의학석사 학위논문

내측 개방형 경골 근위부 절골술 후 무릎 관절선 방향의 예측 모델

2017년 8월

서울대학교 대학원

의학과 정형외과학 전공

박 재 영

A thesis of the Degree of Master of Philosophy

Prediction model of knee joint line orientation after medial open wedge high tibial osteotomy

August, 2017

Department of Orthopaedic Surgery

Seoul National University

College of Medicine

Jae-Young Park

Abstract

Prediction model of knee joint line orientation after medial open wedge high tibial osteotomy

Jae-Young Park
Department of Orthopaedic Surgery
College of Medicine
Seoul National University

Background: A joint line parallel to the floor is an important objective after medial open wedge high tibial osteotomy (MOWHTO). One of the methods to assess the coronal alignment of the knee after MOWHTO is knee joint line orientation relative to the ground (G-KJLO). There are no tools, however, for surgeons that could predict the value of post-operative G-KJLO before the surgery.

Methods: Fourteen radiographic parameters were measured in pre-operative and post-operative full-limb standing anteroposterior radiographs on 50 patients who underwent MOWHTO. The parameters were analyzed using multivariate linear regression to predict the G-KJLO after MOWHTO.

Results: After MOWHTO, G-KJLO increased from a mean value of -0.8° to 2.9° ($P < 0.001$). G-AJLO decreased after MOWHTO from a mean value of 8.3° to 1.5° ($P < 0.001$). Based on the multiple regression analysis by backward elimination of parameters influencing post-operative G-KJLO, we have derived an equation that can estimate post-operative G-KJLO after MOWHTO; post-operative G-KJLO (°) = 8.300 + 0.419 x pre-operative G-KJLO (°) + 0.923 x pre-operative medial proximal tibial angle(MPTA) (°) - 0.095 x pre-operative tibial width (mm) - 0.655 x pre-operative hip-knee-ankle(HKA) angle (°) + 0.444 x lateral distal femoral angle(LDFA) (°) + 0.662 x pre-operative joint space tilt angle(JSTA) (°) + 0.421 x aimed correction angle (°).

Conclusion: This study analyzed the effects of pre-operative anatomical alignment parameters to the post-operative G-KJLO. We established an equation which predicts post−operative G−KJLO with pre−operative anatomical alignment factors. This equation might help selecting optimal patients and operative plan for MOWHTO.

−−

Keywords: high tibial osteotomy; knee joint line orientation; medial proximal tibial angle; hip−knee−ankle angle

Student number: 2013−23484

CONTENTS

List of Figures

List of Tables

List of abbreviations and symbols

MOWHTO	medial open wedge high tibial osteotomy
G-KJLO	knee joint line orientation relative to the ground
G-AJLO	ankle joint line orientation relative to the ground
OA	osteoarthritis
AP	anteroposterior
HKA	hip-knee-ankle
LDFA	lateral distal femoral angle
MPTA	medial proximal tibial angle
JSTA	joint space tilt angle
FBA	femoral bowing angle

Introduction

MOWHTO is a realignment procedure used in patients with symptomatic medial tibiofemoral osteoarthritis (OA) with varus malalignment of the knee. MOWHTO has gained popularity over the years due to advantages of better fixation system, better archiving of the target correction angle, and better preservation of proximal tibiofibular joint.[1,2,3] MOWHTO, however, has limitation in that it can only alter the proximal tibial geometry irrespective of the source of varus alignment of the lower limb. Also, it is reported that there are more than 10 percent proportion of unacceptable alignment after MOWHTO.[4]

The most commonly used method when planning MOWHTO is to visualize the movement of lower leg below the osteotomy site. The aim of alignment after MOWHTO is usually a mechanical axis that passes from the hip center to tibiotalar joint center while passing through the knee joint.[5] The controversial subject is exactly where the mechanical axis should cross in the knee joint. Fujisawa *et al.* recommended that the mechanical axis should pass between 30 percent and 40 percent lateral to the center of the tibial spines; this is called the Fujisawa point.[6] This study, however failed to provide a mechanical rationale. Victor *et al.* explained that in knees of constitutional varus with advanced arthritis, correcting only the proximal tibia with the aim of achieving a normal mechanical axis with HTO may result in overcorrection of the tibia.[7]

Current understanding of the onset and progression of knee OA is mainly limited to the coronal alignment of the lower limb.[8] Coronal alignment of the lower limb is important in analyzing the balance of forces across the knee joint. It decides how much load is transmitted through the medial and lateral compartment of the knee.[9] Within the understanding of coronal alignment, knee joint line orientation relative to the ground (G−KJLO) is an important factor.[10,11] Cooke et al. observed the major contributor to coronal malalignment as proximal tibial and distal femoral anatomy.[12] Bellemans et al. described that the proximal tibial and distal femoral anatomy contributed for 70% of varus deformity.[13] Victor et al. identified that the joint line was parallel to the floor in constitutional varus individuals.[7] Despite the ability of G−KJLO to describe the geometry of the bone relative to the mechanical axis, it has received little attention. The importance of G−KJLO lies in its relation to biomechanical outcomes of shear stress and joint loading.[10] G-KJLO is predicted that it will influence the estimated loads that are transmitted through cartilage and subchondral bone.[7]

As recent studies argue that a joint line parallel to the floor is an important objective after MOWHTO,[14] however, there are no tools for surgeons that could predict the value of post-operative G-KJLO before the surgery. G-KJLO could only be measured a few months after MOWHTO when the patient was strong enough to stand up and take a standing full-limb anteroposterior (AP) radiograph.

The aim of this study was first to determine the effects of various pre-operative anatomical alignment parameters to the post-operative G-KJLO. Based upon this analysis, we aimed to devise an equation that predicts the value of post-operative G-KJLO.

Materials and Methods

Study subjects

We retrospectively analyzed 59 consecutive patients who underwent MOWHTO in a single center between December 2009 and May 2016 by a single surgeon. Inclusion criteria were patients who underwent MOWHTO due to symptomatic varus knee OA with follow-up radiographs at 1 year after MOWHTO. The exclusion criteria were as follows; 1. MOWHTO was performed due to diseases other than primary OA, such as ligament injuries (posterolateral corner injury of the knee and anterior cruciate ligament injury), developmental deformity of the knee, and malunion of a proximal tibial fracture 2. Patients with poor radiographic quality.

We estimated sample size that could detect 2º difference in the mean post-operative G-KJLO which was considered clinically meaningful using an independent t-test. Based on the data from a previous study[7], at least 46 patients were required to detect this difference. The type 1 error was 0.05 and power was 0.8. This study was approved by the institutional review board of our hospital.

Radiographic evaluation

Fourteen radiographic measures including (1) pre-operative and post-operative G-KJLO, (2) pre-operative and post-operative G-AJLO, (3) pre-operative and post-operative MPTA, (4) pre-operative and post-operative HKA angle, (5) tibial length, (6) tibial width, (7) LDFA (8) JSTA, (9) FBA, (10) correction angle were assessed using pre-operative and post-operative six month or one year standing full-limb AP radiographs. Standing full-limb AP radiographs were obtained on a 14 x 51 inch (36 x 130 cm) grid cassette at a source-to-image distance of 240 cm using a UT 2000 X-ray machine (Phillips Research, Eindhoven, The Netherlands) set to 90 kV and 50 mA/s. To control the rotational position of the AP radiograph, foot rotation angle was held constant with a reference foot template on the platform of our plane radiographic system. In addition, the appropriate knee position (patellar facing forward) confirmed using a preview monitor before final acquisition of the full-limb AP radiograph[15]. All radiographic images were digitally acquired using a picture archiving and communication system (PACS). Assessment was performed on a 24 inch (61 cm) monitor (U2412 M; Dell, Round Rock, TX, USA) in portrait mode using PACS software (Maroview, Seoul, Korea), which allowed the investigator to detect the bisecting point of any area on the femur or the tibia and to measure the angle between any two lines drawn on the digital image. The minimum differences that the software could detect were 0.1° in angle and 0.1 mm in length.

HKA angle was defined as the angle formed by the intersection of the mechanical axis of the femur (the line from the femoral head center to femoral intercondylar notch center) with the tibia (the line from ankle talus center to the center of the tibial spine tips); a negative value was given to the knee in varus [Fig. 1(A)]. LDFA was defined as the angle between the mechanical axis of the femur and the tangent to the subchondral plates of both femoral condyles subtracted from 90°; a negative value was given in varus orientation [Fig. 1(B)]. FBA was defined as the angle between the line connecting the points bisecting the femur at 0 and 5 cm below the lowest portion of the lesser trochanter and the line connecting the points bisecting the femur at 5 cm and 10 cm above the lowest portion of the lateral femoral condyle (a positive value was given to subjects with lateral bowing) [Fig. 1(C)]. MPTA was defined as the angle between the mechanical axis of the tibia and the tangent to the subchondral plate of the tibia subtracted by 90° ; a negative value was given in varus orientation [Fig. 1(D)]. The tibial length was defined as the distance between the central point of the tibial spine and the central point of the tibial plafond surface. The tibial width was defined as the distance between the lateral and medial end of the subchondral plate of the proximal tibia [Fig. 1(E)]. JSTA was defined as the angle between the tangent to the subchondral plates of both femoral condyles and the tangent to the subchondral plate of the tibia; a negative value was given to the knee in more lateral space opening [Fig. 1(F)]. G-KJLO was defined as the angle between the line connecting the mid-points of the medial and lateral knee joint space, and a horizontal grid line on radiographs that was parallel to the floor; a negative value was given when the mid-joint space line tilted medially relative to the horizontal grid line [Fig. 1(G)]. G-AJLO was defined as the angle between the tangent to the subchondral plate of the talus and the horizontal grid line on radiographs; a negative value was given when the tangent of the talus surface tilted medially relative to the horizontal grid line [Fig. 1(H)]. Correction angle was defined as the value derived from subtraction of pre-operative MPTA from post-operative MPTA.

Fig. 1. Radiographic measurements

Statistical analysis

All the statistical analyses were carried out with SPSS for Windows version 17.0 (SPSS Inc., Chicago, Illinois), and *P* values < 0.05 were considered significant. Values of the four radiographic measures were compared before and after HTO using the paired t-test. Various factors associated with the post-operative G-KJLO were analyzed with the use of multivariate regression analyses with backward stepwise method. Multiple regression analysis results were summarized by use of standardized coefficients, that is, β-coefficients, P values, and coefficients of determination (R^2).

Results

We excluded a total of 18 patients: eight patients in whom an MOWHTO was performed due to diseases other than primary OA, such as ligament injuries (posterolateral corner injury of the knee and anterior cruciate ligament injury), developmental deformity of the knee, and malunion of a proximal tibial fracture, nine patients with poor radiographic quality, and one patient who was lost in follow-up. Finally, 41 eligible patients (50 knees) remained who underwent MOWHTO due to symptomatic varus knee OA (Fig. 2).

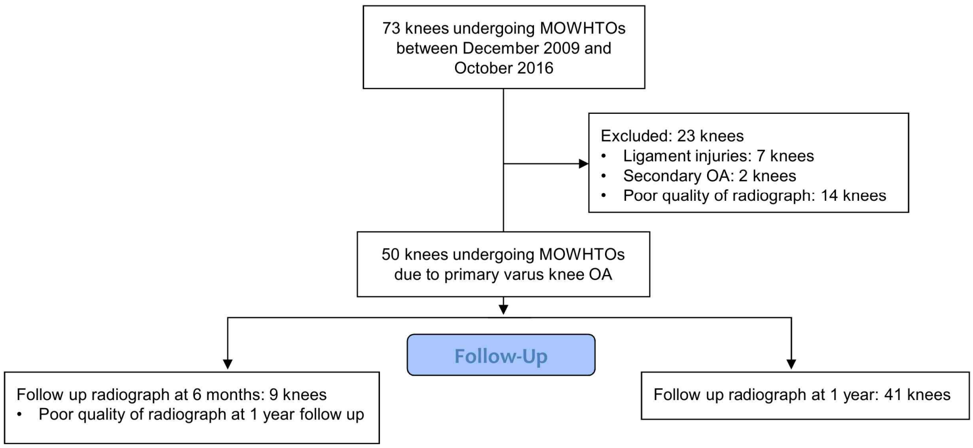

Fig. 2. Study subjects enrollment flowchart

To determine intra- and interobserver reliabilities of radiographic assessment, two orthopedic surgeons performed all radiographic measurements in 30 randomly selected knees twice, with a 3-week interval between evaluations. The intra- and interobserver reliabilities of measurements for the thirteen radiographic measures were evaluated using intraclass correlation coefficients (ICCs). All ICCs of intra- and interobserver reliabilities of alignment measurements were satisfactory, > 0.89 (range, 0.89-0.99); thus measurements taken by one investigator were used in the analysis

Baseline characteristics

This group included 36 women and five men with a mean age of 55 years (SD 4.8; range 39 to 64) and a mean body mass index (BMI) of 26.1 kg/m^2 (SD 3.2; range, 20.3 to 32.7) (Table 1).

HKA angle, MPTA, G-KJLO, and G-AJLO significantly changed after MOWHTO. G-KJLO increased after MOWHTO from a mean value of −0.8° to 2.9° (P < 0.001). G-AJLO decreased after MOWHTO from a mean value of 8.3° to 1.5° (P < 0.001) (Table 2).

Clinical characteristics	HTO group (n = 50)	
	Mean	SD (range)
Age (years)	55.5	4.85 (39 to 64)
Male (n)	5 (12.1%)	
BMI	26.1	3.21 (20.3 to 32.7)
Left operation (n)	30 (60%)	
Pre−operative G−KJLO (°)	−0.8	2.4 (−5.6 to 3.9)
Pre−operative G−AJLO (°)	8.39	3.3 (0.8 to 15)
Pre−operative MPTA (°)	−5.7	2.0 (−10.5 to −2.5)
Pre−operative HKA angle (°)	−7.7	2.1 (−12.9 to −2.3)
Pre−operative TW (mm)	73.1	4.4 (66.7 to 86)
Pre−operative TL (mm)	340.47	21.7 (296 to 392)
Pre−operative JSTA (°)	−3.6	2.2 (−9.6 to −0.1)
Pre−operative FBA (°)	−0.07	3.1 (−7.4 to 7.1)
Correction Angle (°)	9.1	3.2 (1.2 to 15.2)

Table 1. Baseline characteristics of the study group

Parameter	Pre-HTO		Post-HTO		Mean difference (Range)	*P*-value
	Mean	95% CI	Mean	95% CI		
HKA angle	−7.7°	−9.8° to −5.6°	2.4°	0° to 4.8°	10.2° (9.2° to 11.2°)	<0.001
MPTA	−5.8°	−7.8° to −3.8°	3.3°	0° to 6.6 °	9.0° (8.1° to 10°)	<0.001
G-KJLO	−0.8°	−3.2° to 1.6°	2.9°	0.3° to 5.5 °	3.8° (3.2° to 4.4°)	<0.001
G-AJLO	8.3°	5° to 11.6°	1.5°	−2.2° to 5.2°	6.8° (6° to 7.6°)	<0.001

Table 2. Comparative results of the four-radiographic measure before and after MOWHTO

Covariate	Coefficient	*t* ratio	Adjusted R^2	*P*-value
Postoperative G-KJLO (°)			0.764	
Preoperative G-KJLO (°)	0.419	3.511		0.001
Preoperative MPTA (°)	0.923	3.890		<0.001
Preoperative HKA angle (°)	−0.655	−2.956		0.005
Preoperative tibial width (mm)	−0.095	−1.993		0.05
Preoperative LDFA (°)	0.444	1.689		0.099
Preoperative JSTA (°)	0.662	2.824		0.007
Correction angle (°) ≠	0.421	5.481		<0.001

Table 3. Multiple regression analysis of factors influencing postoperative G-KJLO after MOWHTO included (n = 50)

Prediction model for G-KJLO

Pre-operative MPTA and aimed correction angle were the most significant contributors to post-operative G-KJLO ($P < 0.001$, Table 2). Pre-operative G-KJLO, pre-operative HKA angle, and tibial width also showed to be a significant contributor to post-operative G-KJLO (P = 0.001, 0.005, 0.05, and 0.007, respectively). Pre-operative G-AJLO, tibial length, and FBA were removed from the equation due to lack of significance (P = 0.831, 0.387, and 0.372, respectively). The coefficients for G-KJLO, MPTA, HKA angle, tibial width, LDFA, JSTA, and aimed correction angle was 0.419, 0.923, −0.655, −0.095, 0.444, 0.662, and 0.421, respectively (Table 3)

Based on the multiple regression analysis by backward elimination of parameters influencing post-operative G-KJLO, we have derived an equation that can estimate post-operative G-KJLO after HTO. The equation is as follows: post-operative G-KJLO (°) = 8.300 + 0.419 x pre-operative G-KJLO (°) + 0.923 x pre-operative MPTA (°) - 0.095 x pre-operative tibial width (mm) - 0.655 x pre-operative HKA angle (°) + 0.444 x pre-operative LDFA (°) + 0.662 x pre-operative JSTA (°) + 0.421 x aimed correction angle (°).

The adjusted R^2 value was 0.764. The t ratio values suggest that the coefficient values are statistically significantly different from 0 at the 90% confidence (Table 3).

Exemplary model of the equation

Patient 1 is a 49-year-old female patient who underwent MOWHTO due to symptomatic varus OA in her left knee. Based upon her pre-operative full-limb AP radiograph (Fig. 3A), G-KJLO (solid line) was −2.5° relative to the ground (dotted line). MPTA was −4.2°, HKA angle was −7°, TW was 74mm, LDFA was 2.9°, JSTA was −5.1°, and aimed correction angle was 9°. When we put these variables in the equation, the estimated value of G-KJLO is 2.6°. Actual post-operative G-KJLO measured from (Fig. 3B) is 2.1°.

Patient 2 is a 58-year-old female patient who underwent MOWHTO due to symptomatic varus OA in her right knee. Based upon her pre-operative full-limb AP radiograph (Fig. 3C), G-KJLO (solid line) was −5.6° relative to the ground (dotted line). MPTA was −6.7°, HKA angle was −3.2°, TW was 70.5mm, LDFA was 4.1°, JSTA was −1.2°, and aimed correction angle was 7°. When we put these variables in the equation, the estimated value of G-KJLO is −

0.8° . Actual post-operative G-KJLO measured from (Fig. 3D) is -0.5° .

Patient 3 is a 57-year-old female patient who underwent MOWHTO due to symptomatic varus OA in her left knee. Based upon her pre-operative full-limb AP radiograph (Fig. 3E), G-KJLO (solid line) was -4° relative to the ground (dotted line). MPTA was -5.3° , HKA angle was -7.2° , TW was 70.2mm, LDFA was 1.2° , JSTA was -2.1° , and aimed correction angle was 9° . When we put these variables in the equation, the estimated value of G-KJLO is 2.7° . Actual post-operative G-KJLO measured from (Fig. 3F) is 2.4° .

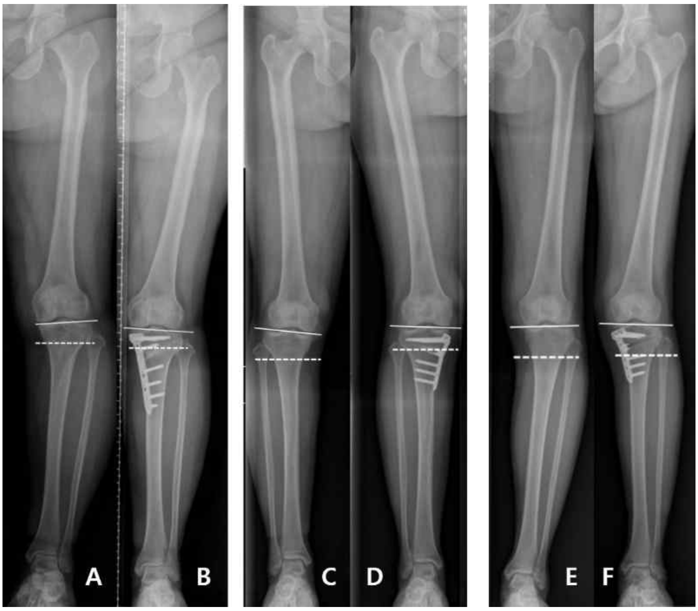

Fig. 3. Radiographs of three patients showing the efficacy of the equation

Discussion

In this study, we established an equation that predicts the post-operative G-KJLO based on pre-operative anatomical parameters measured from a single radiograph of the lower limb. A novel finding in this study is that it established the relationship between post-operative G-KJLO and various pre-operative anatomical alignment parameters.

Accurate pre-operative planning is mandatory in the success of MOWHTO. Several methods have been proposed by Hernigou *et al.*[2], Miniaci *et al.*,[16], and Dugdale *et al.*[5] using a full-limb radiograph. These methods help the surgeons in determining the correction angle. Intra-operatively, Krettek *et al.* introduced the "cable method"[17] and Lobenhoffer *et al.* used the "alignment rod method" to check the mechanical axis.[18] However, post-operative value of G-KJLO was unknown until a few months after the operation when the patient is strong enough to stand up straight to take a full-limb radiograph. With the use of our equation, the surgeon can estimate the post-operative value of G-KJLO, pre-operatively. Predicting the G-KJLO before the surgery is very helpful to the surgeon because there are cases in which the post-operative G-KJLO is greater than 10°

while the mechanical axis is within normal range after MOWHTO. Victor *et al.* explained that in knees of constitutional varus with advanced arthritis, G-KJLO is opened towards medial side because of the bone loss at the level of the medial distal femur.[7] MOWHTO is an alignment procedure correcting only the proximal tibia, therefore the bone loss at distal femur is not corrected. The aim to achieve normal mechanical axis with MOWHTO when anatomical factors contributing to varus alignment is still present such as in distal femur, results in overcorrection of the tibia.[19] This might be the reason why the G-KJLO can be abnormal after HTO while the mechanical is within normal range.

As shown in our equation to predict post-operative G-KJLO, there are many anatomical factors involved in the equation. This represents that G-KJLO is not simply decided by a single factor, but rather by a complex mixture of factors. Cooke et al.[12] described that coronal plane orientation is decided by proximal tibial and distal femoral anatomy. One notable fact is that in our equation, aimed correction angle is the only factor that can be controlled by the surgeon. Other factors are anatomical factors already decided before the surgery. It is a reasonable derivation to conclude that increasing 1 degree of correction angle in HTO increases 0.421 degree of G-KJLO. MPTA and aimed angle of correction was the most predictable factors associated with G-KJLO. Pre-operative G-KJLO, pre-operative HKA angle, pre-operative tibial width, and pre-operative JSTA also showed to be significantly related to G-KJLO. In previous studies, JSTA was known to be correlated with soft tissue laxity.[20,21] Pre-operative soft tissue laxity can cause overcorrection or under correction in MOWHTO. We believe that because of the consideration of soft tissue laxity, JSTA was included in our equation. We expected that pre-operative G-AJLO would significantly affect the value of post-operative G-KJLO. Thus, it would have been included in our final equation because in our previous study, we have reported that G-KJLO changed significantly less than did the MPTA after MOWHTO because of the compensatory changes of G-AJLO.[22] However, in our multiple regression analysis in backward elimination method, pre-operative G-AJLO was eliminated due to the lack of significance ($P = 0.831$). We believe this is because the effect of G-AJLO was already taken into account in other anatomical factors such as HKA angle.

Within the category of coronal alignment, G-KJLO is an important factor.[10,11] Despite the ability of G−KJLO to describe the geometry of the bone relative to the mechanical axis, it has received little attention. The importance of G−KJLO lies in its relation to biomechanical outcomes of shear stress and joint loading.[10] G−KJLO is predicted that it will influence the estimated loads that are transmitted through cartilage and subchondral bone.[7] It has been generally accepted that a slope (medial or lateral) of more than 10 degrees is not permissible.[23] Hernigou *et al.* had emphasized the importance of balancing the unloading of the medial compartment and harmful effects of excessive pressure at the lateral compartment. In their study, five patients had undergone HTO of more than six degrees valgus angulation. Hernigou reported that all five patients suffered with severe lateral compartment arthrosis at the follow−up of 11.5 years.[2] This may be explained by the fact that a too much lateral slope may have caused transverse shearing forces of the femur. Due to the tibiofemoral articular geometry which is adapted to the human gait loading pattern, the less congruent lateral compartment of the knee is subject to higher contact stresses compared to the more congruent medial compartment.[9] The importance of knee joint line orientation is emphasized in certain groups that to maintain the knee joint line, there are opinions in which double level osteotomy of the distal femur and the proximal tibia should be considered in cases where a single level osteotomy of the knee may lead to unacceptable medial or lateral slope of the knee joint.[24]

As seen in our algorithm (Fig. 4), if the estimated post−operative G−KJLO is expected to be greater than 10º, the surgeon should consider for an additional surgery such as distal femoral osteotomy on top of MOWHTO. If the estimated post−operative G−KJLO is less than 10º, the surgeon should undergo just the MOWHTO as planned. Knowing the possibility of a secondary surgery beforehand is very helpful to the surgeon because there are a lot of factors influenced by an additional surgery; surgical time, surgical instruments, and tourniquet position. It is also very informative to the patient to know the possibility of a secondary surgery beforehand.

Some limitation should be noted in our study. First, this study only included patients with varus alignment that underwent MOWHTO. The equation is not assured for the use in patients with valgus alignment who is planned for varus−producing osteotomy. Second, the anatomical alignment factors analyzed in this study were measured only from standing full−limb AP radiographs. X−ray only reflects a

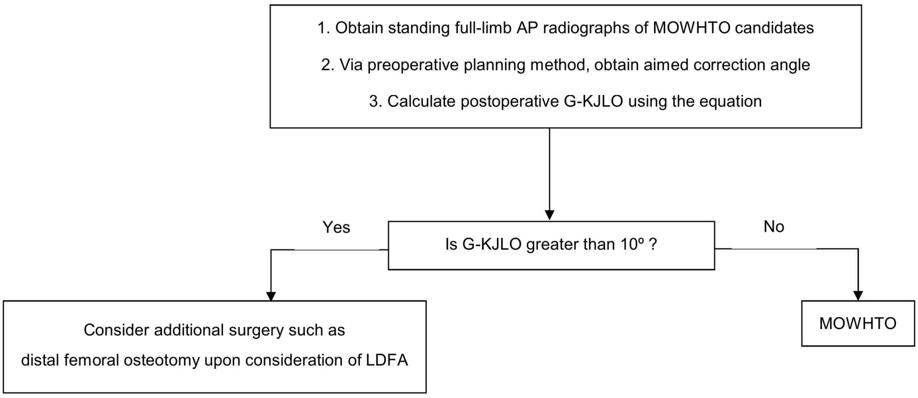

Fig. 4. Algorithm in planning MOWHTO

two-dimensional aspect of a three-dimensional human structure. Therefore, predicting G-KJLO would have been more accurate if it was done with means of a three-dimensional computed tomography or even with the help of a lateral X-ray of the lower limb. We tried, however, to make the equation as simple and practical as possible, making it possible to derive G-KJLO with the use of only one AP radiograph of the lower limb. Third, we tried to micromanage the method the standing full-limb AP radiograph was taken. However, there are some variations in the quality of the X-ray taken. Thus, there may be measurement errors in our data. It is also important for future users of this equation to meticulously measure their preoperative alignment parameters in a satisfactory full-limb AP radiograph.

In conclusion, our study was able to analyze which pre-operative anatomical alignment factors contributed to the post-operative G-KJLO. Based on this analysis, we were able to devise an equation that could predict post-operative G-KJLO with pre-operative anatomical alignment factors. This equation is expected to help select optimal patients and operative plan for MOWHTO. Further studies should evaluate the long-term clinical outcomes of G-KJLO after MOWHTO.

References

1. Wang JH, Bae JH, Lim HC, Shon WY, Kim CW, Cho JW. Medial open wedge high tibial osteotomy: the effect of the cortical hinge on posterior tibial slope. The American journal of sports medicine 2009;37:2411-8.

2. Hernigou P, Medevielle D, Debeyre J, Goutallier D. Proximal tibial osteotomy for osteoarthritis with varus deformity. A ten to thirteen-year follow-up study. The Journal of bone and joint surgery American volume 1987;69:332-54.

3. El-Azab H, Halawa A, Anetzberger H, Imhoff AB, Hinterwimmer S. The effect of closed- and open-wedge high tibial osteotomy on tibial slope: a retrospective radiological review of 120 cases. The Journal of bone and joint surgery British volume 2008;90:1193-7.

4. El-Azab HM, Morgenstern M, Ahrens P, Schuster T, Imhoff AB, Lorenz SG. Limb alignment after open-wedge high tibial osteotomy and its effect on the clinical outcome. Orthopedics 2011;34:e622-8.

5. Dugdale TW, Noyes FR, Styer D. Preoperative planning for high tibial osteotomy. The effect of lateral tibiofemoral separation and tibiofemoral length. Clinical orthopaedics and related research 1992:248-64.

6. Fujisawa Y, Masuhara K, Shiomi S. The effect of high tibial osteotomy on osteoarthritis of the knee. An arthroscopic study of 54 knee joints. The Orthopedic clinics of North America 1979;10:585-608.

7. Victor JM, Bassens D, Bellemans J, Gursu S, Dhollander AA, Verdonk PC. Constitutional varus does not affect joint line orientation in the coronal plane. Clinical orthopaedics and related research 2014;472:98-104.

8. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA 2001;286:188-95.

9. Amis AA. Biomechanics of high tibial osteotomy. Knee surgery, sports traumatology, arthroscopy : official journal of

the ESSKA 2013;21:197-205.

10. Cooke TD, Pichora D, Siu D, Scudamore RA, Bryant JT. Surgical implications of varus deformity of the knee with obliquity of joint surfaces. The Journal of bone and joint surgery British volume 1989;71:560-5.

11. Cooke TD, Li J, Scudamore RA. Radiographic assessment of bony contributions to knee deformity. The Orthopedic clinics of North America 1994;25:387-93.

12. Cooke D, Scudamore A, Li J, Wyss U, Bryant T, Costigan P. Axial lower-limb alignment: comparison of knee geometry in normal volunteers and osteoarthritis patients. Osteoarthritis and cartilage / OARS, Osteoarthritis Research Society 1997;5:39-47.

13. Bellemans J, Colyn W, Vandenneucker H, Victor J. The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clinical orthopaedics and related research 2012;470:45-53.

14. Thienpont E, Cornu O, Bellemans J, Victor J. Current

opinions about coronal plane alignment in total knee arthroplasty: A survey article. Acta orthopaedica Belgica 2015;81:471-7.

15. Paley D, Herzenberg JE, Tetsworth K, McKie J, Bhave A. Deformity planning for frontal and sagittal plane corrective osteotomies. The Orthopedic clinics of North America 1994;25:425-65.

16. Miniaci A, Ballmer FT, Ballmer PM, Jakob RP. Proximal tibial osteotomy. A new fixation device. Clinical orthopaedics and related research 1989:250-9.

17. Krettek C, Miclau T, Grun O, Schandelmaier P, Tscherne H. Intraoperative control of axes, rotation and length in femoral and tibial fractures. Technical note. Injury 1998;29 Suppl 3:C29-39.

18. Freiling D, van Heerwaarden R, Staubli A, Lobenhoffer P. [The medial closed-wedge osteotomy of the distal femur for the treatment of unicompartmental lateral osteoarthritis of the knee]. Operative Orthopadie und Traumatologie 2010;22:317-34.

19. Floerkemeier S, Staubli AE, Schroeter S, Goldhahn S, Lobenhoffer P. Outcome after high tibial open-wedge osteotomy: a retrospective evaluation of 533 patients. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2013;21:170-80.

20. Lee DH, Park SC, Park HJ, Han SB. Effect of soft tissue laxity of the knee joint on limb alignment correction in open-wedge high tibial osteotomy. Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA 2015.

21. Ogawa H, Matsumoto K, Ogawa T, Takeuchi K, Akiyama H. Preoperative varus laxity correlates with overcorrection in medial opening wedge high tibial osteotomy. Archives of orthopaedic and trauma surgery 2016;136:1337-42.

22. Lee KM, Chang CB, Park MS, Kang SB, Kim TK, Chung CY. Changes of knee joint and ankle joint orientations after high tibial osteotomy. Osteoarthritis and cartilage / OARS, Osteoarthritis Research Society 2015;23:232-8.

23. Coventry MB. Proximal tibial varus osteotomy for

osteoarthritis of the lateral compartment of the knee. The Journal of bone and joint surgery American volume 1987;69:32-8.

24. Babis GC, An KN, Chao EY, Rand JA, Sim FH. Double level osteotomy of the knee: a method to retain joint-line obliquity. Clinical results. The Journal of bone and joint surgery American volume 2002;84-A:1380-8.

국문 초록

배 경: 지면과 평행한 무릎 관절선은 내측 개방형 경골 근위부 절골술 후 중요한 목표이다. 내측 개방형 경골 근위부 절골술 후 무릎의 관상면 정렬을 평가하는 방법 중 하나는 무릎 관절선의 방향이다. 수술 전 및 수술 후 무릎의 관상면 정렬의 값을 예측할 수 있는 방법은 현재 없다.

대상 및 방법: 내측 개방형 경골 근위부 절골술을 시행한 50명의 환자를 대상으로 수술 전 및 수술 후 하지전장방사선 영상을 대상으로 14개의 방사선학적 지표들을 측정하였다. 내측 개방형 경골 근위부 절골술 후 무릎 관절선의 방향을 예측하기 위해 다중 변수 선형 회귀 분석을 사용하여 변수들을 분석하였다.

결 과: 내측 개방형 경골 근위부 절골술 후 무릎 관절선은 평균 −0.8° 에서 2.9° 로 증가하였다(P <0.001). 발목 관절선은 내측 개방형 경골 근위부 절골술 후 평균 8.3° 에서 1.5° 로 감소하였다(P <0.001). 다중 선형 회귀 분석을 이용하여 수술 후 무릎 관절선에 영향을 미치는 변수들을 분석하였고 내측 개방형 경골 근위부 절골술 후 무릎 관절선을 예측할 수 있는 식을 도출하였다. 수술 후 무릎 관절선(°) = 8.3 + 0.419 x 수술 전 무릎 관절선(°) + 0.923 x 수술 전 근위 경골 각(°) − 0.095 x 수술 전 근위 경골 폭(mm) − 0.655 x 수술 전 고관절−슬관절−족관절 각(°) + 0.444 x 원위대퇴골 각(°) + 0.662 x 수술 전

슬관절 기울기 각(°) + 0.421 x 목표한 교정 각도(°).

결 론: 수술 전 하지의 해부학적 지표를 이용하여 수술 후 무릎의 관절선에 미치는 영향을 분석하였다. 이를 통해, 수술 전 해부학 적 정렬 지표들을 이용하여 수술 후 무릎의 관절선을 예측하는 식을 도출하였다. 이 식은 내측 개방형 경골 근위부 절골술을 시행함에 있어 최적의 환자군을 고르고 수술 계획을 수립함에 있어 도움을 줄 것이다.

색인 단어: 근위 경골 절골술, 무릎 관절선, 근위경골각, 고관절-슬관절-족관절 각

학 번: 2013-23484