Analysis of bone union after medial closing wedge distal femoral osteotomy using a new radiographic scoring system

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Abstract

Introduction: To compare bone union after medial closing wedge distal femoral osteotomy (MCWDFO) with that after lateral closing wedge distal femoral osteotomy (LCWDFO) using a novel scoring system.

Materials and Methods: The data of thirty patients who received biplanar MCWDFO for valgus knees (MCWDFO group) were retrospectively examined and compared to that of 22 patients (25 knees) who underwent biplanar LCWDFO via a double-level osteotomy (DLO) for varus knees (LCWDFO group). The progression of bone union of the transverse osteotomy plane in the femur was assessed using a newly-developed scoring system using radiographs taken immediately after surgery and three and six months postoperatively. The scoring system is based on a scale of zero to six points with higher scores indicating better bone union. The incidence of hinge fractures was assessed using CT images, and the rates of reoperation were evaluated using medical record data.

Results: The mean bone union score was significantly lower in the MCWDFO group than in the LCWDFO group three months (2.1 ± 1.9 vs. 3.7 ± 1.7, $P < 0.01$) and six months (3.8 ± 2.1 vs 4.9 ± 1.5, $P < 0.05$) postoperatively. The incidence ratio of hinge fractures was significantly higher in the MCWDFO group than in the LCWDFO group (70.0% vs. 32.0%, $P < 0.01$). Two patients in the MCWDFO group underwent reoperation for delayed bone union or non-union.

Conclusion: Bone union progression was slower and hinge fractures were more frequently observed

after MCWDFO than after LCWDFO via DLO. MCWDFO is technically challenging, and patients must be monitored closely during and after surgery.

Keywords:

Distal femoral osteotomy, bone union, medial closing wedge, double-level osteotomy

List of abbreviations

MCWDFO: medial closing wedge distal femoral osteotomy

LCWDFO: lateral closing wedge distal femoral osteotomy

DLO: double-level osteotomy

HTO: high tibial osteotomy

Introduction

Distal femoral osteotomy (DFO) is a surgical method used solely or combined with proximal tibial osteotomy to treat patients with mal-alignment of the lower limb [1-12]. Medial closing wedge distal femoral osteotomy (MCWDFO) is performed to treat patients with valgus knee osteoarthritis (OA) [3,8,13-15], while lateral closing wedge distal femoral osteotomy (LCWDFO) is often paired with a high tibial osteotomy (HTO) and performed via a double-level osteotomy (DLO) to treat patients with severe varus knee OA [10,16-21].

Although MCWDFO is a useful surgical technique, complications after DFO including vascular injury, plate irritation, delayed union, non-union, and hinge fractures have been reported [22-24]. Hinge fractures are a possible cause of non-union and delayed union, and have a high incidence after MCWDFO. Various fixation methods have been used to improve fixation stability. A previous biomechanical study showed that biplanar MCWDFO with a locking plate was more stable than that with a condylar plate [25]; locking plates are currently the standard plate type used for DFO. Although improved locking plates and surgical techniques have increased stability and rendered DFO a reliable surgical option, postoperative bone union after DFO remains a common concern [26]. Several previous studies have described the timing of bone union after biplanar MCWDFO; however, the evaluation details and methods were not reported clearly. In addition, bone union after biplanar MCWDFO has not yet been fully examined using a validated method.

The primary purpose of this study was to compare femoral bone union after MCWDFO for valgus knees with that after LCWDFO via DLO for varus knees using a novel scoring system. The second purpose of this study was to examine the factors associated with delayed union after biplanar MCWDFO. We hypothesize that bone union after biplanar MCWDFO is slower than that after biplanar LCWDFO via DLO and that hinge fractures and the female sex are risk factors associated with delayed union after MCWDFO.

Material and methods

Patients

This retrospective study was approved by the Institutional Review Board of our hospital. All the patients provided written informed consent for inclusion of this study. Between 2012 and 2019, 30 patients underwent biplanar MCWDFO for valgus knees. Fourteen patients underwent MCWDFO due to post-lateral meniscectomized OA, seven patients due to primary OA, three patients due to post tibial plateau fractures, two patients due to post-traumatic cartilage injuries, two patients due to habitual patellar dislocation combined with lateral compartment OA, and two patients due to valgus knee OA after total hip arthroplasty. Concomitant surgeries included an osteochondral plug transplantation in one patient, an autologous chondrocyte implantation in one patient, a lateral meniscal repair in four patients, a lateral meniscectomy in one patient, a lateral meniscal centralization in seven patients, and a tibial tuberosity transfer in one patient. All 30 patients who underwent MCWDFO were included in this study (MCWDFO group). Twenty-two patients who received DLO for varus knee OA were included as a control group (LCWDFO group), including three patients who underwent bilateral DLO; therefore, 25 femurs were included in the LCWDFO group.

Surgical indication

The surgical indications for MCWDFO were lateral compartmental OA with cartilage injury and patellar dislocation with a mechanical lateral distal femoral angle ≤ 85° and a mechanical axis (MA) percentage ≥ 55%. The surgical indications for DLO were medial osteoarthritis, a medial opening gap that was expected to be > 20 mm or a mechanical proximal angle > 95° when planning for opening wedge HTO. In patients with a mechanical lateral distal femoral angle ≥ 90°, DLO was performed. All surgeries were performed by one of four attendant surgeons.

Surgical procedures

MCWDFO was initiated with a 7-cm skin incision in the mid-medial side of the thigh. The fascia of the vastus medialis oblique (VMO) was incised, and the VMO was elevated to expose the medial aspect of the distal femur. The periosteum was carefully released, and a retractor was inserted to protect the neurovascular bundle. Two distal guide pins were inserted in parallel under fluoroscopy approximately four cm above the medial epicondyle. Two additional guide pins were inserted according to the size of the wedge determined during preoperative planning. The distance between the guidewires was recorded as the width of the resected bone wedge. The aiming hinge point was set as the inflection point between the lateral metaphysis and diaphysis. An oblique transverse osteotomy was performed with guide pins. For a bi-planar osteotomy, the anterior ascending cut was made from the anterior one-fourth of the femur to the anterior proximal diaphysis to create a 2-2.5-cm anterior flange. After removal of the wedge bone, the gap was closed gently. In the first five patients, a proximal tibial fixation plate (DePuy Synthes, Solothurn, Switzerland) was used, and an MDF plate (DePuy Synthes) was used in the next ten patients. A different MDF plate (Olympus Terumo Biomaterials Corp., Tokyo, Japan) was used in the final 15 patients. Plate fixation was secured using bi-cortical fixation. When the fragment was displaced due to a hinge fracture, the fragment was reduced manually and compression was applied to the hinge using a cortical screw. No patients required additional plates or fixation on the lateral side during the initial surgery.

DLO was initiated with a skin incision over the mid-lateral thigh and the lateral aspect of the distal femur between the vastus lateralis and iliotibial tract. Distal guide pins were inserted approximately four cm above the lateral epicondyle, and the distance between the proximal guide was determined during preoperative planning. Similar to MCWDFO, a bi-planar osteotomy was performed, and fixation was achieved using a locking plate. In the first ten knees, an MDF plate (DePuy Synthes) was used on the contralateral side by bending the plate to fit the distal femur. A locking plate (Olympus Terumo Biomaterials Corp.) was used in the next 15 knees. After the lateral closing wedge osteotomy, a medial opening wedge high tibial osteotomy was performed using a Tomo fix plate (DePuy Synthes) or a Tris plate (Olympus Terumo Biomaterials Corp.).

Low-intensity pulsed ultrasound (SAFHS; Teijin Pharma, Ltd, Tokyo, Japan) was used for the treatment of delayed union and non-union. The patients' need for reoperation was evaluated and discussed six months postoperatively.

Postoperative rehabilitation

Range of motion exercises were initiated on postoperative day three and progressed according to the patient's condition. Partial weight bearing (PWB) of one-third of the body weight was permitted three to four weeks postoperatively, and full weight bearing was permitted eight weeks after surgery. PWB was permitted six weeks postoperatively in patients with hinge fractures, and FWB was permitted depending on the callus formation in these patients. The same rehabilitation protocol was used for patients who underwent DLO. If a hinge fracture was identified postoperatively, the patient was advised to use double crutches, and PWB of one-third of the body weight was permitted until callus formation was confirmed.

Radiographic assessments

Bone union was assessed using anteroposterior plain radiographs obtained immediately after surgery and at three and six months postoperatively. The progression of bone union at the transverse osteotomy plane in the femur was assessed using a newly-developed scoring system. The transverse osteotomy line extending to the opposite cortex was divided into three zones: zone 1, hinge zone; zone 2, mid-zone; and zone 3, closing zone. Each zone was scored zero to two points depending on the status of the osteotomy line (0: presence of clear line or radiolucent area, 1: partial presence or disappearance of the line or partial union, 2: Unidentifiable osteotomy line or complete disappearance of the osteotomy line). The scores of each zone were summed to obtain the total score (Figure 1). The scoring was performed independently by three examiners who were blinded to patient information. To evaluate intra-observer reliability, the second assessment was performed three months after the first assessment.

CT images were obtained approximately three to four weeks after surgery. The patients were placed in a supine position with the knee extended. One-millimeter thick slices were used to evaluate bone union using a Picture Archiving and Communication (PACS) system (Shade Quest/View R-DG ver. 1.27; Fujifilm Solution Co., Ltd., Tokyo, Japan). The presence of hinge fractures was assessed using CT images. When disruption of the cortex was observed in the medial or lateral hinge area, it was defined as a hinge fracture. Fractures were classified into three types according to a previous report [27]: type 1: fracture line extended along the osteotomy line; type 2: fracture extends in the proximal direction; and type 3: fracture extends in the distal direction. The hinge positions were assessed using a line tangential to the upper border of the lateral and medial condyles to divide the area into supra-condylar and intra-condylar parts on anteroposterior radiographs, as previously reported [28]. The hinge positions were then classified as supra-condylar or intra-condylar (Figure 2). The crossing point of the mechanical axis (MA) at the tibial plateau was expressed as the percentage of the total length of the tibial plateau (%MA). The hip-knee-ankle angle (HKAA) was measured as the angle between the line from the hip center to the knee center and the line from the ankle center to the knee center. The varus alignment was expressed as a negative value, and the valgus alignment was expressed as a positive value. The joint line convergence angle (JLCA) was measured as the angle between the line tangential to the medial and lateral condyles and the line parallel to the tibial joint surface. The mechanical lateral distal femoral angle (mLDFA) was measured as the angle between the line from the hip center to the knee center and the line tangential to the medial and lateral condyles. The %MA, HKAA, JLCA, and mLDFA were measured on preoperative and 1-year postoperative standing radiographs. Δ%MA, ΔHKAA, ΔJLCA, and ΔmLDFA were expressed as absolute values. All radiographic measurements were performed using the PACS software.

Sub-group analyses

Patients in the MCWDFO and LCWDFO groups were divided into hinge fracture and non-fracture groups (MCWDFO-fracture, MCWDFO-non-fracture, LCWDFO-fracture, and LCWDFO-non-fracture) to examine the effect of hinge fractures on the bone union score.

Factors associated with delayed union and sufficient union six months after MCWDFO

A bone score ≤ 2 at six months postoperatively was defined as delayed union while a bone score ≥ 5 was defined as sufficient union. The definitions of delayed union and sufficient union were agreed upon by five orthopaedic surgeons. A binominal logistic regression analysis was performed to identify factors associated with delayed union and bone union.

Statistics

The Mann-Whitney U test or Student’s t-test was used to compare continuous values between the two groups depending on the data normality. Fisher’s exact test was used to compare categorical values. Inter-class correlation coefficients (ICCs) were calculated using a two-way mixed effect model with absolute agreement to assess interobserver reliability. Values < 0.5 were considered to have poor reliability, those between 0.5 and 0.75 were considered to have moderate reliability, those between 0.75 and 0.9 were considered to have good reliability, and those > 0.90 were considered to have excellent reliability [29]. A priori power analysis using G*Power (Heinrich Heine Universität Dǜsseldorf, Germany) showed that a minimum of 21 patients for each group were required to detect the difference in the bone union between the two groups with a power of 0.80 and an α of 0.05. The Kruskal-Wallis test and Dunn’s multiple comparison test were used to assess the bone union of the four subgroups. Binominal logistic regression analyses were performed with delayed union or sufficient union as the dependent variables and age, sex, presence of hinge fractures, and wedge width as independent variables. All statistical analyses were performed using SPSS for Windows version 16 (SPSS Inc., Chicago, IL, USA) and GraphPad Prism (GraphPad Software, San Diego, CA, USA). Statistical significance was set at $P < 0.05$.

Results

Validation of the new scoring system for bone union

The detailed ICC values for each zone are summarized in Table 1. Overall, good to excellent inter-rater agreement was obtained for both MCWDFO and LCWDFO. Similarly, good to excellent ICC values for intra-rater reliability were also obtained (Supplemental table 1).

Comparison of bone union between MCWDFO and LCWDFO

The mean wedge width of the resected bone in the MCWDFO group was significantly greater than that in the LCWDFO group (8.0 ± 2.4 vs 6.2 ± 1.5, $P < 0.01$) (Table 2). The incidence of hinge fractures was significantly higher in the MCWDFO group than in the LCWDFO group (70.0% vs. 32.0%, $P < 0.01$). The ratio of the supra-condylar hinge position was significantly higher in the MCWDFO group than in the LCWDFO group (80.0 % vs. 36.0%, respectively, $P < 0.05$) (Table 2). Two patients in the MCWDFO group underwent reoperation for delayed bone union or non-union. One patient underwent reoperation at six months after the initial operation, and one patient underwent reoperation after one year.

The mean bone score at three months postoperatively was significantly greater than that immediately after surgery in the LCWDFO group, though the mean bone score at three months postoperatively was not significantly different from that immediately after surgery in the MCWDFO group. The bone union scores six months after surgery were significantly improved compared to those immediately and three months after surgery ($P < 0.01$, respectively) (Figure 3). The mean bone union score was significantly lower in the MCWDFO group than in the LCWDFO group three months ($P < 0.01$) and six months ($P < 0.05$) after surgery (Figure 3). A similar tendency was also observed when wedge width was adjusted by selecting the patients who had a wedge width of more than 8 mm (Supplemental tables 2 and 3). There was no significant difference in the mean bone union score among the patient groups according to plate type who received MCWDFO or LCWDFO.

MCWDFO-fracture group vs non-fracture group

The total bone union score in the MCWDFO-fracture group (1.5 ± 1.5) was significantly lower than that in the MCWDFO-non-fracture group (3.8 ± 1.9, $P < 0.05$) and the LCWDFO-non-fracture group (4.2 ± 1.3, $P < 0.001$) at three months postoperatively. The bone union scores in the MCWFO-fracture and LCWDFO-fracture groups were lower than those in the non-fracture groups at six months postoperatively, although the differences were not statistically significant (Figure 4).

Factors associated with delayed union and union six months after MCWDFO

Seven patients in the MCWDFO group had a bone union score ≤ 2 at six months postoperatively. All seven patients had a hinge fracture, and 6 were female. A typical case of delayed union is shown in Figure 5. Female sex (odds ratio (OR): 15; 95% confidence interval (CI): 1.3-167.6; $P = 0.03$) was associated with delayed union after MCWDFO. Sufficient union at six months postoperatively was positively associated with male sex (OR: 7.4; 95% CI: 1.1-48.5; P = 0.04) and negatively associated with wedge width (OR: 0.58; 95% CI: 0.35-0.96; P = 0.03).

Discussion

The main findings of the present study were that the assessment of bone union after MCWDFO using the new scoring system was significantly slower than that after LCWDFO via DLO and a higher incidence of hinge fracture was observed after MCWDFO. In addition, bone union after MCWDFO was slower in patients with hinge fractures than in those without hinge fractures. Delayed bone union six months after MCWDFO was associated with female sex.

Favourable clinical outcomes after MCWDFO have been reported [7,13,15,30,31]. However, few studies regarding the timing of bone union after surgery have been reported, and the definition of bone union has not been well described. In this study, a new scoring system was developed to evaluate bone union after MCWDFO and LCWDFO. Overall, moderate to excellent ICCs were obtained in the validation of this new system, suggesting that the scoring system may be useful as an assessment tool for bone union after surgery.

The mean total bone union scores at three and six months postoperatively were significantly lower in patients who underwent MCWDFO than in those who underwent LCWDFO via DLO. The mean patient age was significantly lower in the MCWDFO group. As hinge fractures were observed at a significantly higher rate in the MCWDFO group than in the LCWDFO group, delayed bone union may be associated with the high incidence of hinge fractures after MCWDFO. van der Woude et al. reported a shorter bone healing time after biplanar distal valgus osteotomy compared to that after uniplanar distal valgus osteotomy [32]. In their report, 50% of the patients had hinge fractures without complete displacement, and these patients tended to have longer healing times [32]. In a study conducted by Forkel et al., 11/23 patients (47.8%) had hinge fractures after MCWDFO and one patient underwent a revision surgery due to correction loss while the remaining ten patients achieved bone union without additional surgery [33]. Although the timing of bone union was not addressed in the previous study, the results suggest that unstable hinge fractures affect the time to bone union.

Several studies regarding hinge fractures after DFO have been reported recently. Kim et al. reported that forty-two percent of patients who received DFO, including MCWDFO, LCWDFO, medial opening wedge DFO, and lateral opening wedge DFO had hinge fractures [28]. Nakayama et al. reported that the incidence of hinge fractures was 30.6% after LCWDFO via DLO [27] while Rupp reported an incidence of 48% [20]. Very recently, Fujita et al. reported that hinge fracture was found in 57% of the patients after MCWDFO [26]. Although the incidence of hinge fractures after LCWDFO in this study was comparable to previously-reported values, the incidence of hinge fractures was significantly higher after MCWDFO. To identify the possible cause of the differences in the incidence ratio of hinge fractures between MCWDFO and LCWDFO via DLO, demographic and surgical data and radiographic measurements were compared. One possible reason for the higher incidence of hinge fracture after MCWDFO was a larger wedge width in the MCWDFO group than in the LCWDFO group. A large bone volume was removed in most patients who underwent MCWDFO to correct alignment in the femur only, while alignment was corrected in both the femur and the tibia in DLO, which required a relatively small volume of bone to be removed from the femur. Therefore, a larger bending stress was applied on the hinge area during the closure of the gap in MCWDFO, contributing to the higher incidence of hinge fractures. To support this idea, Rupp et al. reported that the resected wedge width was significantly larger in patients with medial hinge fractures compared to that in patients without hinge fractures after LCWDFO [20]. Meanwhile, the hinge position may also be associated with the incidence of hinge fractures. Na et al. found that the incidence of lateral hinge fractures was significantly higher in the supracondylar hinges than in the lateral condylar hinges of cadaveric knees during MCWDFO [34]. Kim et al. suggested that the upper border of the lateral femoral condyle is an ideal hinge position where the lateral head of the gastrocnemius tendon function as a possible soft tissue stabilizer in patients with MCWDFO [35]. In this study, the hinge point was more frequently located in the condylar area in the LCWDFO group than in the MCWDFO group. Therefore, the more proximal location of the hinge point may be associated with the higher incidence of hinge fractures in the MCWDFO group in this study.

As slower bone union was observed after MCWDFO, the factors associated with delayed bone union (a bone union score ≤ 2) at six months postoperatively were also assessed. Female sex was found to be associated with delayed bone union, while the presence of hinge fractures was not a statistically significant factor. While the bone union scores in the hinge fracture groups were lower than those in the non-fracture groups in the subgroup analyses, the presence of hinge fractures was not identified as a significant factor associated with delayed bone union. Previously, Takeuchi et al. reported that in type II fractures, the fracture line is distal to the proximal tibiofibular joint and is associated with the delayed bone union after open-wedge HTO [36]. Unlike this report of open-wedge HTO, no significant influence of fracture type on bone union was observed in this study. These results suggest that bone union can be affected by several factors, including patient age, sex, fracture site, and hinge position, while hinge fractures may also affect the time to bone union. In our study, some young male patients achieved bone union uneventfully at six months postoperatively, even when a displaced hinge fracture occurred during surgery. Therefore, female patients with hinge fractures may be at high risk for delayed bone union after MCWDFO and must be monitored carefully while sufficient bone union at six months postoperatively can be expected in male patients who undergo the resection of a small bone wedge. Liska et al. examined the risk factors for non-union after LCWDFO and lateral open wedge DFO and found that smoking and obesity (BMI > 30) were associated with non-union [37], which is not consistent with the results of this study. However, this study included only one patient who smoked and most patients had a BMI < 30. Therefore, the differences between the results of the previous study and the current study may be due to patient demographics. However, smoking and high BMI are generally considered risk factors for non-union after fractures; thus, patients with these factors should be monitored carefully. In this study, no additional surgical treatment was performed during the patients' initial surgeries. However, to manage relatively high-risk patients for delayed union and non-union, additional plating to the lateral side may be a treatment option to consider if a hinge fracture was detected during surgery [38].

Limitations

This study is not without limitations. First, the surgical methods and PWB after hinge fractures were not consistent, although relatively similar techniques and rehabilitation protocols were used. Second, there were significant differences in the demographic data between the MCWDFO and LCWDFO groups. Although patient age and BMI were higher in the LCWDFO group, these factors were generally considered a disadvantage for bone union. Therefore, this difference most likely did not affect the result regarding bone union. Third, the high incidence of hinge fractures in this study may affect the statistical analysis of the influence of hinge fractures on bone union score. In addition, if patients with comparable wedge width were included in both MCWDFO and LCWDFO group, the results may be different, although wedge width tends to be smaller in LCWDFO via DLO than that in MCWDFO in general. Fourth, the high incidence of hinge fractures may be related to a poor surgical technique for MCWDFO. Fifth, although no significant influence of the plate difference on bone union was observed, it may have been detected if more patients were included in the study. Last, the number of patients in each group was relatively small and no final clinical outcomes were considered in this study. Despite these limitations, this study provides important information for surgeons who perform MCWDFO.

Conclusion

Bone union after MCWDFO was significantly slower than that after LCWDFO via DLO, and a higher incidence of hinge fractures was observed after MCWDFO. The bone union and occurrence of hinge fractures in patients who undergo MCWDFO must be monitored carefully.

Declarations

Ethical approval

All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards

Conflict of interest

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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Tables

Table 1. Interclass correlation coefficients for bone union scores after closing distal femoral osteotomies

Table 2. Patient demographics, surgical data, and radiographic measurements

Figure legends

Figure 1. Novel bone union scoring system for the transverse osteotomy plane after distal femoral osteotomy. (a) Scoring system (b) Examples of scoring for bone union after MCWDFO and LCWDFO.

Figure 2. Radiographic assessment of hinge fractures and hinge positions

(a) Hinge fracture types. (b) Hinge positions. A broken line tangential to the upper border of the lateral and medial condyles was drawn to divide the area into supra-condylar and intra-condylar parts.

Figure 3. Changes in bone union scores after MCWDFO and LCWDFO.

0D; immediately after surgery; 3M: postoperatively three months; 6M: postoperatively six months. * P <0.05, ** P< 0.001. Values in the table are mean ± standard deviation.

Figure 4. Bone union score in the hinge fracture and non-hinge fracture groups after MCWDFO and LCWDFO.

Black bar: MCWDFO-fracture group; White bar: MCWDFO-non-fracture group; Gray bar: LCWDFO-fracture group; Oblique line bar: LCWDFO-non-fracture group. Data are shown as the mean ± standard deviation. * P <0.05, *** P< 0.001. Abbreviations: FX = fracture; NF = non-fracture

Figure 5. Delayed union after MCWDFO.

A 57-year-old female patient underwent medial closing wedge distal femoral osteotomy. The bone union score was 0 at six months postoperatively. The patient preferred conservative treatment, and bone union was achieved 18 months postoperatively without the need for additional surgery.

Table 1. Interclass correlation coefficient values for bone union score after closing distal femoral osteotomy

		0 day	3 months	6 months
MCWDFO	1st	0.69 (0.41-0.86)	0.89 (0.75-0.96)	0.97 (0.81-0.97)
	2nd	0.77 (0.54-0.91)	0.81 (0.61-0.93)	0.96 (0.9-0.99)
LCWDFO	1st	0.63 (0.34-0.84)	0.93 (0.84-0.97)	0.85 (0.69-0.94)
	2nd	0.71 (0.45-0.88)	0.83 (0.65-0.93)	0.85 (0.69-0.94)

Data are shown as value (95% confidence interval).

Table 2. Patient demographic, surgical data and radiographic evaluation.

	MCWDFO (n = 30)	LCWDFO (n = 25)	Statistical analysis
Patient demographic			
Age (years old)	46.1 ± 10.1	58.3 ± 7.1	P < 0.01
Gender (male/female)	16/14	18/7	n.s
Height (cm)	168.9 ± 9.1	166.8 ± 7.6	n.s
Weight (kg)	69.8 ± 14.3	80.4 ± 13.9	P < 0.01
BMI (kg/m^2)	24.3 ± 3.6	28.7 ± 3.9	P < 0.01
Surgical data			
Resected wedge width (mm)	8.0 ± 2.4	6.2 ± 1.5	P < 0.01
Radiographic evaluation			
Preoperative %MA	75.7 ± 15.5	-8.4 ± 16.0	P < 0.01
Postoperative %MA	37.2 ± 17.1	55.0 ± 17.7	P < 0.01
Δ%MA	38.6 ± 21.5	63.4 ± 24.7	P < 0.01
Preoperative HKAA	7.1 ± 3.9	-12.3 ± 3.6	P < 0.01
Postoperative HKAA	-1.5 ± 3.6	2.5 ± 4.2	P < 0.01
ΔHKAA	8.7 ± 4.3	14.8 ± 5.0	P < 0.01
Preoperative JLCA	-1.3 ± 2.4	5.4 ± 2.8	P < 0.01
Postoperative JLCA	-0.2 ± 2.1	1.8 ± 2.3	P < 0.01
ΔJLCA	1.0 ± 1.1	3.6 ± 3.8	P < 0.01
Preoperative mLDFA	82.8 ± 2.0	91.1 ± 1.6	P < 0.01
Postoperative mLDFA	90.2 ± 3.2	86.4 ± 2.8	P < 0.01
ΔmLDFA	7.4 ± 3.7	4.7 ± 2.3	P < 0.01
Hinge fracture [n (%)]	21(70.0%)	8 (32.0%)	P < 0.01
Fracture type (I/II/III)	10/8/3	3/3/2	n.s
Hinge location (SC/IC)	24/6	16/9	P < 0.05

N=number of knees. MA: mechanical axis. SC: supra-condyle. IC: Intra-condyle.

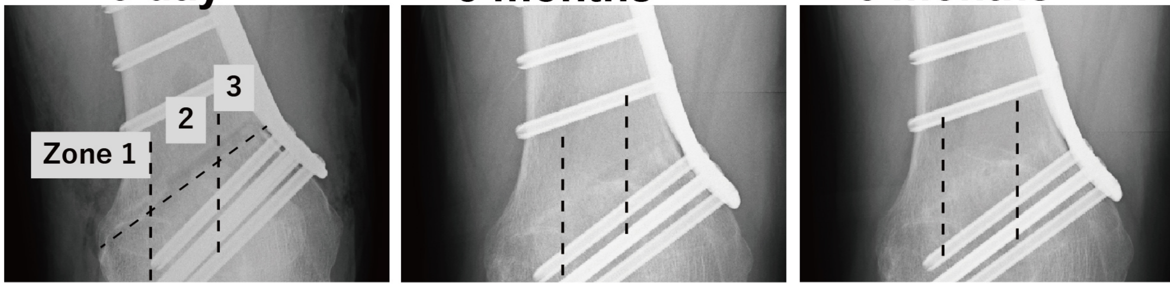
Δ%MA: Absolute difference between preoperative and postoperative change. n.s: not significant

HKAA: Hip-Knee-Ankle angle. JLCA: Joint line convergence angle. mLDFA: mechanical distal femoral angle. Δ%MA, ΔHKAA, ΔJLCA, and ΔmLDFA were expressed as absolute values.

Figure 1

a

0 day	3 months	6 months



	0 day				3 months				6 months			
Zone	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total
Score	1	0	0	1	2	1	1	4	2	2	2	6

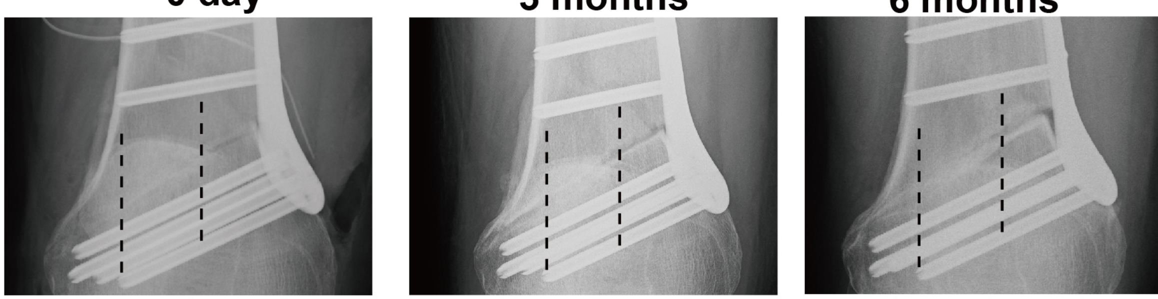
Osteotomy line extending to the opposite cortex was divided into three zones.
Zone 1, hinge zone; Zone 2, mid-zone; Zone 3, closing zone.
Each zone was scored 0-2 points.
The scores of each zone were summed to obtain total score (minimum 0, maximum 6 points).

0 : Clear osteotomy line / radiolucent lucent area
1 : Partial presence or disappearance of the osteotomy line
2 : Unidentifiable osteotomy line or complete disappearance of the osteotomy line / consolidation

b

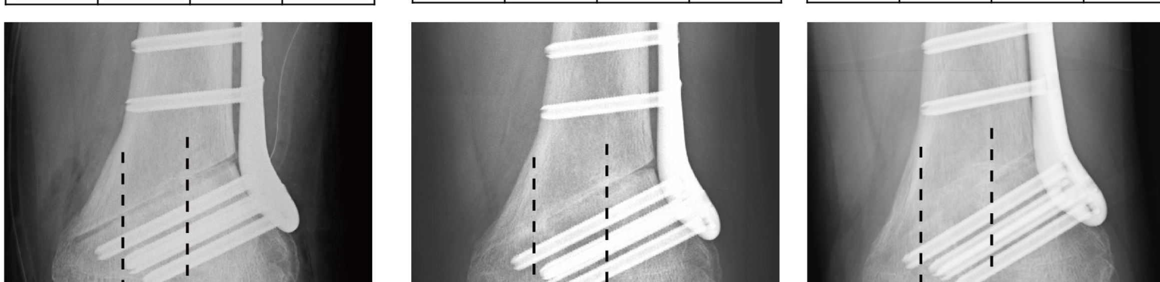
0 day	3 months	6 months

MCWDFO



	0 day				3 months				6 months			
Zone	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total
Score	1	1	0	2	0	1	0	1	2	1	1	4

LCWDFO



	0 day				3 months				6 months			
Zone	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total	Zone 1	Zone 2	Zone 3	Total
Score	0	0	0	0	2	1	1	4	2	2	2	6

Figure 2

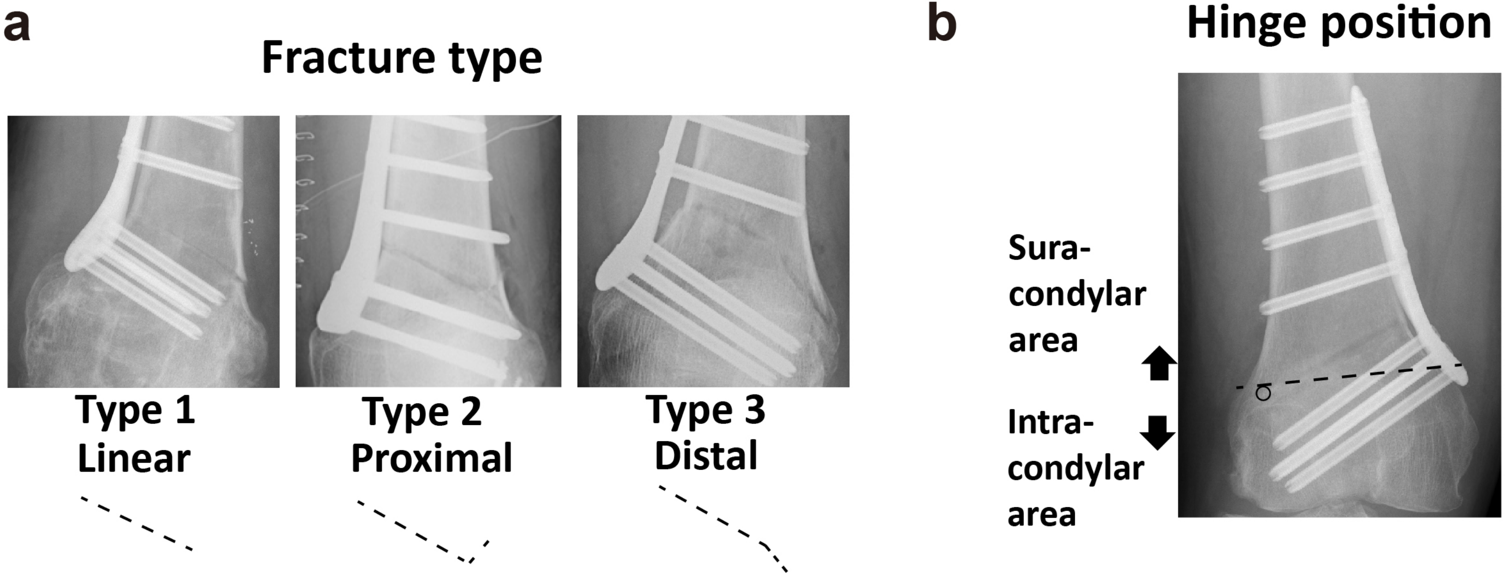
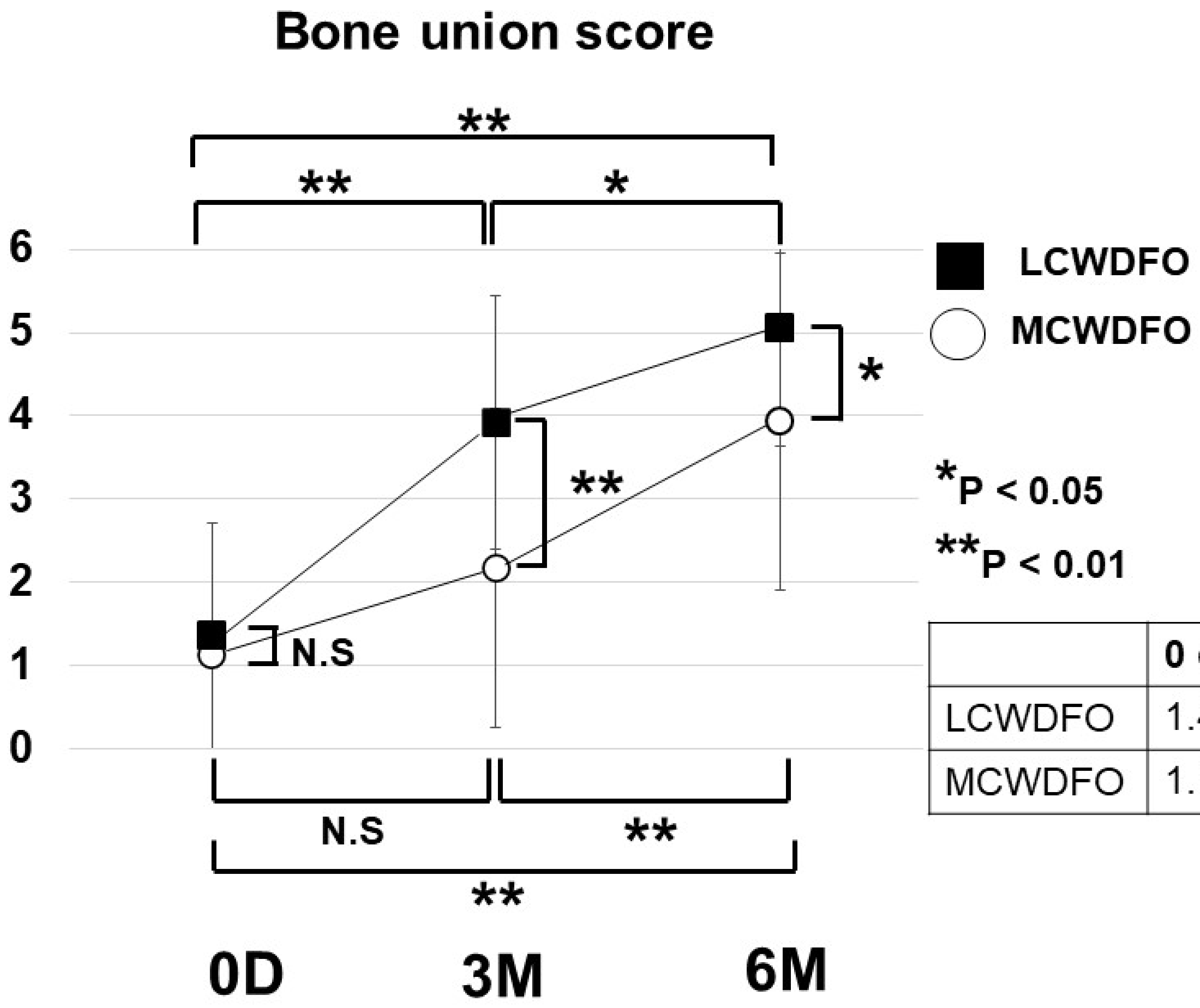

a
Fracture type
Type 1
Linear
Type 2
Proximal
Type 3
Distal
b
Hinge position
Sura-
condylar
area
Intra-
condylar
area

Figure 3



	0 day	3 months	6 months
LCWDFO	1.4 ± 1.4	3.7 ± 1.7	4.9 ± 1.5
MCWDFO	1.1 ± 1.6	2.1 ± 1.9	3.8 ± 2.1

Figure 4

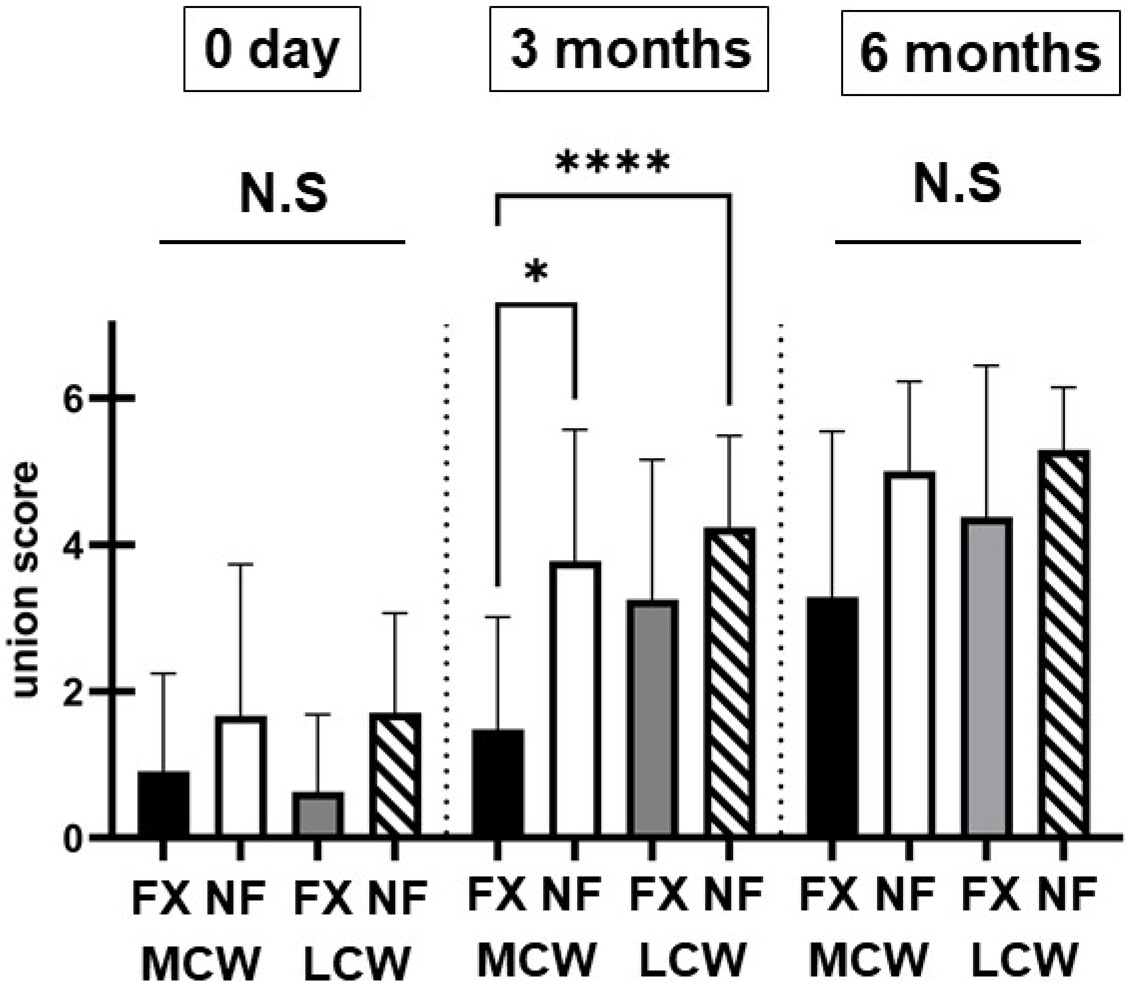

0 day
3 months
6 months
N.S
****
*
N.S
union score
0
2
4
6
FX NF FX NF
MCW LCW
FX NF FX NF
MCW LCW
FX NF FX NF
MCW LCW

Figure 5