bridges. Therefore, the union of a MOWHTO was assessed based on the osteotomy filling index introduced by Brosset et al. using an AP radiograph [32]. From lateral to medial opening wedge, areas were divided into five zones. Each zone corresponded to 20% of the total width. If the filling or bridging of the callus extended into 40 to 60% of the area (zone 3), the osteotomy site was considered stable and united.

Radiographic assessments were conducted by two blinded independent orthopedic surgeons. The average value from these two independent observers was used. The intraclass correlation coefficient (ICC) values of the interobserver and intraobserver reliabilities were substantial to nearly perfect (kappa > 0.80).

Surgical technique

Preoperative measurements were made by an orthopedic surgeon participating in the operation. A single senior surgeon double-checked the preoperative plan before surgery to diminish the opportunity for error. The target of correction was 62.5% of the tibial plateau measured from medial, which is referred to as the Fujisawa point [33]. The correction angle was determined using the Dugdale method, with a weight-bearing full-length hip-to-ankle radiograph [34].

The surgical table was prepared with an additional transparent lower extremity extension board for fluoroscopic identification at the center of the hip joint and in the ankle joint. All patients were positioned in a supine position under general anesthesia. Arthroscopic procedures for the medial compartment, such as microfracture or meniscectomy, were done on demand, as necessary. Subsequently, a 5 cm vertical incision was made on the medial aspect of the proximal leg. The Pes anserinus and the superficial medial collateral ligament were released in all patients to expose the posteromedial crest of the osteotomy site. Under fluoroscopic control, a locking plate (TomoFix®, DePuySynthes, Solothurn, Switzerland) was applied to fix the level of the plate position relative to the joint line and the osteotomy entry. With the use of two Kirschner wires, the endpoint of the osteotomy was targeted toward the "safe zone" [22].

A biplanar osteotomy was carried out in all patients. Primary osteotomies were done on the distal side of the Kirschner wire guides, reaching near the lateral cortex of the tibia, while protecting the neurovascular structures with the use of a transparent Hohmann retractor [35]. A sufficient osteotomy, reaching 5 mm near the lateral tibial cortex, was done on both the anterior and posterior cortices toward the level of the fibular head, to prevent LHFs [23]. With the use of a reciprocating saw, a secondary osteotomy was performed in an ascending manner, just posterior to the tibial tuberosity in all cases. The osteotomy gap opening was meticulously controlled by the angle scale of the spreader. Under fluoroscopic control, the centers of the femoral head and the talar dome were identified and the lower extremity alignment was adjusted until an electrocautery cable was able to pass through the Fujisawa point at the tibial plateau. During this adjustment, a gentle valgus force was applied to minimize the effect of the lateral soft tissue laxity of the knee [36]. After obtaining an ideal correction, the osteotomy was fixed using a Tomofix plate [37]. To promote bony union, allogeneic bone chips grafts (123 cases) or autologous iliac bone grafts (1 smoker case) were performed to fill the osteotomy gap. Eight patients had neither allogeneic nor autologous bone grafts at the osteotomy gap [32].

Postoperative rehabilitation

Regardless of the presence or absence of LHFs, all patients underwent the same postoperative care. On the first postoperative day, quadriceps-setting exercises and continuous passive motion of the knee joint were initiated. A gradual increase in the range-of-motion was instituted, according to individual compliance. Non-weight-bearing three-point crutch ambulation was taught to all patients immediately following surgery. Partial to full weight-bearing was allowed 6 weeks after surgery for all subjects, including LHF patients [36].

Statistical methods

All data were reported as the average and standard deviation. Parametric or non-parametric tests were performed according to the results of tests for normality. A chi-squared test was also performed to compare the incidence of LHFs between the four chronologically divided groups. A Mann–Whitney U test was performed to analyze numerical data. A p value of <0.05 was considered to be statistically significant. Statistical analyses were performed with SPSS version 22.0 software (SPSS Inc., Chicago, Illinois).

Results

LHFs were detected postoperatively in 32 knees, for an incidence of 24.2% (32/132), in a mean follow-up period of 23.8 months (range 12–48 months). Among the 32 cases with LHFs, 26 were detected on immediate postoperative radiographs and six were diagnosed from postoperative CT scans (Fig. 2). There were six cases of LHFs which were detected by fluoroscopy during the surgery, but additional fixation procedures were not done. Referring to the Takeuchi classifications, 28 cases (87.5%) presented as type I LHFs, where the fracture line extended just proximal to or within the tibiofibular joints, one case (3.1%) was identified as a type II LHF extending distal to the tibiofibular joint, and three cases (9.4%) were type III LHFs which extended to the lateral plateaus of the proximal tibias (Fig. 3).

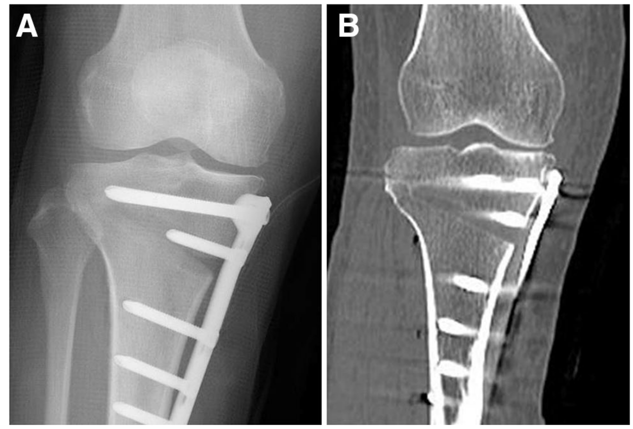

Fig. 2 A 61-year-old female underwent medial opening-wedge high tibial osteotomy. An immediate postoperative radiography of the right knee without definite lateral hinge fracture (**a**). At postoperative 2 days, CT scan shows lateral hinge fracture (**b**). Interference of the locking screw with the osteotomy gap was unintended

In terms of demographics, there were no statistical differences in age, gender, BMI, smoking or drinking status, underlying diabetes, hypertension, or anemia between the groups. The only difference between the groups was the operated side (Table 1).

One hundred thirty-two knees with LHFs were arbitrarily divided into four groups of the same size in chronological order, as shown in Fig. 4. Of the first 33 patients, seven had LHFs. This pattern continued as nine patients among the second 33 patients, eight patients among the third 33 patients, and eight patients of the last 33 patients had LHFs. The incidence of LHFs was determined to be 21.2%, 27.3%, 24.2%, and 24.2% in each sequentially divided group over time, and were not statistically significant ($p=0.954$).

Radiographic comparisons between the LHF and non-LHF groups are shown in Table 2. The osteotomy angle in both groups was not statistically different ($p=0.285$). The mean osteotomy opening distance was not statistically different between the groups ($p=0.134$). There were no statistic differences in the changes in HKA angles, MPTAs, and WBL ratios 1 year post-surgery between the groups ($p>0.05$ in each case). However, the non-LHF group showed significantly faster bony unions than the LHF group ($p<0.001$). Among the 132 cases of MOWHTOs, 123 cases (93.2%) received allogeneic bone grafts, one case (0.8%) received an autogenic bone graft, and eight cases received no grafting

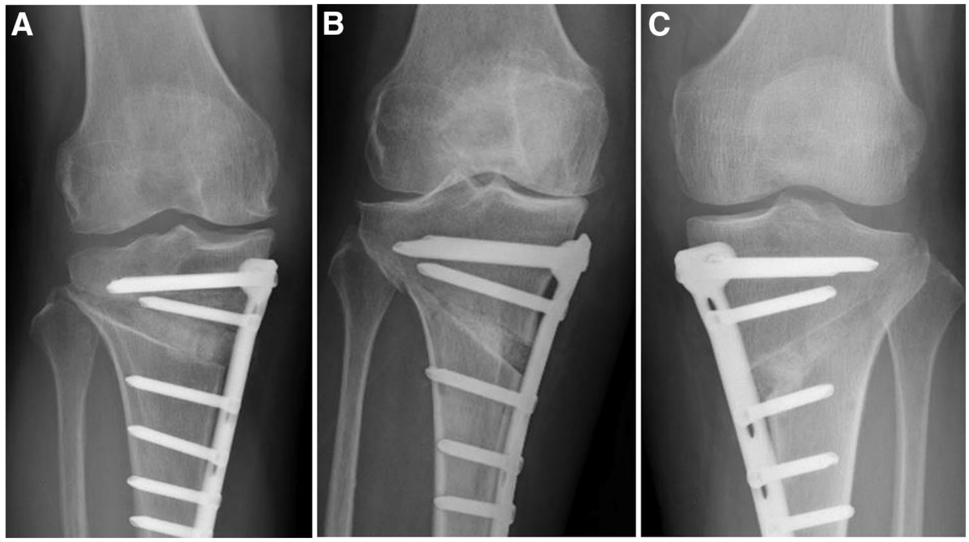

Fig. 3 A 39-year-old male underwent medial opening-wedge high tibial osteotomy, Takeuchi type I fracture was noticed on immediate post-operative radiography (**a**). A 53-year-old female with Takeuchi type II fracture (**b**). A 63-year-old female with Takeuchi type III fracture (**c**). All fractures healed uneventfully

Table 1 Demographic data and preoperative clinical status

	Non-LHF ($n=100$)	LHF ($n=32$)	*p* value
Age, years	55.7 ± 7.2 (27–65)	55.9 ± 5.1 (39–64)	0.576
Sex, female/male, *n*	87/13	30/2	0.295
Operated side, right/left, *n*	50/50	8/24	0.013
Body weight, kg	65.7 ± 11.8 (45–118)	65.8 ± 9.2 (52–89.2)	0.736
Body height, cm	158.9 ± 7.8 (141.2–181.0)	157.2 ± 6.5 (143.0–172.0)	0.428
Body mass index, kg/m^2	25.9 ± 3.7 (18.5–38.1)	26.6 ± 3.4 (21.5–34.0)	0.330
Current smoker, *n*	2	1	0.710
Current drinker, *n*	3	2	0.402
Underlying disease			
Hypertension, *n*	26	11	0.359
Diabetes Mellitus, *n*	9	1	0.274
Anemia, *n*	7	0	0.124

Values are presented as mean and SD with the ranges in parentheses

LHF lateral hinge fracture

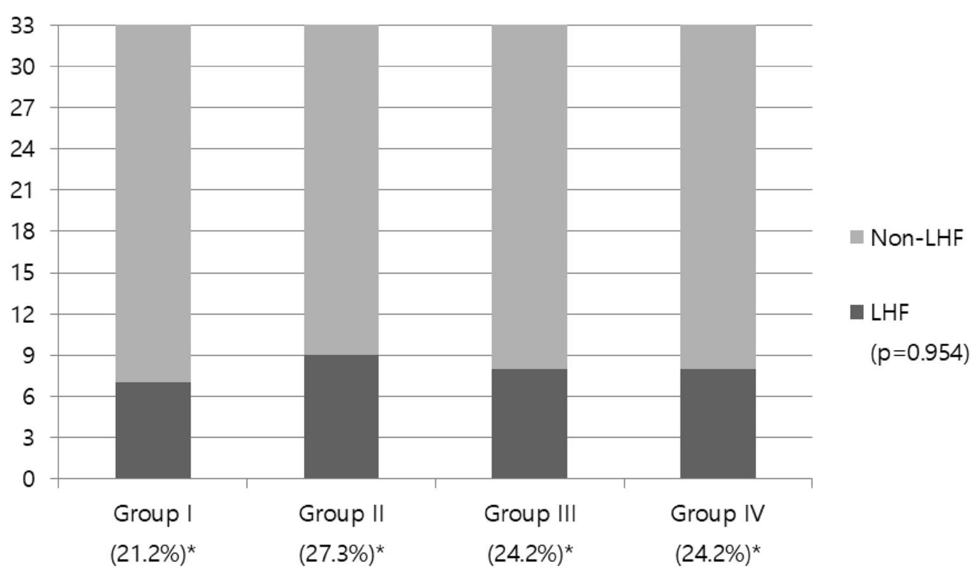

Fig. 4 Incidence of LHFs among 132 MOWHTOs divided into four groups in chronological order with 33 cases in each group. *LHF* lateral hinge fracture. *Incidence of LHF in each group

Table 2 Preoperative and postoperative radiologic findings

	Non-LHF ($n=100$)	LHF ($n=32$)	p value
Preoperative			
HKA angle	− 7.4 ± 2.8 (− 14.4 to − 0.9)	− 7.6 ± 3.3 (− 13.6 to 0.7)	0.588
WBL ratio, %	18.3 ± 12.3 (− 21.14 to 48.23)	17.5 ± 14.0 (− 8.86 to 49.38)	0.782
MPTA	84.0 ± 2.2 (77.6 to 89.3)	83.8 ± 2.2 (79.4 to 89.2)	0.440
PTS angle	8.2 ± 3.1 (1.0 to 14.0)	8.2 ± 2.4 (3.1 to 13.7)	0.657
Intraoperative			
Osteotomy angle	33.3 ± 5.4 (22.2 to 44.7)	34.7 ± 5.6 (20.3 to 44.8)	0.285
Opening distance, mm	11.7 ± 2.8 (5.8 to 24.1)	12.4 ± 2.2 (6.8 to 18.0)	0.134
Safe zone achievement, %	90 (90.0%)	27 (84.4%)	0.383
Immediate postoperative			
HKA angle	1.4 ± 2.1 (− 3.6 to 7.5)	1.5 ± 2.5 (− 6.9 to 5.5)	0.491
WBL ratio, %	57.2 ± 9.2 (34.3 to 83.9)	59.7 ± 10.5 (20.6 to 76.8)	0.056
MPTA	92.4 ± 2.2 (87.6 to 97.0)	92.3 ± 2.9 (85.0 to 98.3)	0.783
PTS angle	8.2 ± 3.2 (1.3 to 17.1)	6.8 ± 4.3 (− 2.1 to 14.6)	0.099
Postoperative 1 year			
HKA angle	0.9 ± 2.0 (− 4.2 to 6.1)	1.0 ± 2.8 (− 8.4 to 7.1)	0.750
WBL ratio, %	54.4 ± 9.2 (26.8 to 79.4)	57.0 ± 12.1 (13.2 to 81.0)	0.184
MPTA	92.2 ± 2.0 (86.8 to 97.2)	92.1 ± 2.8 (83.2 to 98.2)	1.000
PTS angle	8.2 ± 3.3 (− 0.5 to 17.9)	7.2 ± 4.3 (− 2.2 to 15.2)	0.233
Angle change			
HKA angle	0.4 ± 1.2 (− 2.7 to 4.6)	0.4 ± 1.3 (− 3.2 to 3.7)	0.856
WBL ratio, %	2.6 ± 5.4 (− 11.0 to 20.3)	2.5 ± 5.9 (− 12.8 to 15.7)	0.762
MPTA	0.3 ± 1.0 (− 2.3 to 3.8)	0.2 ± 1.3 (− 2.3 to 3.3)	0.459
PTS angle	− 0.8 ± 2.1 (− 6.4 to 5.5)	− 0.7 ± 2.1 (− 6.9 to 3.7)	0.508
Time to union, months	5.0 ± 2.2 (3 to 12)	7.3 ± 2.8 (3 to12)	< 0.001

Values are presented as mean and SD with the ranges in parentheses

LHF lateral hinge fracture, *HKA angle* hip–knee–ankle angle, *WBL* weight bearing line, *MPTA* medial proximal tibial angle, *PTS angle* posterior tibial slope angle

(6.1%). The gap filling methods did not have a statistical correlation with the incidence of LHFs ($p=0.612$).

Clinical symptom assessment by the KSS and IKDC scores revealed statistically significant improvements in both the non-LHF and LHF groups compared to baseline scores (Table 3). And, no statistical difference in KSS and IKDC was shown between the groups after 1 year ($p>0.05$ in each case). Five cases in the non-LHF group showed wound infections, including four cases of superficial infections which were controlled by the use of intravenous antibiotics in two cases and incisional drainage of the infection site with intravenous antibiotics in the other two cases. Deep infection occurred in one knee, which had undergone early removal of hardware 10 months postoperatively, with

Table 3 Preoperative and postoperative clinical scores

	Non-LHF ($n=100$)	LHF ($n=32$)	p value
KSS			
Preoperative	137.0 ± 33.8 (20–195)	130.7 ± 22.0 (90–168)	0.258
Postoperative 1 year	175.3 ± 18.1 (120–200)	175.2 ± 19.9 (115–200)	0.997
p value	< 0.001	< 0.001	
WOMAC score			
Preoperative	49.0 ± 15.2 (11–86)	47.0 ± 17.9 (7–80)	0.552
Postoperative 1 year	16.3 ± 8.1 (2–38)	20.8 ± 12.1 (2–44)	0.122
p value	< 0.001	< 0.001	

Values are presented as mean and SD with the ranges in parentheses

WOMAC Western Ontario and McMaster Universities Osteoarthritis Index, *KSS* Knee Society Score evidence of union of the osteotomy site. Symptomatic deep vein thrombosis was seen in one case from the non-LHF group and was resolved with conservative care.

Discussion

The most important finding of this study was that there was no change in the incidence of LHFs during MOWHTOs over time. The results might indicate that surgical tips reported by others did not improve the learning curve enough to prevent the occurrence of LHFs during MOWHTOs. The incidence of LHFs was maintained at a constant rate over time. However, patients with or without LHFs showed similar clinical and radiographic results, except for time to bony union.

The occurrence of LHFs as a consequence of MOWHTOs has been an important issue. Furthermore, LHF can be a critical factor in correction loss, instability, and delayed union or nonunion [17–20, 38, 39]. In a mechanical study, Miller et al. [19] reviewed 50 replicate tibias to evaluate the stability of LHFs during MOWHTOs with non-locking osteotomy plates. In their report, disruption of the lateral cortex resulted in a reduction of axial and torsional stiffness, subsequently causing instability of the osteotomy site, which may contribute to delayed union or nonunion. van Raaij et al. [39] reported 15 cases of LHFs from 43 MOWHTOs in a prospective cohort study using Puddu plates. At the 1-year follow-up, the MOWHTO cases with LHFs had correction loss following recurrent varus malalignment, and two cases showed nonunion, requiring additional surgeries.

Nevertheless, according to our findings, LHFs did not result in considerable loss of correction or nonunion compared to patients without LHFs. In this study, particular attention was paid to technical advancements in MOWHTOs reported by many authors. Such techniques included aiming the osteotomy at an area between the tip of the circumference line of the fibular head referred to as the "safe zone" [22], performing a sufficient osteotomy to reach the "lateral zone" beyond the fibular head on the axial plane [23], and avoiding close proximity to the joint when approaching the target point [35]. Type II fractures have especially been reported to lead to a higher incidence of failure, including delayed union, nonunion, and loss of correction [21]. In a review of 71 patients with 82 MOWHTOs fixated with locking plates, Ogawa et al. [23] reported no cases of type II fractures, which is consistent with the fact that no osteotomies were performed below the lower endpoint of the fibula head. Similarly, in our case, among 132 MOWHTOs, only one case showed a type II fracture, and no cases had their osteotomy endpoint distal to the lower margin of the fibula head.

Introduction of a new locking plate specifically designed for high tibial osteotomy fixation has been reported to show favorable results compared to conventional plates [40]. Locking compression plates, as replacements for pre-existing fixation devices, have shown much more firm fixation and resistance to micromotion of the fracture sites [41], which is a strong advantage when LHFs do occur. And, despite efforts to prevent LHFs by targeting the "safe zone" during osteotomies, unintended LHFs can still gain stability through a femorotibial lateral capsule positioned laterally to the fracture site [22].

Attempts to reduce the risk of LHFs in MOWHTOs have been mentioned in many studies [22, 23, 35]. To the best of our knowledge, however, the learning curve of the procedure and the incidence of LHFs are not well-studied. Cheng et al. [42] reported that the complication rates in total knee arthroplasties tended to decrease to a plateau, along with the learning curve, as surgical volume increased over time. We hypothesized that, as surgeons became accustomed to the procedure, the likelihood of LHFs would be reduced. This study included very early cases of MOWHTOs using locking plates by the senior surgeon. Before the use of MOWHTOs, the surgeon had performed lateral closing-wedge high tibial osteotomies with staples for medial unicompartmental OA knees with varus deformities. All cases were required to be performed using techniques reported to prevent lateral hinge fractures. However, in our study, acclimatizing to the procedure did not reduce the risk of lateral hinge fractures. From the earliest to the latest group, the incidence of LHF did not show any expected decrease in LHFs, comparing each sequentially divided group over time.

While LHFs in MOWHTOs seemed not to crucially affect patients' 1 year radiographic and clinical outcomes, they still represented a drawback of the procedure. The amount of time to union in the LHF group was 7.3 months, compared to 5.0 months in the non-LHF group, showing a statistically significant difference ($p < 0.001$). Brosset et al. [32] reported union progress in 51 MOWHTO cases using Tomofix without any filling of the osteotomy gap. The average reported period to gap union was 4.5 months, which is consistent with our results from the non-LHF group. Siboni et al. [43] reported a correlation between LHFs and a consolidation delay of the osteotomies in 41 cases of MOWHTOs using locking plates. Of these 41 cases, five showed nonunion, requiring corticocancellous iliac grafts. Nonetheless, in our cases, there was no nonunion case requiring additional surgery. The delayed union of osteotomies with LHFs was not reflected in any poorer clinical outcomes 1 year after surgery.

Takeuchi et al. [21] previously reported classification of LHFs according to the location of the extension of the fracture line related to the proximal tibiofibular joint. In our cases, the majority of the fractures occurred as type I fractures, which is consistent with the report by Takeuchi et al. While previous studies have considered type II and type III fractures to be unstable, the incidence of these fractures were minuscule in our study, which differed from the results of Takeuchi et al. We believe that the occurrence of these type II and type III fractures can be curtailed by following the above-described surgical techniques to prevent LHFs.

The opening distance during the correction has been reported to correlate with the incidence of LHFs in MOWHTOs [21, 25, 44, 45]. Miller et al. [25] reviewed 46 patients with MOWHTOs and reported statistically significant associations between the wedge size and complication incidences, especially in both intra- and postoperative fractures ($p < 0.0063$). Nonetheless, the opening distance of the osteotomy did not have a statistically meaningful correlation with the incidence of LHFs during MOWHTOs in our study ($p = 0.134$). Nelissen et al. [24] reviewed 49 cases of MOWHTOs and concluded that there was no significant relationship between the size of the wedge and the occurrence of LHFs, which is consistent with the results of our study. Han et al. [22] also indicated that there was no correlation between opening distances and LHFs.

Since there is no definitively determined entry point for primary osteotomy, the osteotomy angle might be ambiguous and controversial. However, considering the design of the locking plate with threaded screw holes, which allows screw to thread to the plate as a fixed angle, the entry point for osteotomy was decided on the level of the long shaft portion of the plate between proximal and distal screw holes. The osteotomy angle was measured to prevent too shallow or too steep of an angle. Notably, in our study, the osteotomy angle in all cases did not go beyond 44.8° maximum and 20.3° minimum, with a mean value of 33.71 ± 5.68°. An excessively acute osteotomy angle targeting the lateral cortex below the fibula head may result in type II fractures [23], and an osteotomy angle toward the joint line may result in type III fractures.

There were several limitations to this study. First, the absolute number of MOWHTO cases was small, although it was meaningful in the sense that all operations were done by a single senior surgeon and all cases were performed with the same locking compressing plate under consistent surgical techniques. Second, most of the patients undergoing MOWHTO in our study were female. However, a higher female incidence of OA in the Korean population has been reported before [46]. Third, this study had a relatively short follow-up period of a minimum of 1 year. Despite the fact that the assessment of LHFs and union of the osteotomy site was fully possible and comprehensive within this period, a longer follow-up period is still needed. Fourth, the study population was rather inhomogeneous in regard to osteotomy gap filling. Fifth, 6 weeks of non-weight-bearing after surgery as our rehabilitation protocol might have affected the result of our study.

Conclusion

The incidence of LHFs during MOWHTOs remained consistent at 24.2%, despite surgeons' accumulating experience with the procedure over time. Although patients with LHFs required longer times to achieve bony union, they showed radiographic and clinical results similarly favorable to those of patients without LHFs 1 year after surgery.

Funding There was no external funding source in this investigation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest. There are no financial remuneration of any authors, any members of their family.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Hankemeier S, Mommsen P, Krettek C, Jagodzinski M, Brand J, Meyer C, Meller R (2010) Accuracy of high tibial osteotomy: comparison between open- and closed-wedge technique. Knee Surg Sports Traumatol Arthrosc 18(10):1328–1333
2. Ogawa H, Matsumoto K, Ogawa T, Takeuchi K, Akiyama H (2016) Preoperative varus laxity correlates with overcorrection in medial opening wedge high tibial osteotomy. Arch Orthop Trauma Surg 136(10):1337–1342
3. Petersen W, Metzlaff S (2016) Open wedge high tibial osteotomy (HTO) versus mobile bearing unicondylar medial joint replacement: five years results. Arch Orthop Trauma Surg 136(7):983–989
4. Saito T, Kumagai K, Akamatsu Y, Kobayashi H, Kusayama Y (2014) Five- to ten-year outcome following medial opening-wedge high tibial osteotomy with rigid plate fixation in combination with an artificial bone substitute. Bone Joint J 96-B(3):339-344.
5. Takeuchi R, Aratake M, Bito H, Saito I, Kumagai K, Hayashi R, Sasaki Y, Akamatsu Y, Ishikawa H, Amakado E, Aota Y, Saito T (2009) Clinical results and radiographical evaluation of opening wedge high tibial osteotomy for spontaneous osteonecrosis of the knee. Knee Surg Sports Traumatol Arthrosc 17(4):361–368
6. DeMeo PJ, Johnson EM, Chiang PP, Flamm AM, Miller MC (2010) Midterm follow-up of opening-wedge high tibial osteotomy. Am J Sports Med 38(10):2077–2084
7. Matsunaga D, Akizuki S, Takizawa T, Yamazaki I, Kuraishi J (2007) Repair of articular cartilage and clinical outcome after osteotomy with microfracture or abrasion arthroplasty for medial gonarthrosis. Knee 14(6):465–471
8. Gaasbeek RD, Sonneveld H, van Heerwaarden RJ, Jacobs WC, Wymenga AB (2004) Distal tuberosity osteotomy in open wedge high tibial osteotomy can prevent patella infera: a new technique. Knee 11(6):457–461
9. Gaasbeek R, Welsing R, Barink M, Verdonschot N, van Kampen A (2007) The influence of open and closed high tibial osteotomy on dynamic patellar tracking: a biomechanical study. Knee Surg Sports Traumatol Arthrosc 15(8):978–984

10. Kesmezacar H, Erginer R, Ogut T, Seyahi A, Babacan M, Tenekecioglu Y (2005) Evaluation of patellar height and measurement methods after valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 13(7):539–544
11. Lee DC, Byun SJ (2012) High tibial osteotomy. Knee Surg Relat Res 24(2):61–69
12. Ogawa H, Matsumoto K, Ogawa T, Takeuchi K, Akiyama H (2016) Effect of wedge insertion angle on posterior tibial slope in medial opening wedge high tibial osteotomy. Orthop J Sports Med 4(2):2325967116630748
13. Song SJ, Bae DK, Kim KI, Lee CH (2016) Conversion total knee arthroplasty after failed high tibial osteotomy. Knee Surg Relat Res 28(2):89–98
14. Wright JM, Heavrin B, Begg M, Sakyrd G, Sterett W (2001) Observations on patellar height following opening wedge proximal tibial osteotomy. Am J Knee Surg 14(3):163–173
15. Kim KI, Kim DK, Song SJ, Lee SH, Bae DK (2017) Medial open-wedge high tibial osteotomy may adversely affect the patellofemoral joint. Arthroscopy 33(4):811–816
16. Nha KW, Kim HJ, Ahn HS, Lee DH (2016) Change in posterior tibial slope after open-wedge and closed-wedge high tibial osteotomy: a meta-analysis. Am J Sports Med 44(11):3006–3013
17. Kazimoglu C, Akdogan Y, Sener M, Kurtulmus A, Karapinar H, Uzun B (2008) Which is the best fixation method for lateral cortex disruption in the medial open wedge high tibial osteotomy? A biomechanical study. Knee 15(4):305–308
18. Meidinger G, Imhoff AB, Paul J, Kirchhoff C, Sauerschnig M, Hinterwimmer S (2011) May smokers and overweight patients be treated with a medial open-wedge HTO? Risk factors for non-union. Knee Surg Sports Traumatol Arthrosc 19(3):333–339
19. Miller BS, Dorsey WO, Bryant CR, Austin JC (2005) The effect of lateral cortex disruption and repair on the stability of the medial opening wedge high tibial osteotomy. Am J Sports Med 33(10):1552–1557
20. Rose T, Imhoff AB (2007) Complications after transgenicular osteotomies. Oper Tech Orthop 17(1):80–86
21. Takeuchi R, Ishikawa H, Kumagai K, Yamaguchi Y, Chiba N, Akamatsu Y, Saito T (2012) Fractures around the lateral cortical hinge after a medial opening-wedge high tibial osteotomy: a new classification of lateral hinge fracture. Arthroscopy 28(1):85–94
22. Han SB, Lee DH, Shetty GM, Chae DJ, Song JG, Nha KW (2013) A "safe zone" in medial open-wedge high tibia osteotomy to prevent lateral cortex fracture. Knee Surg Sports Traumatol Arthrosc 21(1):90–95
23. Ogawa H, Matsumoto K, Akiyama H (2017) The prevention of a lateral hinge fracture as a complication of a medial opening wedge high tibial osteotomy: a case control study. Bone Joint J 99-B (7):887–893
24. Nelissen EM, van Langelaan EJ, Nelissen RG (2010) Stability of medial opening wedge high tibial osteotomy: a failure analysis. Int Orthop 34(2):217–223
25. Miller BS, Downie B, McDonough EB, Wojtys EM (2009) Complications after medial opening wedge high tibial osteotomy. Arthroscopy 25(6):639–646
26. Nakamura R, Komatsu N, Murao T, Okamoto Y, Nakamura S, Fujita K, Nishimura H, Katsuki Y (2015) The validity of the classification for lateral hinge fractures in open wedge high tibial osteotomy. Bone Joint J 97-B(9):1226–1231
27. Nakamura R, Komatsu N, Fujita K, Kuroda K, Takahashi M, Omi R, Katsuki Y, Tsuchiya H (2017) Appropriate hinge position for prevention of unstable lateral hinge fracture in open wedge high tibial osteotomy. Bone Joint J 99-B(10):1313–1318
28. Paley D, Herzenberg JE, Tetsworth K, McKie J, Bhave A (1994) Deformity planning for frontal and sagittal plane corrective osteotomies. Orthop Clin North Am 25(3):425–465
29. Lee DH, Han SB, Oh KJ, Lee JS, Kwon JH, Kim JI, Patnaik S, Shetty GM, Nha KW (2014) The weight-bearing scanogram technique provides better coronal limb alignment than the navigation technique in open high tibial osteotomy. Knee 21(2):451–455
30. Insall JN, Dorr LD, Scott RD, Scott WN (1989) Rationale of the Knee Society clinical rating system. Clin Orthop Relat Res 248:13–14
31. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW (1988) Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 15(12):1833–1840
32. Brosset T, Pasquier G, Migaud H, Gougeon F (2011) Opening wedge high tibial osteotomy performed without filling the defect but with locking plate fixation (TomoFix) and early weight-bearing: prospective evaluation of bone union, precision and maintenance of correction in 51 cases. Orthop Traumatol Surg Res 97(7):705–711
33. Fujisawa Y, Masuhara K, Shiomi S (1979) The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am 10(3):585–608
34. Dugdale TW, Noyes FR, Styer D (1992) Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clin Orthop Relat Res 274:248–264
35. Jacobi M, Wahl P, Jakob RP (2010) Avoiding intraoperative complications in open-wedge high tibial valgus osteotomy: technical advancement. Knee Surg Sports Traumatol Arthrosc 18(2):200–203
36. Kim MS, Son JM, Koh IJ, Bahk JH, In Y (2017) Intraoperative adjustment of alignment under valgus stress reduces outliers in patients undergoing medial opening-wedge high tibial osteotomy. Arch Orthop Trauma Surg 137(8):1035–1045
37. Lobenhoffer P, Agneskirchner JD (2003) Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 11(3):132–138
38. Hernigou P, Medevielle D, Debeyre J, Goutallier D (1987) Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Joint Surg Am 69(3):332–354
39. van Raaij TM, Brouwer RW, de Vlieger R, Reijman M, Verhaar JA (2008) Opposite cortical fracture in high tibial osteotomy: lateral closing compared to the medial opening-wedge technique. Acta Orthop 79(4):508–514
40. Staubli AE, De Simoni C, Babst R, Lobenhoffer P (2003) TomoFix: a new LCP-concept for open wedge osteotomy of the medial proximal tibia–early results in 92 cases. Injury 34(Suppl 2):B55–62
41. Frigg R (2001) Locking Compression Plate (LCP). An osteosynthesis plate based on the Dynamic Compression Plate and the Point Contact Fixator (PC-Fix). Injury 32(Suppl 2):63–66
42. Cheng CH, Cheng YT, Chen JS (2011) A learning curve of total knee arthroplasty (TKA) based on surgical volume analysis. Arch Gerontol Geriatr 53(1):e5–9
43. Siboni R, Beaufils P, Boisrenoult P, Steltzlen C, Pujol N (2018) Opening-wedge high tibial osteotomy without bone grafting in severe varus osteoarthritic knee. Rate and risk factors of non-union in 41 cases. Orthop Traumatol Surg Res 104(4):473–476
44. Chae DJ, Shetty GM, Wang KH, Montalban AS Jr, Kim JI, Nha KW (2011) Early complications of medial opening wedge high tibial osteotomy using autologous tricortical iliac bone graft and T-plate fixation. Knee 18(4):278–284
45. Spahn G (2004) Complications in high tibial (medial opening wedge) osteotomy. Arch Orthop Trauma Surg 124(10):649–653
46. Koh IJ, Kim MW, Kim JH, Han SY, In Y (2015) Trends in high tibial osteotomy and knee arthroplasty utilizations and demographics in Korea from 2009 to 2013. J Arthroplast 30(6):939–944