Coronal tibiofemoral subluxation is a risk factor for postoperative overcorrection in high tibial osteotomy

Yong Tae Kim [a], Jun Young Choi [a], Joon Kyu Lee [b], Young Min Lee [a], Joong Il Kim [a,*]

[a] *Department of Orthopaedic Surgery, Hallym University Kangnam Sacred Heart Hospital, Seoul, South Korea*
[b] *Department of Orthopaedic Surgery, Hallym University Sacred Heart Hospital, Anyang-si, South Korea*

ARTICLE INFO

ABSTRACT

Background: Severe tibiofemoral (TF) subluxation > 10 mm is a contraindication for high tibial osteotomy (HTO). However, the relationship between the degree of preoperative TF subluxation at < 10 mm and postoperative radiographic/clinical outcomes remains unclear.
Methods: Sixty-seven patients who underwent open wedge HTO with a planned postoperative mechanical femorotibial angle (mFTA) of three degrees valgus were retrospectively studied. The minimal subluxation (MIN) group included 39 patients with TF subluxation < 5 mm, while the moderate subluxation (MOD) group included 28 patients with TF subluxation of five to 10 mm. The preoperative and one-year postoperative mFTA, TF subluxation, medial proximal tibial angle (MPTA), joint line convergence angle (JLCA), preoperative Kellgren-Lawrence (K–L) grade and varus-valgus laxity were evaluated. Clinical scores and pain visual analogue scale (VAS) were also analyzed.
Results: The mean preoperative TF values in the MIN and MOD groups were 3.1±1.0 mm and 6.7± 1.6 mm (mean±standard deviation, p < 0.001), respectively, with no significant difference in K–L grades. The MIN group demonstrated a significantly smaller varus preoperative mFTA (p < 0.001), larger MPTA (p = 0.011), smaller JLCA (p = 0.004), and less varus laxity (p = 0.023). Postoperative TF subluxation, MPTAs, and JLCAs did not differ significantly between the two groups, while the postoperative mFTA was significantly different (p = 0.001), with unintended overcorrection in the MOD group. No significant difference in clinical scores and VAS were observed.
Conclusions: After HTO, compared to patients with TF subluxation < 5 mm, patients with TF subluxation of five to 10 mm were more likely to demonstrate unintended valgus overcorrection on one-year postoperative radiography.

© 2019 Elsevier B.V. All rights reserved.

1. Introduction

High tibial osteotomy (HTO) is a verified treatment for medial compartment osteoarthritis (OA) of the knee with varus deformity. High tibial osteotomy corrects varus malalignment of the lower limb to a slight valgus axis, such that the concentrated axial force on the medial compartment can be transferred to the lateral compartment [1–3]. This alteration in the weight-bearing axis may alleviate pain and improve knee function, eventually delaying total knee arthroplasty [4–7].

Tibiofemoral (TF) subluxation is a common finding in medial compartment OA of the knee with varus deformity [8]. Radiographic findings of medial compartment OA with TF subluxation include: varus deformity, varus joint line convergence angle (JLCA), medial

---

* Corresponding author at: Department of Orthopaedic Surgery, Hallym University Kangnam Sacred Heart Hospital, 1 Singil-ro, Yeongdeungpo-gu, Seoul, South Korea.
E-mail address: oskji@hallym.or.kr. (J.I. Kim).

joint space narrowing, and lateral joint space widening [9]. From observations of coronal asymmetry, studies suggest that TF subluxation is caused by the difference in laxity of the medial and lateral soft tissues, with the medial tissues tightening due to contracture of the medial collateral ligament, while the lateral tissues loosen from stretching due to varus deforming forces [10,11]. An imbalance of mediolateral soft tissue laxity can be a contributing factor in altering the postoperative axis away from pre-operative calculations after HTO [10,12]. However, little is known about radiological outcomes after HTO in cases of pre-operative TF subluxation. In addition, several studies have shown that pre-operative TF subluxation is associated with poorer pre-operative clinical outcomes in the patient population, but the effect of pre-operative TF subluxation on postoperative clinical outcomes is not well known [13,14].

Severe pre-operative TF subluxation of ≥10 mm is generally considered a contraindication for HTO [15–17]. Despite the consensus regarding the upper limit of pre-operative TF subluxation permitted for HTO, little is known about the correlation between the degree of pre-operative TF subluxation and postoperative radiographic/clinical outcomes. Therefore, the objective of this study was to investigate the association between pre-operative TF subluxation and radiographic/clinical outcomes after HTO for medial compartment OA of the knee with varus deformity. It was hypothesized that even in cases of TF subluxation <10 mm, larger TF subluxation would result in poorer radiographic and clinical outcomes after HTO.

2. Material and methods

2.1. Patients

After receiving approval from the Institutional Review Board and adhering to the ethical standards of the Declaration of Helsinki, a single-centre, single-surgeon, retrospective cohort study was conducted with patients who were: (1) diagnosed with medial compartment OA and received unilateral open wedge HTO (OWHTO) between March 2015 and November 2017; and (2) had medical records available for at least one year of postoperative follow-up. The indications for HTO were Kellgren–Lawrence Grade III–IV medial compartment OA with varus deformity, age ≤60 years, TF subluxation <10 mm, mechanical femorotibial angle (mFTA) <20°, flexion contracture <10°, and range of flexion >90°. Exclusion criteria were: (1) OA in the patellofemoral or lateral compartments; (2) double or triple varus requiring procedures other than HTO; (3) severe chondral damage or meniscal tear requiring procedures other than debridement or partial meniscectomy (i.e., microfracture, subtotal meniscectomy, or meniscus repair); (4) anterior instability evident on pre-operative imaging and physical examination requiring additional procedures (i.e., anterior cruciate ligament (ACL) rupture >50% or a Lachman examination showing ≥6 mm anterior translation, requiring ACL reconstruction); (5) a history of osteotomy or other axis-altering procedures in the ipsilateral knee; (6) the presence of an implant other than that specified in this study; and (7) rheumatoid arthritis.

Sixty-seven patients were included in the study. They were then divided into two groups depending on the severity of TF subluxation. The minimal subluxation (MIN) group included 39 patients with TF subluxation <5 mm, while the moderate subluxation (MOD) group included 28 patients with TF subluxation of five to 10 mm. The cut-off point of five millimetres was selected because it was half the value of the contraindicated 10 mm and produced a comparable number of patients in both groups.

2.2. Surgical intervention

In all cases, the postoperative mFTA was targeted to a valgus angulation of three degrees in excess of neutral alignment. The subsequent correction angle and wedge length to obtain the target postoperative mechanical axis were calculated from full-length standing anteroposterior teleradiography images using the method described by Miniaci et al. [18] and were simulated using a picture archiving communication system (INFINITT® PACS, Infinitt Healthcare, Seoul, Korea) and image processing software (Photoshop® CC 2017, Adobe Systems, CA, USA) to confirm the postoperative mFTA of three degrees [19].

All patients underwent surgery performed by a single senior surgeon who specialized in knee surgery. An eight-centimetre longitudinal skin incision was made in the medial aspect of the proximal tibia. Pes anserinus and the superficial medial collateral ligament (sMCL) were released. To serve as cutting guides, two Steinmann pins were inserted under fluoroscopy from the medial metaphyseal–diaphyseal junction to the tip of the fibular head. Horizontal osteotomy was performed, leaving the lateral cortex intact. An additional biplanar coronal osteotomy exiting above the patellar tendon insertion was performed almost parallel to the anterior tibial cortex. The osteotomy site was gradually opened to the pre-operatively calculated wedge length, and the target mechanical axis was confirmed using metal rods and fluoroscopy, while applying maximum axial compression force on the foot sole to simulate weight-bearing. The osteotomy site was fixed with a locking titanium plate, and a screw construct (OhtoFix®, OhtoMedical, Goyang, Korea) and cancellous bone chips (ReadiGraft®, LifeNet Health, VA, USA) were inserted. After fixation, the axis was further confirmed with fluoroscopy. The released pes tendons and sMCL were loosely reattached above the plate in a tension-free manner.

All patients started continuous passive movement exercises two days after surgery, and partial weight-bearing with crutches was allowed. The patients were encouraged to resume full weight-bearing six weeks postoperatively.

2.3. Data collection and radiographic evaluation

All data were retrospectively retrieved from existing medical records. Demographic data, including age, sex, and body mass index (BMI) at the time of surgery, were acquired.

Pre-operative and one-year postoperative full-length standing anteroposterior teleradiography images with a reference metal ruler were acquired for the following pre-operative and postoperative measurements: TF subluxation, mFTA, medial proximal tibial

Figure 1. Measurement of tibiofemoral subluxation via standing teleradiography. A. pre-operative and B. postoperative measurements of a medial open wedge high tibial osteotomy. *A line perpendicular to the ground is drawn to contact the most lateral point of the lateral femoral condyle. **Another parallel line is drawn to touch the most lateral aspect of the lateral tibial plateau. The shortest distance between the two parallel lines is measured.

angle (MPTA), and JLCA. Tibiofemoral subluxation was defined as the distance between the lines tangential to the most lateral articular margins of the lateral femoral condyle and the lateral tibial condyle (Figure 1), with a positive value indicating that the line drawn to the lateral tibial condyle is more lateral than that drawn to the lateral femoral condyle [20]. The mFTA was defined as the intersecting angle between the mechanical axis of the femur and the mechanical axis of the tibia, with a positive value indicating valgus alignment. The correction angle (CA) was calculated from the pre-operative mFTA as the angle needed to achieve a three degree valgus mFTA. The MPTA was defined as the medial angle between the tibial anatomical axis and the line tangential to the proximal tibial articular surface. The JLCA was defined as the angle formed by two lines, each tangential to the articular surfaces of the distal femur and proximal tibia, with a positive value indicating varus alignment. Pre-operative Kellgren–Lawrence (K–L) grades were also reviewed. The degrees of pre-operative varus and valgus laxity were measured in the same manner as the JLCA in pre-operative varus and valgus stress radiographs, which were obtained using the TELOS® device (Telos GmbH, Weiterstadt, Germany) by applying 150 N of force to the medial or lateral side of the knee joint in 30° flexion. Pre-operative and one-year postoperative clinical parameters were evaluated with the Knee Society Knee Score (KSKS), the Knee Society Function Score (KSFS), and visual analogue scale (VAS) pain scores.

2.4. Statistical analysis

Differences between the two groups were analysed using the independent t-test for continuous variables and Pearson's Chi-squared test or Fisher's exact test for categorical variables. Intra-group analysis of the pre-operative and one-year postoperative radiographic measurements was performed using paired t-tests. Statistical analyses were conducted using IBM SPSS Statistics for Windows, Version 24 (IBM Corp., NY, USA). Values were compared as the mean and standard deviation, and $P < 0.05$ was considered statistically significant.

3. Results

Demographic data of age, sex, and BMI showed no significant differences between the two groups (Table 1). The mean pre-operative TF subluxation measurements in the MIN and MOD groups were 3.1 ± 1.0 mm and 6.7 ± 1.6 mm ($P < 0.001$), respectively. No significant difference in the pre-operative K–L grade was observed. The MIN group showed a significantly smaller varus

Table 1
Demographic data.

	MIN (n = 39)	MOD (n = 28)	P
Age (years)	53.5 ± 4.9	51.4 ± 6.7	0.152
Male:female	16:23	13:15	0.620
BMI (kg/m²)	25.9 ± 3.0	26.8 ± 2.9	0.229

MIN, minimal subluxation group; MOD, moderate subluxation group; BMI, body mass index.

Table 2
Pre-operative radiographic measurements and clinical scores.

	MIN (n = 39)	MOD (n = 28)	P
TFS (mm)	3.1 ± 1.0	6.7 ± 1.6	<**0.001**
KL grades (III:IV)	27:12	20:8	0.974
mFTA (°)	−8.3 ± 2.0	−11.2 ± 2.9	<**0.001**
CA (°)	11.3 ± 2.6	15.2 ± 3.3	<**0.001**
MPTA (°)	82.2 ± 2.8	80.3 ± 3.1	**0.011**
JLCA (°)	3.6 ± 1.4	4.5 ± 0.9	**0.004**
Varus laxity (°)	5.2 ± 1.9	6.5 ± 2.3	**0.023**
Valgus laxity (°)	1.5 ± 1.0	1.8 ± 1.3	0.410
KSKS (points)	70.2 ± 9.8	69.2 ± 11.7	0.617
KSFS (points)	65.3 ± 12.5	66.4 ± 9.2	0.589
VAS (points)	3.7 ± 1.1	4.1 ± 1.3	0.347

MIN, minimal subluxation group; MOD, moderate subluxation group; TFS, tibiofibular subluxation; KL, Kellgren–Lawrence; mFTA, mechanical femorotibial angle; CA, correction angle; MPTA, medial proximal tibial angle; JLCA, joint line convergence angle; KSKS, Knee Society Knee Score; KSFS, Knee Society Function Score; VAS, visual analogue scale.
P-values <0.05 are in bold.

pre-operative mFTA ($P < 0.001$) and therefore a smaller CA ($P < 0.001$) for a target valgus three degree mFTA. The MIN group also demonstrated a significantly larger MPTA ($P = 0.011$), smaller JLCA ($P = 0.004$) and less varus laxity ($P = 0.023$), with no difference in valgus laxity. No significant differences in pre-operative clinical scores were noted (Table 2).

Although a valgus three degree mFTA was targeted for all patients, the one-year postoperative mFTA showed a significant difference (2.9° ± 1.0° in the MIN group vs. 4.0° ± 1.5° in the MOD group) ($P = 0.001$), with the MOD group exhibiting overcorrection. However, postoperative TF subluxation, the MPTA, and the JLCA at the one-year follow-up did not differ significantly between the two groups. No significant differences were identified in other radiographic parameters or postoperative clinical scores (Table 3).

Intra-group analysis confirmed the significant one-year postoperative decreases in TF subluxation within each group (3.1 ± 1.0 to 1.7 ± 1.0 mm in the MIN group, $P < 0.001$ vs. 6.7 ± 1.6 to 2.0 ± 1.2 mm in the MOD group, $P < 0.001$) and significant improvement in all clinical scores ($P < 0.001$ for all scores within both groups).

4. Discussion

The key finding of the present study is that moderately subluxated knees (five to 10 mm) were significantly more likely to progress to overcorrection than knees with minimal TF subluxation (<5 mm) even at the one-year postoperative follow-up. However, this result did not lead to an inferior one-year clinical outcome. Compared with the MIN group, the MOD group showed significantly higher degrees of pre-operative varus malalignment, varus laxity, and varus aligned JLCA.

Excessive valgus overcorrection after HTO is known to cause adverse outcomes, especially in the long term. Multiple studies with follow-ups ranging from seven to 11 years have revealed unfavourable outcomes resulting in lateral compartmental arthritis and revision total arthroplasty in overcorrected knees with >6–10° valgus mFTA [1,21,22]. Therefore, achieving a three to five degree valgus mFTA is advocated by many authors for an optimal outcome, and the importance of matching the pre-operatively planned mFTA to the actual postoperative result cannot be overemphasized [18,23–25].

Because accurate measurement of TF subluxation was paramount in this study, the method was carefully selected. Keene et al. assessed TF subluxation as the distance between the extensions of the anatomical axes of the femur and tibia measured at the plane of the tibial plateau [17]. However, tibia vara, a common finding in patients undergoing HTO, shifts the tibial anatomical axis to a more lateral course at the tibial plateau. This shift may exaggerate the "measured" subluxation between the femorotibial

Table 3
One-year postoperative radiographic measurements and clinical scores.

	MIN (n = 39)	MOD (n = 28)	P
TFS (mm)	1.7 ± 1.0	2.0 ± 1.2	0.209
mFTA (°)	2.9 ± 1.0	4.0 ± 1.5	**0.001**
MPTA (°)	93.2 ± 1.3	93.8 ± 1.3	0.081
JLCA (°)	2.8 ± 1.1	2.3 ± 1.5	0.186
KSKS (points)	91.3 ± 2.1	92.1 ± 3.2	0.521
KSFS (points)	88.3 ± 4.1	89.9 ± 4.1	0.582
VAS (points)	1.1 ± 1.0	1.2 ± 1.0	0.501

MIN, minimal subluxation group; MOD, moderate subluxation group; TFS, tibiofibular subluxation; mFTA, mechanical femorotibial angle; MPTA, medial proximal tibial angle; JLCA, joint line convergence angle; KSKS, Knee Society Knee Score; KSFS, Knee Society Function Score; VAS, visual analogue scale.
P-values <0.05 are in bold.

axes, whereas the "actual" subluxation in terms of joint congruity may be less severe. Furthermore, as HTO modifies the tibial mechanical axis, the above method of measuring TF subluxation may be inappropriate. Therefore, the present study utilized the method published by Vainionpää et al., which measures TF subluxation at the actual articular plane (Figure 1) [20]. Two lines perpendicular to the ground are drawn to contact the most lateral articular margins of the lateral femoral condyle and the lateral tibial plateau. The distance between the lines is subsequently measured. This method better reflects the actual joint congruity independent of the change in the tibial axis after HTO.

Although TF subluxation is a common finding in medial compartment OA, its precise mechanism has not yet been clarified. Ahlbäck reported that patients with knee OA and TF subluxation had varus deformity, medial joint space narrowing, and lateral joint space widening [9]. Based on these sequelae of symptoms, some researchers have assumed that varus deformity and differences in laxity between the medial and lateral joint may be reasons for TF subluxation. Decreased medial soft tissue laxity is due to the formation of osteophytes and contracture of the medial structures, whereas increased lateral soft tissue laxity is due to tensile stress on the lateral compartment caused by varus deformity [10,11]. The present study also supports these previous studies, by showing that the more subluxated group had significantly higher degrees of pre-operative varus deformity and varus laxity.

Increased medial soft tissue laxity after sMCL release during exposure of the osteotomy site has been reported [26,27]. However, other studies have indicated that valgus laxity did not actually increase postoperatively due to healing of the released sMCL and the recovered tension of the medial soft tissues rather than the released sMCL after "opening" the osteotomy plane [28–30]. This supports the findings of the present study, demonstrating that postoperative TF subluxation was corrected to a similar extent in both groups, regardless of the difference in pre-operative TF subluxation.

Most importantly, the tendency of the more subluxated group developing valgus overcorrection should be explained. Akamatsu et al. correlated the amount of postoperative TF subluxation and JLCA correction to postoperative valgus overcorrection [10]. Kim et al. produced similar results with pre-operative JLCA, while Ogawa et al. also correlated pre-operative varus laxity on stress radiographs and the change in postoperative JLCA to postoperative valgus overcorrection [12,31]. The above studies explained these findings as "soft tissue correction", stemming from the imbalance in medial and lateral ligamentous tension. Further developed from these studies, the present study proposed the possibility of pre-operatively predicting whether overcorrection will occur by evaluating JLCA and TF subluxation, which may better represent the pathologic soft tissue imbalance. The JLCA is a result of the discrepancy in joint space width (JSW) between the medial and lateral compartments. The JSW in each compartment is influenced by the tension of the surrounding soft tissue and also, even more so, by the thickness of the remaining cartilage and the status of the meniscus. Therefore, JLCA can be exaggerated by the degenerated medial cartilage and meniscus, in contrast with the relatively intact lateral cartilage and meniscus. Therefore, TF subluxation, which is a measurement of coronal translation that is directly affected by ligamentous laxity and not by the occupying cartilage and menisci, may be more apt in predicting postoperative overcorrection.

It is believed that two papers have evaluated the association between TF subluxation and clinical outcomes. Chang et al. performed a cohort study to identify radiological predictors for symptom severity in patients with knee OA, and found that TF subluxation is a predictor of a poor Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain score [14]. Akamatsu et al. evaluated clinical outcomes before and after OWHTO and reported that KSKS was correlated with pre-operative TF subluxation [10]. However, all scores were not correlated with postoperative TF subluxation. In mild to moderate subluxations <10 mm, the present study did not reveal a significant difference in pre-operative clinical scores or the degree of pre-operative subluxation. As multiple factors – including coronal TF subluxation, joint space width, ligamentous imbalance, notch impingement, and cartilage/ meniscus degeneration – are all accountable for clinical symptoms, it was difficult to support a clear correlation between the degree of pre-operative TF subluxation and pre-operative clinical scores. After HTO, postoperative clinical scores were not different between groups in the present study. Tibiofibular subluxation in both groups was well corrected to within two millimetres. Therefore, this small remaining TF subluxation had little effect on the clinical outcomes.

This study had several limitations. It was conducted in a relatively short-term follow-up period. A long-term study is warranted to investigate whether overcorrection will continue, further resulting in a significant difference in clinical outcomes. Additionally, it only used teleradiography to measure TF subluxation, which is actually a three-dimensional deformity. Although a reproducible foot and patella position was obtained with foot marks on the platform, which was similar to the methods used in many publications that radiographically assessed TF subluxation with reliable results, other modalities may be helpful such as three-dimensional (3D) computed tomography or standing magnetic resonance imaging (MRI) [10,14,32,33]. The conversion of the continuous variable TF subluxation to a categorical variable with a cut-off value of five millimetres must be mentioned. Although this transformation made the present study possible with a relatively small number of cases, further investigations with more participants are warranted for a more methodologically proper analysis. In addition, although the change in postoperative varus/valgus laxity compared with the pre-operative results may have been interesting, this study did not collect these data due to pain from the stress radiographs during the one-year follow-up assessment. Such stress radiographs may be obtained after more postoperative healing. Finally, although this study revealed a connection between pre-operative TF subluxation and postoperative overcorrection, further correlation coefficient studies should be performed to derive a practical equation using pre-operative radiographic values to determine proper correction angles for the desired postoperative axis.

5. Conclusions

Although clinical outcomes were no different between the two groups, the MOD group, which had significantly greater pre-operative varus laxity and greater JLCA, exhibited more valgus overcorrection during the radiographic follow-up in the same period. Further long-term studies are warranted, and caution is suggested in cases with TF subluxation of ≥5 mm, to minimize overcorrection.

Authors' contributions

YTK participated in the study design, performed radiographic measurements, and drafted the manuscript. JYC participated in manuscript revision. JKL performed statistical analysis. YML supervised drafting and manuscript revision. JIK mainly designed the study, supervised the whole study process and helped to draft and review the manuscript. All authors read and approved the final manuscript.

Declaration of Competing Interest

This research did not receive any support or grant from funding agencies in the public, commercial, or not-for-profit sectors. All authors declare that they have no conflict of interest.

References

 [1] Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. J Bone Joint Surg Am 1987;69:332–54. https://doi.org/10.2106/00004623-198769030-00005.
 [2] Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am 1979;10:585–608.
 [3] Coventry MB. Osteotomy about the knee for degenerative and rheumatoid arthritis. J Bone Joint Surg Am 1973;55:23–48. https://doi.org/10.2106/00004623-197355010-00002.
 [4] Lobenhoffer P, Agneskirchner JD. Improvements in surgical technique of valgus high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2003;11:132–8. https://doi.org/10.1007/s00167-002-0334-7.
 [5] Flecher X, Parratte S, Aubaniac J-M, J-NA Argenson. A 12–28-year follow-up study of closing wedge high tibial osteotomy. Clin Orthop Relat Res 2006;452:91–6. https://doi.org/10.1097/01.blo.0000229362.12244.f6.
 [6] Akizuki S, Shibakawa A, Takizawa T, Yamazaki I, Horiuchi H. The long-term outcome of high tibial osteotomy: a 10- to 20-year follow-up. J Bone Joint Surg Br 2008;90-B:592–6. https://doi.org/10.1302/0301-620x.90b5.20386.
 [7] Michaela G, Florian P, Michael L, Christian B. Long-term outcome after high tibial osteotomy. Arch Orthop Trauma Surg 2007;128:111–5. https://doi.org/10.1007/s00402-007-0438-0.
 [8] Khamaisy S, Zuiderbaan HA, Thein R, Gladnick BP, Pearle AD. Coronal tibiofemoral subluxation in knee osteoarthritis. Skeletal Radiol 2015;45:57–61. https://doi.org/10.1007/s00256-015-2244-z.
 [9] Ahlbäck S. Osteoarthrosis of the knee. A radiographic investigation. Acta Radiol Diagn 1968;277:1–71. https://doi.org/10.1556/AAlim.2015.0002.
[10] Akamatsu Y, Ohno S, Kobayashi H, Kusayama Y, Kumagai K, Saito T. Coronal subluxation of the proximal tibia relative to the distal femur after opening wedge high tibial osteotomy. Knee 2017;24:70–5. https://doi.org/10.1016/j.knee.2016.09.009.
[11] Okamoto S, Okazaki K, Mitsuyasu H, Matsuda S, Iwamoto Y. Lateral soft tissue laxity increases but medial laxity does not contract with varus deformity in total knee arthroplasty. Clin Orthop Relat Res 2012;471:1334–42. https://doi.org/10.1007/s11999-012-2745-1.
[12] Ogawa H, Matsumoto K, Ogawa T, Takeuchi K, Akiyama H. Pre-operative varus laxity correlates with overcorrection in medial opening wedge high tibial osteotomy. Arch Orthop Trauma Surg 2016;136:1337–42. https://doi.org/10.1007/s00402-016-2521-x.
[13] Scott RD, Santore RF. Unicondylar unicompartmental replacement for osteoarthritis of the knee. J Bone Joint Surg Am 1981;63:536–44. https://doi.org/10.2106/00004623-198163040-00004.
[14] Chang CB, Koh IJ, Seo ES, Kang YG, Seong SC, Kim TK. The radiographic predictors of symptom severity in advanced knee osteoarthritis with varus deformity. Knee 2011;18:456–60. https://doi.org/10.1016/j.knee.2010.08.010.
[15] Crenshaw AH. Soft tissue procedures and corrective osteotomies about the knee. In: Canale ST, Beaty J, editors. Campbell's Operative Orthopaedics. 12th ed. New York: Elsevier; 2013. p. 453–83. https://doi.org/10.1016/B978-0-323-07243-4.00009-8.
[16] Gomoll AH. High tibial osteotomy for the treatment of unicompartmental knee osteoarthritis: a review of the literature, indications, and technique. Phys Sports Med 2011;39:45–54. https://doi.org/10.3810/psm.2011.09.1920.
[17] Keene JS, Dyreby JR. High tibial osteotomy in the treatment of osteoarthritis of the knee. The role of pre-operative arthroscopy. J Bone Joint Surg Am 1983;65:36–42. https://doi.org/10.2106/00004623-198365010-00006.
[18] Miniaci A, Ballmer FT, Ballmer PM, Jakob RP. Proximal tibial osteotomy. A new fixation device. Clin Orthop Relat Res 1989;246:250–259.
[19] Lee YS, Kim MK, Byun HW, Kim SB, Kim JG. Reliability of the imaging software in the pre-operative planning of the open-wedge high tibial osteotomy. Knee Surg Sports Traumatol Arthrosc 2015;23:846–51.
[20] Vainionpää S, Läike E, Kirves P, Tiusanen P. Tibial osteotomy for osteoarthritis of the knee. A five to ten-year follow-up study. J Bone Joint Surg Am 1981;63:938–46. https://doi.org/10.2106/00004623-198163060-00011.
[21] Valenti JR, Calvo R, Lopez R, Cañadell J. Long-term evaluation of high tibial valgus osteotomy. Int Orthop 1990;14:347–9. https://doi.org/10.1007/BF00182642.
[22] Tjörnstrand BA, Egund N, Hagstedt BV. High tibial osteotomy: a seven-year clinical and radiographic follow-up. Clin Orthop Relat Res 1981;160:124–136.
[23] Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. Orthop Clin North Am 1979;10:585–608.
[24] Dugdale TW, Noyes FR, Styer D. Pre-operative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clin Orthop Relat Res 1992;274:248–264.
[25] Lee DC, Byun SJ. High tibial osteotomy. Knee Surg Relat Res 2012;24:61–9. https://doi.org/10.5792/ksrr.2012.24.2.61.
[26] Pape D, Duchow J, Rupp S, Seil R, Kohn D. Partial release of the superficial medial collateral ligament for open-wedge high tibial osteotomy. A human cadaver study evaluating medial joint opening by stress radiography. Knee Surg Sports Traumatol Arthrosc 2006;14:141–8. https://doi.org/10.1007/s00167-005-0649-2.
[27] van Egmond N, Hannink G, Janssen D, Vrancken AC, Verdonschot N, van Kampen A. Relaxation of the MCL after an Open-Wedge High Tibial Osteotomy results in decreasing contact pressures of the knee over time. Knee Surg Sports Traumatol Arthrosc 2017;25:800–7. https://doi.org/10.1007/s00167-017-4438-5.
[28] Seo SS, Kim CW, Seo JH, Kim DH, Lee CR. Does superficial medial collateral ligament release in open-wedge high tibial osteotomy for varus osteoarthritic knees increase valgus laxity? Am J Sports Med 2015;44:908–15. https://doi.org/10.1177/0363546515624925.
[29] Hoell S, Suttmoeller J, Stoll V, Fuchs S, Gosheger G. The high tibial osteotomy, open versus closed wedge, a comparison of methods in 108 patients. Arch Orthop Trauma Surg 2005;125:638–43. https://doi.org/10.1007/s00402-005-0004-6.
[30] Gaasbeek RDA, Nicolaas L, Rijnberg WJ, Van Loon CJM, Van Kampen A. Correction accuracy and collateral laxity in open versus closed wedge high tibial osteotomy. A one-year randomised controlled study. Int Orthop 2010;34:201–7. https://doi.org/10.1007/s00264-009-0861-7.
[31] Kim SH, Ro DH, Lee YM, Cho Y, Lee S, Lee MC. Factors associated with discrepancies between pre-operatively planned and postoperative alignments in patients undergoing closed-wedge high tibial osteotomy. Knee 2017;24:1129–37. https://doi.org/10.1016/j.knee.2017.05.013.
[32] Khamaisy S, Zuiderbaan HA, Thein R, Nawabi DH, Joskowicz L, Pearle AD. Coronal tibiofemoral subluxation: a new measurement method. Knee 2014;21:1069–71. https://doi.org/10.1016/j.knee.2014.07.013.
[33] Nam D, Khamaisy S, Gladnick BP, Paul S, Pearle AD. Is tibiofemoral subluxation correctable in unicompartmental knee arthroplasty? J Arthroplasty 2013;28:1575–9. https://doi.org/10.1016/j.arth.2013.03.001.