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Original Article

Time to Bone Union after Hybrid Closed-Wedge High Tibial Osteotomy

Yasuhiro Takahara[a]*, Takayuki Furumatsu[b], Hirotaka Nakashima[a], Satoru Itani[a], Makoto Nakamura[a], Yoichiro Uchida[a], Hisayoshi Kato[a], Yoshitaka Tsujimura[a], Yuichi Iwasaki[a], and Nobuaki Ochi[a]

[a]*Department of Orthopedic Surgery, Nippon Kokan Fukuyama Hospital, Fukuyama, Hiroshima 721-0927, Japan,*
[b]*Department of Orthopaedic Surgery, Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences, Okayama 700-8558, Japan*

Medial open- and lateral closed-wedge high tibial osteotomy (hybrid CWHTO) can overcome the limitations of conventional CWHTO and open-wedge HTO (OWHTO) for medial compartmental osteoarthritis (OA) of the knee. Hybrid CWHTO increases stability by using a rigid locking plate and allows early full weight-bearing. However, the literature contains no information about time to bone union after this new procedure. The aim of this study is to evaluate the time to bone union after hybrid CWHTO. We reviewed 44 knees treated with hybrid CWHTO. Patients were able to stand on both legs on the day after surgery and walked with full weight-bearing within 4 weeks of the procedure. The time to achievement of bone union at the osteotomy site was defined as the number of months until bone union was confirmed on radiographic imaging. The mean time to radiographic confirmation of bone union was 4.5 ± 1.5 months after surgery. Eleven knees (25.0%) required 6 months or more. Radiographic analysis and JOA score improved significantly between before and 1 year after surgery ($p < 0.01$). Hybrid CWHTO is a very useful method for treating medial OA, but radiographic bone union requires 4.5 months on average. We must be aware of bone union after hybrid CWHTO.

Key words: bone union, hybrid closed-wedge high tibial osteotomy, osteoarthritis

There are many options to treat medial compartmental osteoarthritis (OA) of the knee, such as arthroscopic debridement [1,2], abrasion arthroplasty [3], high tibial osteotomy (HTO) [4-6], unicompartmental knee arthroplasty (UKA) [7], and total knee arthroplasty (TKA). HTO is a common surgical procedure for medial compartmental OA of the knee. HTO's most appealing advantage is that it allows us to preserve the knee joint better than UKA or TKA. But, in the past, the main disadvantage of closed-wedge HTO (CWHTO) was a long period of rehabilitation. Open-wedge high tibial osteotomy (OWHTO) using a TomoFix locking plate (DePuy Synthes, Switzerland) was introduced [8] in 2003. Since then, excellent clinical results [9,10] have been reported. In recent years, however, some concerns have arisen regarding patellofemoral joint damage after OWHTO [11,12] or indications for advanced stage because of OA progression [13].

To overcome the limitations of conventional CWHTO and OWHTO, a new method, medial open- and lateral closed-wedge HTO (hybrid CWHTO), was established by Takeuchi in 2014 [14] (Fig. 1 shows an osteotomy line with a hybrid CWHTO technique). At our institute, HTO has been indicated for OA patients of all ages who exhibit varus limb alignment, localized medial compartment lesions, and knee pain persisting

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*Corresponding author. Phone: +81-84-945-3106; Fax: +81-84-945-3564
E-mail: yasuhiro_takahara@nkfh.or.jp (Y. Takahara)

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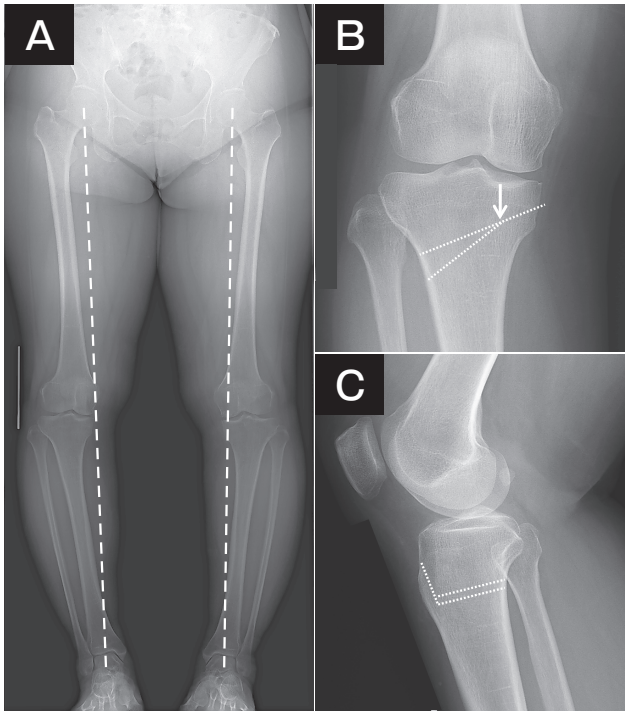

Fig. 1 Radiographic images of a 58-year-old woman. (A) Standing AP view. (B) Dotted lines indicate osteotomy lines. Hinge point (arrow). (C) Lateral view.

after 3 months of conservative treatment. As HTO is a physiological procedure that requires careful post-treatment care, patients indicated for HTO should be those who can understand and perform post-operative rehabilitation and who express a desire for joint preservation. HTO is not indicated for cases involving infection, flexion contracture of ≥20°, or a restricted range of motion of <90°. There is no age restriction or BMI threshold in our indications for HTO. It is important for surgeons to note that patient education is essential for successful postoperative rehabilitation after hybrid HTO.

A previous study, using lateral closing wedge osteotomy, showed that the results of HTO deteriorate with time, but that the survival of HTO could be improved through careful patient selection and surgical technique [15]. Hybrid CWHTO has many advantages: the removed bone block is smaller, and the lateral cortex of the proximal and distal fragments is firmly attached by oblique osteotomy with a locking plate. So patients are permitted to stand on both legs on the day after surgery and walk with early full weight-bearing after this procedure. Nevertheless, the time to bone union after this new procedure is not known well. We hypothesized that this technique affords early bone union at the osteotomy site. Therefore, we studied the time to bone union after hybrid CWHTO with early full weight-bearing.

Materials and Methods

We performed hybrid CWHTO on 45 knees between September 2015 and December 2016 at our hospital. Forty-four knees with at least 1 year of postoperative follow-up were included in this study. The surgical approach used was that of Takeuchi [14], with the medial side open and the lateral side closed, and with preservation of the medial soft tissue. A TomoFix locking plate (DePuy Synthes) was used in all patients. There were 12 men (12 knees) and 30 women (32 knees), and the mean age at surgery was 66.8 ± 5.8 years (range, 56-81 years). The mean postoperative follow-up period was 13.8 ± 2.1 months (range, 13-33 months). Table 1 shows the patients data. Mean body height, body weight, and body mass index (BMI) at surgery were 156.8 ± 7.4 cm (range, 145-179 cm), 67.5 ± 9.8 kg (range, 50-89 kg), and 27.4 ± 3.7 kg/m^2 (range, 21.7-39.5 kg/m^2), respectively. OA was assessed using the Kellgren-Lawrence (KL) classification system [15]. The KL classifications at the time of surgery were KL3 for 15 knees and KL4 for 29 knees.

The timing of bone union was determined using radiographic imaging. The criterion for bone union in this study was confirmation of the continuity of bone trabeculae at the lateral inter-osteotomy line. Our hospital's postoperative rehabilitation protocol following hybrid CWHTO in this series included one-third partial weight-bearing (PWB) walking and range-of-motion

Table 1 Patient demographics

Variables	
Patients (men/women)	42 (12/30)
Knees (men/women)	44 (12/32)
Age (years)	66.8 ± 5.8
Kellgren-Lawrence grade 3/4	15/29
Height (m)	1.57 ± 0.7
Body weight (kg)	67.5 ± 9.8
Body mass index (kg/m^2)	27.4 ± 3.7
Follow-up (months)	13.8 ± 2.1

Data of age, height, body weight, body mass index, and follow-up are presented as means ± standard deviations.

training starting on the day after surgery, followed by one-half PWB starting at 2 weeks, two-thirds PWB at 3 weeks, and full weight-bearing (FWB) at 4 weeks. The patient was discharged at 1 month after surgery (Table 2). After discharge, outpatient follow-up was performed at 2, 3, and 6 months and 1 year after surgery. If there were problems with bone union or if any other issues were observed at those times, monthly examinations were continued (Fig. 2). The time to bone union was defined as the number of months until bone union was confirmed on radiographic imaging and by two authors using a picture archiving and communication system. To assess intra-observer reliability, a single surgeon evaluated each radiograph of bone union twice, with an interval of at least 1 week between the measurements. In order to assess inter-observer reliability, two surgeons who were blinded to the clinical data and to the details of the radiology reports independently reviewed the radiographs. Intra-class correlation coefficients (ICCs) and corresponding 95% CIs were calculated to quantify inter- and intra-observer reliability for continuous variables. ICCs of 1.0 were indicative of perfect agreement, and the strength of agreement was interpreted based upon the ICC values: 0.80 indicated almost perfect agreement, 0.61-0.80 indicated substantial agreement, 0.41-0.60 indicated moderate agreement, and 0.21-0.40 indicated fair agreement.

Preoperative and postoperative radiographic assessments of the mechanical leg axis, standing and supine femorotibial angle (FTA), medial proximal tibial angle (MPTA), and joint line congruence angle (JLCA) were performed. The Japanese Orthopaedic Association (JOA) score and knee range of motion were studied as clinical evaluation. The visual analogue scale (VAS) score was also measured before and after surgery according to patient self-assessments. The Wilcoxon test was used for statistical analysis before and after surgery, and significance was defined as a hazard ratio of less than 1% (**) and 5% (*).

This study was approved by our institutional review board as a retrospective case series.

Table 2 Rehabilitation protocol

Postoperative	
1 week	1/3 PWB, ROM exercise
2 weeks	1/2 PWB
3 weeks	2/3 PWB
4 weeks	FWB

PWB, partial weight bearing; ROM, range of motion; FWB, full weight bearing.

Results

The mean time to radiographic confirmation of bone union was 4.5 ± 1.5 months after surgery (Fig. 3). Eleven patients (25.0%) required 6 months or more until radiographic bone union after surgery. Radiographic analysis (mechanical leg axis, standing FTA, supine FTA, MPTA), JOA score, and extension improved significantly before and 1 year after surgery ($p < 0.01$). JLCA improved significantly before and 1 year after surgery ($p < 0.05$) (Table 3). The mean VAS score improved significantly, from 4.6 before surgery to 2.2, 1.4, and 1.1 at 3 months, 6 months, and 1 year after surgery ($p < 0.01$) (Fig. 4).

Inter- and intra-observer reliability. We assessed the inter- and intra-observer reliability of bone union. The inter- and intra-observer ICC were 0.942 and 0.893, respectively. This indicated almost perfect agreement. Finally, measurements by a single observer were adopted in this study.

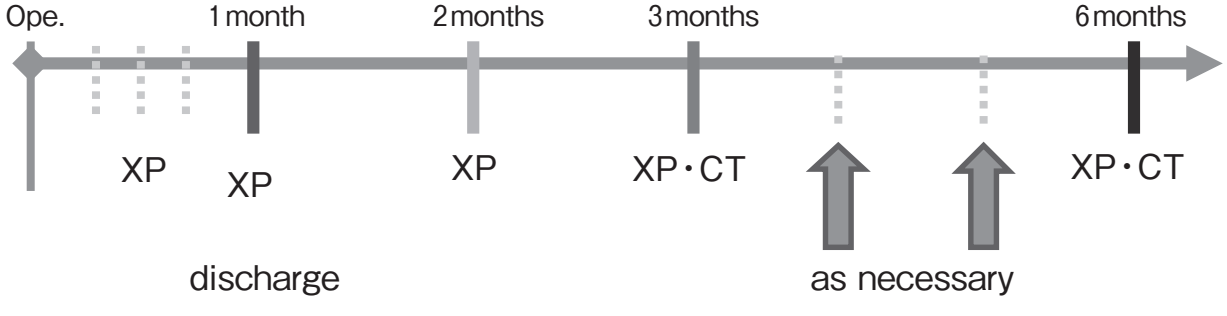

Fig. 2 Outpatient follow-up.

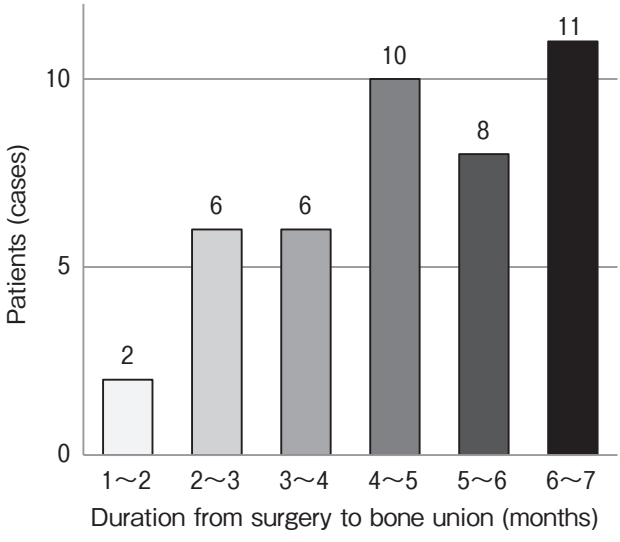

Fig. 3 Duration from hybrid CWHTO to radiographic bone union.

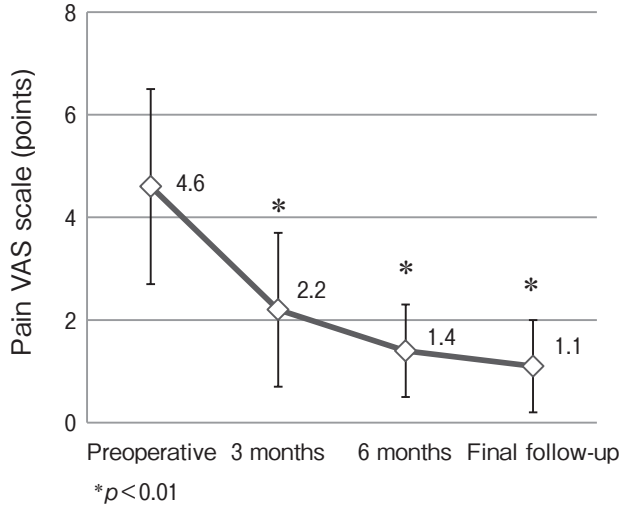

Fig. 4 Pain VAS score at preoperative and postoperative evaluations.

Table 3 Clinical findings

	Preoperative	Postoperative 1 year
Mechanical axis (%)	2.0 ± 15.2	52.1 ± 10.8**
Standing FTA (°)	184.9 ± 4.2	172.6 ± 3.0**
Supine FTA (°)	182.8 ± 3.1	172.6 ± 3.5**
MPTA (°)	83.0 ± 2.4	92.0 ± 3.4**
JLCA (°)	3.8 ± 2.0	3.4 ± 2.1*
JOA score (point)	61.0 ± 10.5	86.4 ± 8.1**
Extension (°)	−8.3 ± 5.8	−2.0 ± 3.7**
Flexion (°)	120.0 ± 13.0	127.8 ± 10.9
VAS (point)	4.6 ± 1.9	1.0 ± 0.9**

Data are presented as means ± standard deviations.
FTA, femorotibial angle; MPTA, medial proximal tibial angle; JLCA, joint line congruence angle; JOA, Japanese Orthopaedic Association; VAS, visual analogue scale. $^{**}p < 0.01$, $^{*}p < 0.05$.

Case presentation. A representative case among our study subjects was a 58-year-old woman with the following characteristics: height, 150 cm; weight, 69.2 kg; and BMI, 30.7. She was referred to our hospital for a consultation regarding pre-existing pain in both knees. The right knee range of motion at the time of her initial evaluation was 0° extension/135° flexion. Radiographic assessment showed the following results: mechanical leg axis, 0%; standing FTA, 184°; MPTA, 79.6°; mechanical lateral distal femoral angle (mLDFA), 86.6°; JLCA, 2.7°; and JOA score, 70 points (Fig. 1). Fifteen-degree hybrid CWHTO was performed on her right knee. Figure 5 shows the changes at 2, 4, and 6 months after surgery. Sufficient bone union was not obtained at 4 months after surgery but was confirmed at 6 months after surgery. Knee range of motion at that time was 0° extension/145° flexion, with a JOA score of 90 points.

Discussion

High tibial osteotomy is a widely accepted treatment option for medial OA of the knee. CWHTO generally produces a good outcome with precise indication and surgical technique [16]. However, the closed wedge technique has several disadvantages, such as the need for fibular osteotomy, a large amount of bone loss, leg shortening, delayed or non-union, and possible peroneal nerve palsy [17].

Lobenhoffer *et al.* [8] of the AO group introduced the OWHTO procedure for medial knee OA. With that method, fibular osteotomy is unnecessary and there is no risk of peroneal nerve palsy. Moreover, Takeuchi *et al.* reported that using artificial bone for the open area makes it possible to achieve FWB early after surgery [18]. Therefore, the number of patients undergoing this procedure has been increasing. In recent years, however, some reports have addressed concerns regarding the patellofemoral joint after OWHTO [11, 12]. It is believed that OWHTO would result in negative effects on the patellofemoral joint. The clinical score is thought to deteriorate with time, in especially advanced-stage OA [13]. The hybrid CWHTO method

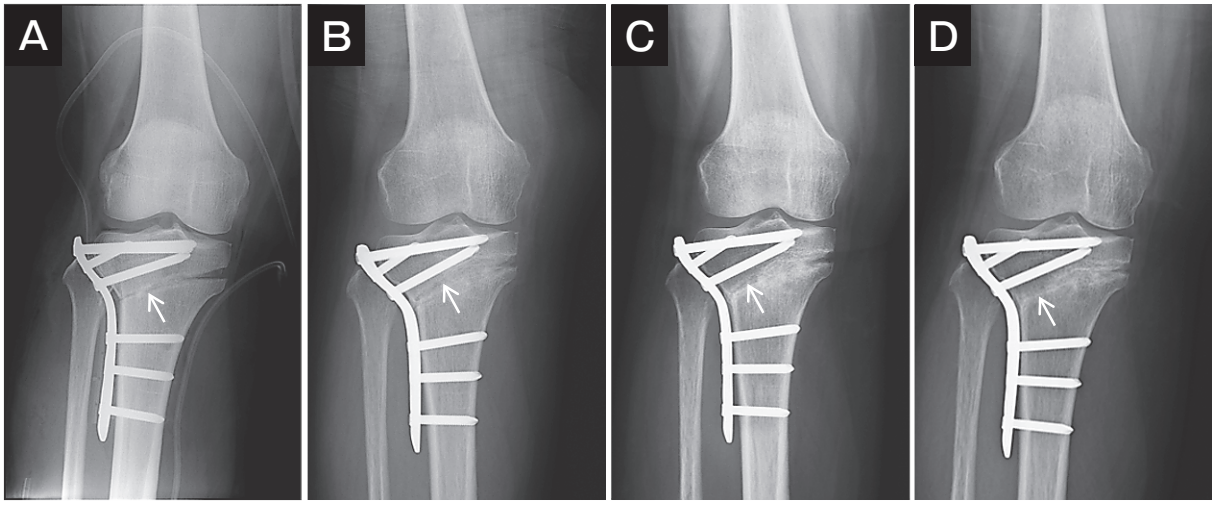

Fig. 5 Postoperative radiographs. (A) Postoperative day 0. Fifteen degrees of correction. Hinge point, 2 : 1. Radiographic images at 2 (B), 4 (C), and 6 months (D) postoperatively. Arrow indicates osteotomy line.

combines the advantages of conventional CWHTO and OWHTO. In hybrid CWHTO, a hinge point is set midway on the tibial osteotomy line; therefore, the fragment that is removed is smaller than that in conventional CWHTO. We can reduce leg length discrepancy. The tibial tuberosity, which is the site of the patellar tendon attachment, is also moved to a more proximal and anterior position. We can decompress the patellofemoral joint with this procedure. If a knee has a flexion contracture, knee extension can be used to handle the decrease in tibial posterior slope. Hybrid CWHTO is broadly indicated and very useful.

However, CWHTO has some pitfalls. The hinge point may move to a more medial position when medial soft tissue is tight, resulting in insufficient correction [19]. We experienced cases that required a long time to achieve radiographic bone union, which is why we conducted this study. Bone union is affected by various factors, such as changes in the bone contact surface depending on hinge position, the extent of osteoporosis, the condition of the medial soft tissue, the presence of a fixation implant, BMI, and postoperative rehabilitation. In this study, the mean time to confirm radiographic bone union was 4.5 months after surgery, with 11 patients (25%) needing 6 months or more. Walking with one-third PWB was started the day after surgery, and the load was increased with each week on a rehabilitation program that was followed for approximately 1 month after surgery. Patients could walk even if bone union did not occur with a rigidly fixed locking plate. When performing hybrid CWHTO, we must consider the rehabilitation program because there is no medial bone cortex hinge. Our program after hybrid CWHTO has changed; one-third PWB is maintained until approximately 3 weeks after surgery, when bone union starts. After that point, the load is increased. Delayed union was defined as the presence of pain at the osteotomy site with an absence of radiographic evidence of union at 6 months [20]. In our cases, all patients were able to achieve bone union, and there was no need for additional procedures such as low-intensity pulsed ultrasound or bone graft. VAS scores improved from 3 months to 1 year after surgery. So not all cases were defined as delayed union even if there was no radiographic evidence of bone union at 6 months. But it will be important to follow patients carefully and to conduct an appropriate postoperative program depending on the details of each case.

In conclusion, our findings indicated that the mean time to confirmed radiographic bone union after hybrid CWHTO was 4.5 months after surgery. Hybrid CWHTO is thought to be a very useful method for medial OA; however, we must consider bone union and the postoperative program after hybrid CWHTO.

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