Changes in patellar baja progress until 3 months after medial open-wedge high tibial osteotomy

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Abstract

Purpose: The purpose of this study was to evaluate sequential patellar height changes as well as the factors leading to these changes after medial open-wedge high tibial osteotomy (MOWHTO).

Methods: The study cohort constituted 37 knees from 36 patients who underwent MOWHTO for varus knee. The Caton–Deschamps index (CDI) for patellar height was measured preoperatively and at 2 weeks and 3, 6, and 12 months postoperatively. The factors related to sequential changes in patellar height were evaluated.

Results: Significant differences were observed between preoperative CDI and postoperative CDI at all time points (p < .05). Two-week postoperative CDI and postoperative CDI at 3, 6, 12-months was also significantly different (p < .05). The only significant factor for the change in patellar height between preoperative CDI and postoperative CDI at 2-weeks and 12-months was the change in the Δ medial proximal tibial angle (ΔMPTA) (postoperative MPTA – preoperative MPTA). We could not identify the factor that affected the change in patellar height change from 2-weeks postoperatively.

Conclusion: The change in patellar height continued sequentially until at least 3 months postoperatively. ΔMPTA was associated with the change in patellar height at 2 weeks postoperatively as compared with preoperatively; however, no factors associated with the change in patellar height from 2 weeks postoperatively to 3, 6, and 12-months postoperatively were identified.

Keywords

caton–deschamps index, medial open-wedge high tibial osteotomy, patellar height, patellofemoral osteoarthritis, patellar tendon contracture, level of evidence, therapeutic level IV, retrospective study

Introduction

Medial open-wedge high tibial osteotomy (MOWHTO) is a widely performed surgical procedure for patients with varus malalignment and medial compartment knee osteoarthritis (OA). Good long-term clinical results have been reported (10-years survival rate of 90%).\(^1\) The reported complications of MOWHTO include patella baja, hinge fracture, non-union, infection, and hardware-related irritation.\(^2\)–\(^4\) Many studies have reported patella baja progression until 3 months after MOWHTO.\(^5\)–\(^9\) However, patellar height changes in the short term after MOWHTO have not been reported.\(^5\) Therefore, the purpose of this study was to evaluate sequential patellar height changes as well as the factors leading to these changes after MOWHTO.
baja after MOWHTO as a major complication of the procedure (incidence rate: 80%–100%). Patellar height is reduced during MOWHTO because of distalization of the tuberosity. In general, the change in patellar height had finished at direct postoperatively. However, El-Azab et al. reported a significant decrease in patellar height at direct postoperatively compared with before surgery, and the number of patellar infera cases increased before removal of the hardware compared with direct postoperatively. Moreover, some scholars have reported that patellar tendon contracture may reduce patellar height after OWHTO. Therefore, in this study, we measured patellar height sequentially after MOWHTO to determine when patellar height change occur. We hypothesized that the patellar height changes sequentially after MOWHTO. The purpose of this study was to evaluate the sequential changes in patellar height and the factors that contribute to these changes after MOWHTO.

**Materials and methods**

**Patients**

This study was approved by the Institutional Review Board of Fukuoka University Hospital (U21-01-014), and informed consent was obtained from all patients. This study was a retrospective, nonrandomized, and sequential study. The study cohort constituted 37 knees from 36 consecutive patients (male/female, n = 13/24) who underwent MOWHTO. All surgical procedures were performed by one senior surgeon to treat medial OA of the knee at our institution from April 2017 to August 2020. The mean age of the patients was 64.3 ± 6.9 years (range, 52–77 years), and the mean body mass index (BMI) was 26.3 ± 3.8 kg/m² (range, 19.6–32.7 kg/m²). 14 patients had Kellgren–Lawrence grade II disease, 18 patients had grade III, and five patients had grade IV. Clinical function was evaluated using the Knee Injury and Osteoarthritis Outcome Score (KOOS).

**Surgical technique and postoperative rehabilitation**

A longitudinal skin incision was made over the pes anserinus insertion at the anteromedial aspect of the tibia. The medial proximal tibia was exposed by releasing the pes anserinus and the medial collateral ligament. First, osteotomy was performed at the medial cortical margin of the proximal tibia, along the osteotomy guide, and stopped approximately 5 mm from the lateral cortical margin, targeting the proximal tibiofibular joint. Second, osteotomy was performed in the frontal plane while protecting the patellar tendon and maintaining a tibial tubercle thickness of approximately 10 mm. The osteotomy site was opened using an opener until the preoperatively planned medial proximal tibial angle (MPTA) was reached. β-Tricalcium phosphate and two β-tricalcium phosphate wedges were inserted into the osteotomy gap. The medial osteotomy site was fixed using a locking compression plate after the pes anserinus was repaired.

Isometric quadriceps exercises, active ankle exercises, straight leg raises, and continuous passive motion with no limitation were started on postoperative day 3. Patients were allowed to begin half partial weight-bearing exercises 2 weeks after surgery and were allowed to begin full weight-bearing exercises 4 weeks after surgery. Patients with microfractures were allowed to begin half partial weight-bearing exercises 3 weeks postoperatively and were allowed to begin full weight-bearing exercises 5 weeks postoperatively.

**Radiographic evaluation**

The % mechanical axis (%MA) and the MPTA were measured using standing anteroposterior full-length radiographs of the lower limb (Figure 1). The MA represents the point at which the Mikulicz line (the line connecting the center of the femoral head to the center of the talus) passes from the most medial side of the tibial plateau. The %MA is calculated as the ratio of the horizontal distance from the medial edge of the tibial plateau to the intersection of the MA. The MPTA is defined as the medial angle between the tibial anatomic axis and the joint line of the proximal tibia. The posterior tibial slope (PTS) was measured on the lateral diagram of the knee according to the method of Brazier et al. (Figure 2). The Caton-Deschamps index (CDI) was used to measure the patellar height preoperatively (preCDI) and at 2 weeks (post2WCDI) and 3, 6, and 12 months postoperatively (post3MCDI, post6MCDI, and post12-MCDI, respectively) (Figure 3). Many reports have shown that the CDI is a reliable and reproducible method, and it is also a more direct method to measure patellar height compared with the Insall-Salvati index (ISI), which measures the patellar tendon length. Furthermore, the CDI is poorly influenced by the quadriceps muscle. The ISI has demonstrated poor reproducibility and repeatability because of the difficulty in identify the location of the patellar tendon and the anterior tibial tubercle on postoperative X-ray. The Blackburne-Peel index (BPI) may not be an accurate method to assess patellar height after high tibial osteotomy (HTO), because BPI depends on the change in the posterior tibial slope, which frequently occurs in HTO. Therefore, we believe that the CDI is the most suitable method to assess patellar height after HTO.

**Statistical analysis**

Paired t-tests were used to evaluate pre- and postoperative differences in alignment parameters and KOOS. The CDI
was measured to evaluate sequential changes in patellar height after MOWHTO. The repeated-measures analysis of variance (ANOVA) with Tukey’s post-hoc test was used to compare the CDI at different time points. Significant differences identified with Tukey’s test were defined as ΔCDI. Multiple regression was used to predict changes in ΔCDI based on preoperative %MA and PTS, ΔMPTA (postoperative MPTA – preoperative MPTA), age, sex, BMI, and OA grade.

Correlations between ΔKOOS (post12MKOOS – preKOOS) and ΔCDI (preCDI – post12MCDI) were assessed using Spearman’s rank correlation coefficient analysis to determine whether patellar baja negatively impacted the clinical outcome.

A p value of <0.05 was considered statistically significant. The post-hoc analyses showed that a sample size of 24 achieved a power of 80% and a significance level of 5%, which verified the adequacy of the present sample size. All statistical analyses were performed using SPSS software (version 23.0, IBM Corp. Armonk, NY, USA).

**Results**

The patients’ characteristics are summarized in Table 1, and the radiographic parameters are presented in Table 2. The preoperative mean %MA was 21.5% ± 12.2% (range, −10%–44%), which improved to 58.2% ± 8.2% (range, 37%–75%) postoperatively. The mean preoperative
MPTA was $84.8° \pm 2.2°$ (range, $79°$–$95.5°$), which increased to $92.1° \pm 2.7°$ (range, $88°$–$95.5°$) postoperatively. The mean preoperative PTS was $6.0° \pm 2.6°$ (range, $0°$–$11.3°$), which increased to $8.4° \pm 3.2°$ (range, $3.1°$–$14.4°$) postoperatively ($p < 0.001$). There was a significant improvement in lower extremity alignment and a significant increase in PTS.

All preoperative mean KOOS categories (total KOOS, pain, symptoms, activities of daily living, sports/recreation function, and knee-related quality of life) improved postoperatively (Table 3). Clinical outcomes were significantly improved after MOWHTO. The repeated-measures ANOVA showed significant differences in the CDI values (preCDI = $0.92 \pm 0.12$; post2WCDI = $0.75 \pm 0.12$; post3MCDI = $0.70 \pm 0.13$; post6MCDI = $0.70 \pm 0.10$; post12MCDI = $0.70 \pm 0.12$) ($p < 0.05$). Tukey’s post-hoc test showed significant differences between preCDI and postCDI (2 weeks, 3 months, 12 months) ($p < 0.05$), as well

### Table 1. The patients’ demographic characteristics ($n = 30$).

| Patient characteristics | Value |
|-------------------------|-------|
| Age                     | $64.3 \pm 6.9$ |
| Gender (male/female)    | 13/24 |
| Body mass index (kg/m$^2$) | $26.3 \pm 3.8$ |
| KL grade (I/II/III/IV)  | 0/14/18/5 |

Data are presented as mean ± standard deviation or number of patients. KL, Kellgren–Lawrence.

### Table 2. Preoperative and postoperative radiographic measurements.

| Parameter                      | Pre-HTO     | Post-HTO    | $p$ value |
|-------------------------------|-------------|-------------|-----------|
| MA (%)                        | $21.5 \pm 12.2$ | $58.2 \pm 8.2$ | $<0.001$ |
| MPTA(°)                       | $84.8 \pm 2.2$ | $92.1 \pm 2.7$ | $<0.001$ |
| Posterior tibial slope (°)    | $6.0 \pm 2.6$ | $8.4 \pm 3.2$ | $<0.001$ |

Pre- (Pre) and postoperative (Post) measurements were compared using paired $t$ tests. Abbreviation: HTO, high tibial osteotomy; MA, mechanical axis; MPTA, mechanical medial proximal tibial angle.
as between post2WCDI and postCDI (3 months, 6 months, 12 months) \((p < 0.001)\) (Figure 4, Table 4). Post2WCDI, post3MCDI, post6MCDI, and post12MCDI decreased significantly compared with preCDI. There were significant decreases in post3MCDI, post6MCDI, and post12MCDI compared with post2WCDI. However, there was no significant decrease in post6MCDI or post12MCDI compared with post3MCDI. Thus, patellar height decreased until 3 months after MOWHTO. A total of 97.3% of the knees showed a decrease in patellar height at 2 weeks after MOWHTO compared with before MOWHTO, and 70.3% of the knees showed a decrease in patellar height at 3 months after MOWHTO compared with at 2 weeks after MOWHTO.

The time points at which a significant difference was detected were defined as Δpre-post2WCDI (preCDI – post2WCDI), Δpre-post12MCDI (preCDI – post12MCDI), Δpost2W-post3MCDI (post2WCDI – post3MCDI), Δpost2W-post6MCDI (post2WCDI – post6MCDI), and Δpost2W-post12MCDI (post2WCDI – post12MCDI).

A multiple regression analysis was performed with pre-

\%MA, pre-PTS, AMPTA, age, sex, BMI, and OA grade as the dependent variables. The only significant predictor of Δpre-post2WCDI and Δpre-post12MCDI was ΔAMPTA (Δpre-post2WCDI: \(β = 0.603, p = 0.005\); Δpre-post12MCDI: \(β = 0.546, p = 0.012\)). However, no significant predictors of Δpost2W-post3MCDI, Δpost2W-post6MCDI and Δ post2W-post12MCDI were identified (Tables 5–9).

Although ΔAMPTA was associated with ΔCDI (pre-post2WCDI and pre-post12MCDI), no factors were found associated with the change in CDI from 2 weeks after MOWHTO. No significant relationship between ΔpreCDI-post12MCDI and ΔKOOS (post12MKOOS – preKOOS) was detected (total KOOS: \(r = 0.056, p = 0.742\); pain: \(r = 0.063, p = 0.711\); symptoms: \(r = 0.017, p = 0.952\); activities of daily living: \(r = 0.137, p = 0.418\); sports/recreation function: \(r = -0.107, p = 0.885\); and knee-related quality of life (QOL): \(r = -0.306, p = 0.065\) (Table 10).

The reliability of the measurements was assessed by estimating the intra-observer and inter-observer reliability using the intraclass correlation coefficient (ICC). The ICCs were 0.81–1.00 (intra-observer variance) and 0.81 to 1.00 (inter-observer variance).

### Discussion

The most important finding in the present study was that the change in patellar height decreased from 2 weeks to 3 months postoperatively after MOWHTO. This suggests that the change in patellar height had not finished immediately after surgery; rather, it continued to change sequentially. Several reports have described changes in patellar height between pre CDI and early post CDI, or between pre CDI and CDI measured 12 months after surgery; however, we evaluated sequential changes in patellar height and the factors causing sequential changes in patellar height after MOWHTO. Although the change in patellar height from 2 weeks to 3 months postoperatively was small, a previous cadaver study reported that patellar femoral (PF) contact force increased by 3% per 1-mm of change in patellar height. Therefore, this small change is suggested to be clinically significant.

Different methods are available to measure patellar height, such as the ISI, BPI, CDI, and the femoral patellar height Index (FPHI). BPI depends on the change in the PTS, which frequently occurs in HTO; thus, BPI should not be used in HTO. Meanwhile, ISI shows poor reproducibility and repeatability because of the difficulty in locating the patellar tendon and the anterior tibial tubercle on postoperative X-ray.

Although several reports have noted that patellar height decreases after MOWHTO, Ile et al. reported that the FPHI indicates the change in patellar height change after MOWHTO. However, the authors did not analyze the relationship between correction and patellar height. Although the FPHI showed good to excellent intra-observer and inter-observer reliability, which can be measured using standing long-leg radiographs, we consider that if patients have extension contracture, this measurement method is unsuitable. Many reports have shown that CDI is a reliable and reproducible method, and it is also a more direct method to measure patellar height than ISI, which measures the patellar tendon length.

Distalization of the tubercle is the most likely factor causing patella baja. Closed-wedge HTO should mechanically raise the patella by lowering the joint line. During Distal-Tuberosity Osteotomy (DTO), the tibial tuberosity remains attached to the proximal tibia and may not change the patellar height. However, some cases of patellar height reductions have been reported after DTO; therefore, patellar tendon contracture may change patellar height. Several reports have noted that any type of HTO may reduce the patellar height due to the patellar tendon contracture.

Many reports have evaluated the patellar height after MOWHTO at two time points (preoperative and postoperative). The time points at which a significant difference was detected were defined as Δpre-post2WCDI (preCDI – post2WCDI), Δpre-post12MCDI (preCDI – post12MCDI), Δpost2W-post3MCDI (post2WCDI – post3MCDI), Δpost2W-post6MCDI (post2WCDI – post6MCDI), and Δpost2W-post12MCDI (post2WCDI – post12MCDI).

### Table 3. Preoperative and postoperative KOOS

| KOOS                     | Pre-HTO | Post-HTO | \(p\) value |
|--------------------------|---------|----------|-------------|
| Total                    | 55.8 ± 14.6 | 76.6 ± 11.7 | <0.001 |
| Pain                     | 54.1 ± 14.9 | 78.7 ± 15.0 | <0.001 |
| Symptoms                 | 60.5 ± 18.0 | 81.7 ± 11.6 | <0.001 |
| Activities of daily living| 67.3 ± 16.9 | 84.2 ± 11.7 | <0.001 |
| Sports/Recreation        | 30.9 ± 21.4 | 54.3 ± 21.3 | <0.001 |
| Knee-related quality of life | 36.1 ± 18.3 | 60.6 ± 16.7 | <0.001 |

Abbreviation: HTO, high tibial osteotomy; KOOS, Knee injury Osteoarthritis Outcome Score.
These reports have suggested that patellar height is reduced postoperatively compared with preoperatively. However, the time point at which the change in patellar height ceases has not yet been reported. Some studies have reported that patellar tendon contracture may affect the change in patellar height after MOWHTO. Therefore, we hypothesized that patellar height changes sequentially after MOWHTO. This is the first report to show the sequential change in patellar height and the factors affecting the change in patellar height after MOWHTO in detail.

It is not possible to prevent the reduction in patellar height caused by distalization of the tibial tuberosity direct after surgery, and it is also difficult to restore the original patellar height. However, it is possible to prevent the sequential change in patellar height directly after surgery by continuing rehabilitation to prevent patellar tendon contracture. Thus, surgeons

Figure 4. Preoperative Caton–Deschamps index (CDI) (preCDI) and postoperative CDI at 2 weeks (W) and at 3, 6, and 12 months (M) (post2WCDI, post3MCDI, post6MCDI, and post12MCDI) after medial open-wedge high tibial osteotomy. PreCDI versus post2WCDI, preCDI versus post12MCDI, and post2WCDI versus post3MCDI were significantly different. *p < .05.

Table 4. Multiple comparison procedure using Tukey’s post-hoc test.

| Measure | PreCDI vs post2WCDI | PreCDI vs post3MCDI | PreCDI vs post6MCDI | PreCDI vs post12MCDI |
|---------|---------------------|---------------------|---------------------|----------------------|
| p-value | <0.05               | <0.05               | <0.05               | <0.05                |

| Measure | Post2WCDI vs post3MCDI | Post2WCDI vs post6MCDI | Post2WCDI vs post12MCDI | Post3MCDI vs post6MCDI | Post3MCDI vs post12MCDI | Post6MCDI vs post12MCDI |
|---------|------------------------|------------------------|-------------------------|------------------------|------------------------|------------------------|
| p-value | <0.05                  | <0.05                  | 1.000                   | 1.000                  | 1.000                  | 1.000                  |

Abbreviation: CDI, Caton–Deschamps index; post2W, 2 weeks postoperatively; post3M, 3 months postoperatively; post6M, 6 months postoperatively; post12 M, 12 months postoperatively.
### Table 5. Multiple regression to predict $\Delta_{\text{pre-post2W}}$CDI based on preoperative radiographic parameters.

| $\Delta$Pre-Post2WCDI | Coefficient | Standard error | $\beta$ | T Value | p value | 95% CI       |
|-----------------------|-------------|----------------|--------|---------|---------|--------------|
| Age                   | -0.066      | 0.002          | -0.060 | -0.382  | 0.705   | -0.005 to 0.004 |
| Gender                | 0.140       | 0.033          | 0.187  | 1.139   | 0.264   | -0.03 to 0.106  |
| BMI                   | 0.099       | 0.004          | 0.100  | 0.608   | 0.548   | -0.06 to 0.111  |
| Pre PTS               | 0.097       | 0.006          | 0.115  | 0.686   | 0.498   | -0.009 to 0.17  |
| Pre %MA               | -0.215      | 0.002          | 0.601  | 0.647   | 0.523   | -0.002 to 0.005 |
| $\Delta$MPTA          | 0.509       | 0.008          | 0.137  | 3.122   | 0.004   | 0.008 to 0.040  |
| KL grade              | 0.064       | 0.025          | 0.210  | 1.214   | 0.235   | -0.021 to 0.082 |

Abbreviation: $\Delta$, change; BMI, body mass index; CDI, Caton–Deschamps index; KL, Kellgren–Lawrence; MA, mechanical axis; MPTA, medial proximal tibial angle; PTS, posterior tibial slope; post2W, 2 weeks postoperatively.

### Table 6. Multiple regression to predict $\Delta_{\text{pre-post12M}}$CDI based on preoperative radiographic parameters.

| $\Delta$Pre-Post12MCDI | Coefficient | Standard error | $\beta$ | T Value | p value | 95% CI       |
|------------------------|-------------|----------------|--------|---------|---------|--------------|
| Age                    | -0.160      | 0.003          | -0.121 | -0.734  | 0.469   | -0.008 to 0.004 |
| Gender                 | 0.079       | 0.043          | 0.044  | 0.253   | 0.802   | -0.077 to 0.098 |
| BMI                    | -0.058      | 0.005          | -0.094 | -0.537  | 0.595   | -0.014 to 0.008 |
| Pre PTS                | 0.252       | 0.008          | 0.203  | 1.139   | 0.264   | -0.007 to 0.026 |
| Pre %MA                | 0.013       | 0.002          | 0.292  | 1.308   | 0.201   | -0.002 to 0.007 |
| $\Delta$MPTA           | 0.350       | 0.010          | 0.540  | 2.652   | 0.013   | 0.006 to 0.046  |
| KL grade               | -0.077      | 0.032          | 0.032  | 0.589   | 0.560   | -0.047 to 0.085 |

Abbreviation: $\Delta$, change; BMI, body mass index; CDI, Caton–Deschamps index; CI, confidence interval; KL, Kellgren–Lawrence; MA, mechanical axis; MPTA, medial proximal tibial angle; PTS, posterior tibial slope; post12M, 12 months postoperatively.

### Table 7. Multiple regression to predict $\Delta_{\text{post2W-post3M}}$CDI based on preoperative radiographic parameters.

| $\Delta$Post2W-Post3MCDI | Coefficient | Standard error | $\beta$ | T Value | p value | 95% CI       |
|---------------------------|-------------|----------------|--------|---------|---------|--------------|
| Age                       | -0.036      | 0.002          | -0.002 | -0.013  | 0.990   | -0.004 to 0.004 |
| Gender                    | 0.016       | 0.027          | -0.070 | -0.374  | 0.711   | -0.064 to 0.044 |
| BMI                       | -0.211      | 0.003          | -0.208 | -1.133  | 0.275   | -0.111 to 0.003 |
| Pre PTS                   | 0.206       | 0.005          | 0.126  | 0.661   | 0.514   | -0.007 to 0.014 |
| Pre %MA                   | 0.254       | 0.001          | 0.168  | 0.701   | 0.489   | -0.002 to 0.004 |
| $\Delta$MPTA              | -0.257      | 0.006          | -0.145 | -0.664  | 0.512   | -0.017 to 0.008 |
| KL grade                  | -0.087      | 0.020          | -0.031 | -0.156  | 0.877   | -0.044 to 0.038 |

Abbreviation: BMI, body mass index; CDI, Caton–Deschamps index; KL, Kellgren–Lawrence; MA, mechanical axis; MPTA, medial proximal tibial angle; PTS, posterior tibial slope; post2W, postoperative 2 weeks postoperatively; post3M, 3 months postoperatively.

### Table 8. Multiple regression to predict $\Delta_{\text{post2W-post6M}}$CDI based on preoperative radiographic parameters.

| $\Delta$Post2W-Post6MCDI | Coefficient | Standard error | $\beta$ | T Value | p value | 95% CI       |
|--------------------------|-------------|----------------|--------|---------|---------|--------------|
| Age                      | -0.033      | 0.002          | -0.020 | -0.111  | 0.912   | -0.004 to 0.003 |
| Gender                   | 0.011       | 0.027          | -0.037 | -0.199  | 0.844   | -0.060 to 0.049 |
| BMI                      | -0.238      | 0.003          | -0.327 | -1.757  | 0.089   | -0.013 to 0.001 |
| Pre PTS                  | 0.104       | 0.005          | -0.008 | -0.004  | 0.965   | -0.011 to 0.010 |
| Pre %MA                  | 0.128       | 0.001          | 0.363  | 1.522   | 0.139   | -0.001 to 0.005 |
| $\Delta$MPTA             | 0.119       | 0.006          | 0.340  | 1.567   | 0.128   | -0.03 to 0.022  |
| KL grade                 | -0.101      | 0.020          | 0.030  | 0.156   | 0.877   | -0.038 to 0.045 |

Abbreviation: BMI, body mass index; CDI, Caton–Deschamps index; KL, Kellgren–Lawrence; MA, mechanical axis; MPTA, medial proximal tibial angle; PTS, posterior tibial slope; post2W, postoperative 2 weeks postoperatively; post6M, 6 months postoperatively.
Table 9. Multiple regression to predict \( \Delta \text{post2W-post12MCDI} \) based on preoperative radiographic parameters.

| \( \Delta \text{Post2W-Post12MCDI} \) | Coefficient | Standard error | \( \beta \) | T Value | p value | 95% CI |
|--------------------------------------|-------------|----------------|--------|--------|--------|-------|
| Age                                  | -0.151      | 0.002          | -0.104 | -0.601 | 0.552  | -0.005 to 0.003 |
| Gender                               | -0.052      | 0.031          | -0.158 | -0.870 | 0.391  | -0.091 to 0.037 |
| BMI                                  | -0.201      | 0.004          | -0.254 | -1.389 | 0.175  | -0.014 to 0.003 |
| Pre PTS                              | 0.248       | 0.006          | 0.155  | 0.834  | 0.411  | -0.007 to 0.017 |
| Pre %MA                              | 0.274       | 0.002          | 0.259  | 1.109  | 0.277  | -0.001 to 0.005 |
| MPTA                                 | -0.099      | 0.007          | 0.066  | 0.312  | 0.757  | -0.012 to 0.017 |
| KL grade                             | -0.186      | 0.024          | -0.093 | -0.487 | 0.630  | -0.060 to 0.037 |

Abbreviation: BMI, body mass index; CDI, Caton–Deschamps index; KL, Kellgren–Lawrence; MA, mechanical axis; MPTA, medial proximal tibial angle; Pts, posterior tibial slope; post2W, 2 weeks postoperatively; post12M, 12 months postoperatively.

Table 10. Spearman’s rank correlation coefficient analysis between \( \Delta \text{CDI} \) and \( \Delta \text{KOOS} \) (pre-post12 M).

| \( \Delta \text{CDI} \) | \( \Delta \text{KOOS} \) | r     | p     |
|-------------------------|-------------------------|-------|-------|
| Total                   |                         | 0.056 | 0.742 |
| Symptoms                |                         | -0.01 | 0.952 |
| Pain                    |                         | 0.063 | 0.711 |
| Activities of daily living |                     | 0.137 | 0.418 |
| Sports/Recreation function |                      | -0.107 | 0.885 |
| Knee-related QOL        |                         | -0.306 | 0.065 |

Abbreviation: \( \Delta \), change; CDI, Caton–Deschamps index; KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; pre, preoperative; post12 M, 12 months postoperatively.

should evaluate sequential changes in patellar height after MOWHTO.

Otsuki et al. reported that CDI decreased by 1.7% per 1° of correction angle. In our study, \( \Delta \text{MPTA} \) was associated with \( \Delta \text{CDI} \) (pre-post2WCDI and pre-post12MCDI), indicating that correction angle is negatively associated with the change in patellar height change, as we expected. Although one of our objectives was to determine the factors affecting patellar height change from 2 weeks postoperatively to 3 months postoperatively, no factors associated with the change in patellar height preoperatively compared with 2 weeks postoperatively were identified. \( \Delta \text{post2W-post3MCDI} \) may be affected by patellar tendon contracture, and because patellar tendon contracture may reduce patellar height without radiographic changes, sequential patellar height changes on radiography and sequential patellar tendon quality evaluation using magnetic resonance imaging (MRI) and elastography may clarify the details.

An increased in patellar femoral (PF) contact pressure owing to patella baja may be related to cartilage degeneration, anterior knee pain, and crepitus. Although this study showed a small change in patellar height from directly after surgery, it has been previously reported that even a 1 mm reduction in patellar tendon length causes a 1° loss of knee flexion and an increased risk of patellofemoral pain. However, this study showed no correlation between \( \Delta \text{CDI} \) and \( \Delta \text{KOOS} \). Previous reports have noted that PFOA progression and patellar baja do not affect clinical scores. However, clinical scores specific to the PF joint have not been obtained in the previous studies and this study. Therefore, measurements of functional outcomes specific to the PF joint are needed.

This study has several limitations that should be noted. First, this was a retrospective study. Second, the follow-up duration may have been too short to evaluate the clinical outcomes. It is possible that the clinical outcomes may have worsened with PF joint deterioration during the mid- or long-term follow-up. Third, the sample size was small. However, the number of patients exceeded the minimum number of patients required for the post-hoc analysis to achieve a power of 0.8. Fourth, we did not evaluate the patellar tendon directly using MRI or elastography; thus, further studies should make use of these approaches.

Conclusion

Patellar height was reduced immediately after MOWHTO and the change progressed until 3 months after MOWHTO. Although \( \Delta \text{MPTA} \) was associated with the change in patellar height preoperatively compared with 2 weeks postoperatively, no factors associated with the change in patellar height from 2 weeks postoperatively to 3 months postoperatively were identified.

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References

1. Duivenvoorden T, van Diggele P, Reijman M, et al. Adverse events and survival after closing- and opening- wedge high tibial osteotomy: a comparative study of 412 patients. Knee 2017; 25(3): 895–901.
2. Takeuchi R. Fractures around the lateral cortical hinge after a medial opening wedge high Tibial osteotomy: a new classification of lateral hinge fracture. Arthroscopy 2011; 28(1): 85–94.
3. Anagnostakis K, Mosser P and Kohn D. Infections after high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2003; 21(1): 161–169.
4. Woodacre T, Ricketts M, Evans J.T., et al. Complications associated with opening wedge high tibial osteotomy-A review of the literature and of 15 years of experience. The Knee 2016; 23: 276–282.
5. Tigani D, Ferrari D, Trentani P, et al. Patellar height after high tibial osteotomy. Int Orthop 2001; 24: 331–334.
6. Wright JM, Heavrin B, Begg M, et al. Observations on patellar height following opening wedge proximal tibial osteotomy. Am J Knee Surg 2001; 14: 163–170.
7. Amrani M.H. El., Levy B., Scharycki S., et al. Patellar height relevance in opening-wedge high tibial osteotomy. Orthopadi Traumato Surg Res 2010; 96: 37–43.
8. El-Azab Hosam, Glabgly Parpakon, Paul Jochen, et al. Patellar height and posterior tibial slope after open and close wedge high tibial osteotomy: a radiological study on 100 patients. Am J Sports Med. 2010; 38(2): 323–329.
9. Brouwer RW, Bierna-Zeinstra SM and van Koeveringe AJ. Patellar height and inclination of the tibial plateau after high tibial osteotomy. The open versus the closed-wedge technique. J Bone Jt Surg Br 2005; 87: 1227–1232.
10. Portner O. High tibial valgus osteotomy: closing, opening or combined? Patellar height as a determining factor. Clin Orthop Relat Res 2014; 472: 3432–3440.
11. Chae DJ, Shetty GM, Lee DB, et al. Tibial slope and patellar height after opening wedge high tibial osteotomy using autologous tricortical iliac bone graft. Knee 2008; 15: 128–133.
12. Brazier J, Migaud H, Gougeon F, et al. Evaluation of methods for radiographic measurement of the tibial slope: a study of 83 healthy knees. Rev Chir Orthop Reparatrice Appar Mot 1996; 82: 195–200.
13. Caton J, Deschamps G, Chambat P, et al. Patella infera. Apropos of 128 cases. Rev Chir Orthop Reparatrice Appar Mot 1982; 68: 317–325.
14. Berg EE, Mason SL and Lucas MJ. Patellar height ratios. A comparison of four measurement methods. Am J Sports Med 1996; 24: 218–221.
15. Narkbunnam R and Charancheholvanich K. Effect of patient position on measurement of patellar height ratio. Arch Orthop Trauma Surg 2015; 135: 1151–1156.
16. Kesmezcar H, Erginer R, Ogut T, et al. Evaluation of patellar height and measurement methods after valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2005; 13: 539–544.
17. Kaper BP, Bourne RB, Rorabeck CH, et al. Patellar Infera after high tibial osteotomy. J Arthroplasty 2001; 16: 168–173.
18. Amzallag J, Pujipl N, Kumagai K, et al. Patellar height modification after high tibial osteotomy by either medial opening-wedge or lateral closing-wedge osteotomies. Knee Surg Sports Traumatol Arthrosc 2013; 21: 225–229.
19. Yang JH, Lee SH, Nathawat KS, et al. The effect of bialpneal medial opening wedge high tibial osteotomy on patellofemoral joint indices. Knee 2013; 20: 128–132.
20. Lee Ys, Lee SB, Oh WS, et al. Changes in patellofemoral alignment do not cause clinical impact after open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2016; 24: 129–133.
21. Singerman R, Davy DT and Goldberg VM. Effects of patella alta and patella infera on patellofemoral contact forces. J Biomechanics 1994; 27(8): 1059–1065.
22. Ihle C, Ahrend M, Grünwald L, et al. No change in patellar height following open wedge high tibial osteotomy using a novel femur-referenced measurement method. Knee 2017; 24: 1118–1128.
23. Gaasbeek RDA, Sonneveld H, van Heerwaarden RJ, et al. Distal tuberosity osteotomy in open wedge high tibial osteotomy can prevent patellar infera: a new technique. Knee 2004; 11: 457–461.
24. Otsuki S, Murakami T, Okamoto Y, et al. Risk of patellar baja after opening-wedge high tibial osteotomy. J Orthop Surg 2018; 26: 2–7.
25. Lancourt JE and Cristini JA. Patella alta and patella infera. Their etiological role in patellar dislocation, chondromalacia, and apophysitis of the tibial tubercle. J Bone Jt Surg Am 1975; 57: 1112–1115.
26. Meyer SA, Brown TD, Pedersen DR, et al. Retropatellar contact stress in simulated patellar infera. Am J Knee Surg 1997; 10: 129–138.
27. Weale AE, Murray DW, Newman JH, et al. The length of the patellar tendon after unicompartmental and total knee replacement. J Bone Jt Surg Br 1999; 81: 790–795.
28. Goshima K, Sawaguchi T, Shigemoto K, et al. Patellofemoral osteoarthritis progression and alignment changes. Arthroscopy 2017; 33: 1832–1839.