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Changes of Contributors of Coronal Limb Alignment After Open Wedge High Tibial Osteotomy

: Effect of Joint Space Changes on Postoperative Alignment

개방형 경골 근위부 절골술 후 관상면 하지 정렬 기여인자의 변화

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College of Medicine

Orthopedic Surgery Major

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Abstract

Background

We aimed 1) to assess 3 major variables [femoral condylar orientation (FCO), tibia plateau inclination (TPI) and knee joint space tilt angle (JTA)] which would mainly contribute to overall limb alignment in patients undergoing medial open-wedge high tibial osteotomy(HTO) and compare the variables with those of normal knees, 2) to assess the changes of the 3 variables after HTO, and to compare the actual correction amount with the amount computed based on the two planning methods (Dugdale and Miniach methods), 3) to find the factors associated with the amount of JTA changes, and 4) to find factors associated with categories of final alignment after HTO.

Materials and Methods

We assessed 66 patients undergoing open-wedge HTO (HTO group) and 160 normal knees (control group). The weight

loading line (WLL), FCO, TPI, and JTA were measured on whole limb standing anteroposterior (AP) radiographs in all the subjects preoperatively. Additionally, same measurement was performed in the HTO group postoperatively, then the differences of the variables between the pre- and post-HTO were calculated. The amount of correction based on the two planning methods (Dugdale and Miniach methods) were computed, and compared with the actual correction angle calculated using TPI difference. In terms of categories of final alignment, WLL ratio within ±5% from the target WLL were classified as ideal correction, more than +5% as overcorrection and less than −5% as undercorrection. The factors associated with amount of JTA change by HTO were analyzed using the multivariate regression analyses with backward method, and the factor associated with over- and/or undercorrection was investigated using logistic regression analyses.

Results

Compared with the control group, all the variables were more

varus than the HTO group, preoperatively ($P < 0.001$ in all). Particularly, JTA of the HTO group was more than 3 fold of that of the control group (4.1° vs. 1.2°, $P < 0.001$). After HTO, besides the change of TPI, JTA also decreased by 2 degree on average. The amount of JTA change was larger in patients with more preoperative varus alignment and larger preoperative JTA, preoperatively (B = −0.19, $P = 0.006$, and B = −0.28, $P = 0.001$, respectively; R^2 for regression model = 0.361). In comparison between Dugdale and Miniach methods, the correction amount computed by Miniachi method was significantly larger than by Dugdale method (8.6° and 9.7°, $P = 0.028$). Between the two methods, angle computed by Dugdale method was more close to actual amount of correction (8.6° vs. 8.9°, respectively). In terms of categories of final alignment, 37 knees (56%) were classified as ideal correction and 29 knees (44%) as overcorrection. There was no knee classified as undercorrection. Among the radiographic variables evaluated except postoperative WLL, the change of JTA differed significantly between the ideal correction group and the overcorrection group (1.5° and 3.0° respectively, $P < 0.001$).

Conditional logistic regression analysis showed that an overcorrection was associated with the amount of JTA changes (odds ratio = 3.04, $P = 0.002$).

Conclusion

We found that three major variables determining overall coronal alignment was more varus in the HTO group than the control group. Particularly, JTA of the HTO group significantly contributed to the varus limb alignment, and the JTA decreased by 2° on average after HTO which could result in additional valgus realignment effect after HTO. Even though more preoperative varus alignment and more preoperative tilt of JTA were found to be associated with larger change of the JTA after HTO, accurate estimation of the JTA change may not be possible due to low R^2 value. Planning of target angle by Miniachi method showed significantly larger angle than that of Dugdale method. Therefore, if JTA change was not considered, Miniachi method could increase risk of overcorrection after HTO. Development of new method which could estimate the

change of JTA more accurately would be warranted via further studies.

Key words: High tibial osteotomy, Open wedge osteotomy, Overcorrection, Joint space tilt angle

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Introduction

Varus malalignment of the knee is a crucial factor to accelerate progression of medial tibiofemoral (TF) osteoarthritis (OA) of the knee(1,2), and also a strong predictor for poorer symptoms in patients with advanced OA of the knee(3). Thus, realignment procedures would be a reasonable option for young patients with symptomatic medial TF joint OA. The aim of HTO is to realign the lower limb to shift the load distribution from the medial compartment into the lateral compartment, thus leading to a decrease in symptoms related to medial compartment knee OA. Indeed, a number of reports supported the value of realignment procedures in terms of improving pain and functions, and delaying OA progression in the patient group with a little overcorrection(4-7). Additionally, realignment procedure is also an effective and reliable method for treatment of patients with posterolateral rotatory instability with varus malalignment by reducing the excessive adduction moment(8, 9).

Typically, high tibial osteotomy (HTO) has been used as a primary realignment procedure for varus malalignment of the knee.

In the track of HTO progress, lateral closed wedge HTO had been considered as a gold standard during the early period of HTO(10). But, closing wedge HTO involves fibular osteotomy, common peroneal nerve dissection, proximal tibiofibular joint disruption, and bone stock loss(11, 12). Furthermore, with this procedure it is difficult to obtain gradual correction of the axis. For this reason, medial open wedge HTO has been becoming more popular coupled with development of fixation system. And it has definite advantages over lateral closed wedge HTO such as better feasibility to archive target correction angle and prevention of proximal tibio-fibular joint(13). Nevertheless, even with current improvement of the HTO system, it is inherent limitation that this procedure change only the proximal tibial geometry regardless of the source of varus malalignment of the limb(14).

Correct patients selection is mandatory for achieving good results with open-wedge HTO(15). According to the literature, the factors that could influence the prognosis are age, body mass index (BMI), grade of osteoarthritis, range of motion (ROM), and associated instability. There is agreement in the literature regarding the association between age and outcomes of HTO. Some authors found that the risk of failure increased 7.6% for each year of age(16). At 10 years, the survival rate of HTO in patients younger than 65 years was 90% versus 70% in patients older than 65. Recently Howells et al.(17) analyzed 164 patients who underwent HTO, of whom 95 were reviewed at 10 years of follow-up. These authors found that better survival is associated with a pre-operative Western Ontario and McMaster Universities osteoarthritis index (WOMAC) > 45 points, age <55 years and BMI<30. However, in patients older than 55 years, adequate preoperative functional scores (more than 66.7 on the Japanese Orthopaedic Association Knee Score and a WOMAC greater than 45) might provide good survival and functional outcomes(18). The authors recommended the routine use of preoperative functional outcome score to guide decision-making when considering a patient's suitability for HTO(17). The relationship between BMI and open-wedge HTO outcomes is still debated in the literature. Flecher et al.(10), studying 313 patients, found that those with a BMI of less than 30 had better outcomes. This finding was confirmed by Howells et al.(17) in their study of 95 HTO patients. Giagounidis and Sell(19) examined 112 knees (94 patients) after HTO for varus and valgus alignment (the osteotomy was performed on the medial or lateral side in relation to the type of malalignment). They found that patients with a BMI greater than 10% above normal values had a pain-free period of 5 years, as opposed to 7.8 years for those with a BMI lower than 10% above normal values(19). Since normal values of BMI range between 18.5 and 24.9, a BMI greater than 27.4 is associated with poorer outcomes. The severity of medial compartment osteoarthritis is a relevant predictor of outcome after HTO. It is generally agreed in the literature that a low degree of arthrosis is linked to better outcomes(15). It is clear that tricompartmental osteoarthritis is a contraindication to osteotomy(20, 21). In very young patients a neutral alignment seems to be preferable. Correction to a femorotibial angle between 6° and 14° of valgus was associated with an optimal clinical result(10). Undercorrection to less than 5° of femorotibial valgus was associated with a high (62.5%) failure rate(22). Range of motion is another parameter that must be investigated before performing an open-wedge HTO. Several authors have reported an association between reduced range of motion and worse outcomes, with a flexion contracture constituting a contraindication to open-wedge HTO(23−25).

Overall limb alignment can be determined by several anatomical factors. In particular, three anatomical features around the knee would mainly contribute overall limb alignment, namely the femoral condylar orientation, the tibial plateau inclination, and the knee joint space tilt angle. As mentioned above, HTO influences the contributing portion of the tibia to varus limb alignment, thus an attempt to achieve slight valgus alignment, namely slight overcorrection, only with HTO may result in abnormal joint line orientation, which, in theory, affects the knee kinematics adversely. Thus, overcorrection more than the target angle could increase the chance of abnormal joint line orientation and abnormal knee kinematics.

Another unestablished issue is a change of knee joint space tilt angle by HTO. As varus malalignment increases adduction moment of the knee, knees with significant varus malalignment can have increased opening of lateral knee joint space which leads to increase knee joint space tilt angle. Correction of varus malalignment by HTO would eliminate increased adduction moment, and thus may reduce the knee joint space tilt angle. Therefore, if the potential change of knee joint space tilt angle after HTO is not considered, postoperative alignment can be differ from the preoperative planning, which may result in unexpected overcorrection of the alignment.

Historically, undercorrection or loss of correction had been a major issue in the field of HTO, particularly open-wedge HTO. However, coupled with recent improvement of fixator, such as locking plate, surgical technique and planning method, loss of correction after open-wedge HTO seems to become a minor problem. Rather, we anecdotally observed that unexpected overcorrection become more prevalent recent days. Traditionally, the cable method using a radiopaque line or a metal rod has been popular for the determination of correction in HTO as it allows real-time monitoring of the mechanical axis during surgery. However, the results can deviate due to non-weight bearing status and the influence of limb rotation during osteotomy. And it can increase radiation exposure during evaluation of the hip and ankle centers. Accordingly, preoperative planning using full-length weight bearing lower limb radiographs has recently been introduced for calculation of the correction angle and gap in weight bearing status using a picture archiving and communication system (PACS) or special software. But, even though planning method, typically Dugdale method(26) and Miniachi method(27) has been established for estimation of the target angle for HTO, final alignment may differ from the preoperative planning when overlooking the potential change of the joint space tilt angle.

Therefore, we aimed 1) to assess 3 major variables [femoral condylar orientation (FCO), tibia plateau inclination (TPI) and knee joint space tilt angle (JTA)] which would mainly contribute to overall limb alignment in patients undergoing medial open-wedge high tibial osteotomy(HTO) and compare the variables with those of normal knees, 2) to assess the changes of the 3 variables after HTO, and to compare the actual correction amount with the amount computed based on the two planning methods (Dugdale and Miniach methods), 3) to find the factors associated with the amount of JTA changes, and 4) to find factors associated with categories of final alignment after HTO.

Materials and Methods

Subjects

For this comparative study, we developed one experimental group and one control group including the HTO group and the normal knee group, respectively. To enroll the subjects in the HTO group, we reviewed prospectively collected database of 102 consecutive open wedge HTO by one surgeon in two center between January 2008 to February 2015. Of these, a total of 36 knees were excluded for having a diagnosis of other than primary osteoarthritis (OA), or a history of infection. Finally 66 patients undergoing open wedge HTO due to primary varus knee OA(44 patients) or posterolateral rotatory instability with varus malalignment(22 patients) were left. There were 54 women and 12 men with a mean age of 53.5 years(range : 28 years to 73 years) and a mean body mass index (BMI) of 26.8 kg/m^2 (range: 20.2 kg/m^2 to 35.0 kg/m^2).

Then, the normal control group was developed for comparison with the HTO group. The normal knee group included the contralateral normal knees of 160 consecutive patients (80 men and

80 women) undergoing unilateral arthroscopic surgeries due to traumatic meniscal injuries. The mean age and BMI of the normal knee group were 38 years (range: 16 to 64) and 24.2 kg/m^2 (range: 16.6 to 37.4), respectively. The study had ethical approval, and each patient was given informed consent.

Radiographic evaluation

Radiographic evaluations were performed using pre- and postoperative standing full limb anteroposterior (AP) radiographs in the HTO group while using preoperative standing full-limb AP radiographs in normal knee group. In the HTO group, we used postoperative radiographs taken at 1 year or 2 years after HTO. All the radiographs were taken on 14 X 51 inch grid cassettes to ensure that patella was facing directly anterior. All radiographic images were digitally acquired using a picture archiving communication system (PACS). Assessments were performed on a 24-inch LED monitor (U2412M: Dell, Round Rock, TX) in portrait mode using PACS software (Infinite, Seoul, Korea). This software package allows the investigator to detect the bisecting point of any area on the femur or tibia, and to measure the angle between any two lines drawn on the digital image. The minimum detectable changes by the software were 0.1° in angle and 0.1 mm in length measurements.

In all the radiographs, five parameters were measured; mechanical tibiofemoral angle (TFA), weight loading line (WLL) and 3 anatomical parameters, namely, the femoral condylar orientation, the tibial plateau inclination, and the joint space tilt angle. Mechanical TFA was defined as the angle formed by the intersection between the mechanical axis of the femur (the line from the femoral head center to femoral intercondylar notch center) and 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 alignment (Fig 1A). The tibial plateau inclination was defined as the angle between the mechanical axis of the tibia and the tangent to the subchondral plate of the tibia, and a negative value was given in varus orientation (Fig 1B). The femoral condylar orientation was defined as the angle between the mechanical axis of the femur and the tangent to the subchondral plates of both femoral condyles, and a negative value was given in varus orientation (Fig 1C). The joint space tilt angle 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, and a positive value was given to the knee in more lateral space opening (Fig 1D).

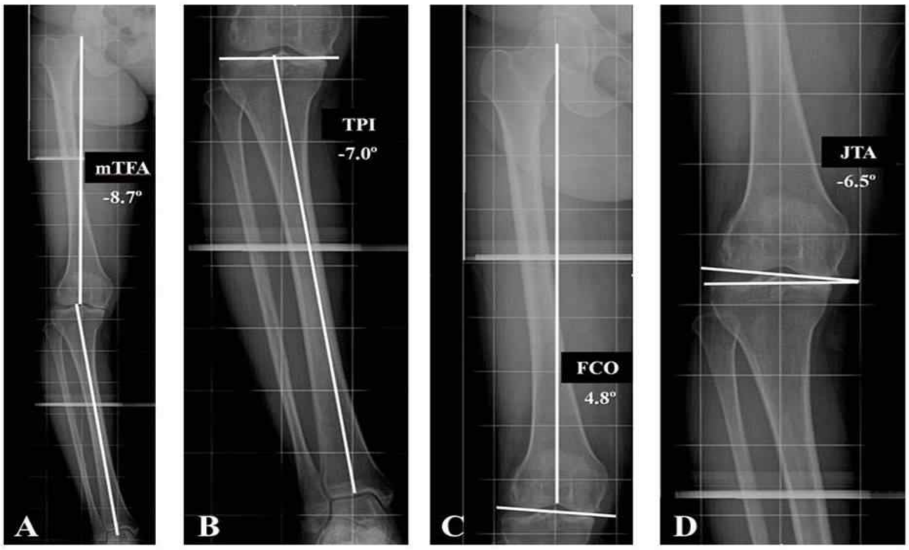

Figure 1A. Mechanical TFA(mTFA) was defined as the angle formed by the intersection between the mechanical axis of the femur(the line from the femoral head center to femoral intercondylar notch center) and the tibia(the line from ankle talus center to the center of the tibia spine tips). A negative value was given to the knee in varus malalignment.

Figure 1B. The tibial plateau inclination(TPI) was defined as the angle between the mechanical axis of the tibia and the tangent to the subchondral plate of the tibia, and a negative value was given in varus orientation.

Figure 1C. The femoral condylar orientation was defined as the angle between the mechanical axis of the femur and the tangent to the subchondral plates of both femoral condyles, and a negative value was given in varus orientation.

Figure 1D. The joint space tilt angle(JTA) 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, and a positive value was given to the knee in more lateral space opening.

For the preoperative planning, we calculated the target angle using Dugdale method(26) and Miniachi method(27), respectively, even made target angle following to Dugdale method. According to the Dugdale method(26), the objective of the osteotomy is to transfer the load from the medial region to the lateral plateau, in a position corresponding to 62% of the tibial joint surface. On the AP radiographs, a line is drawn on the X-ray on the tibial joint surface, setting a point "A" in the lateral compartment at the site corresponding to 62% of that are from medial to lateral. A second line is then drawn from the center of the femoral head to point "A" and another line from the center of the ankle to point "A". The acute angle(X°) formed by the intersection of these two lines determines the angle correction(Fig. 2A). According to the Miniachi method, a line is drawn from the planned position of the medial corticoperiosteal hinge to the center of the ankle joint. And a second line is drawn for the projected mechanical axis that passes from the center of the femoral head through a point 30-40% of the width of the lateral tibia plateau and is extrapolated to the level of projected position of the ankle. A third line is then drawn from the medial corticoperiosteal hinge (because this is the pivot point) to the projected position of the center of the ankle. The first and third lines thus subtend an angle(X°), which is the desired angle of correction.(Fig. 2B)

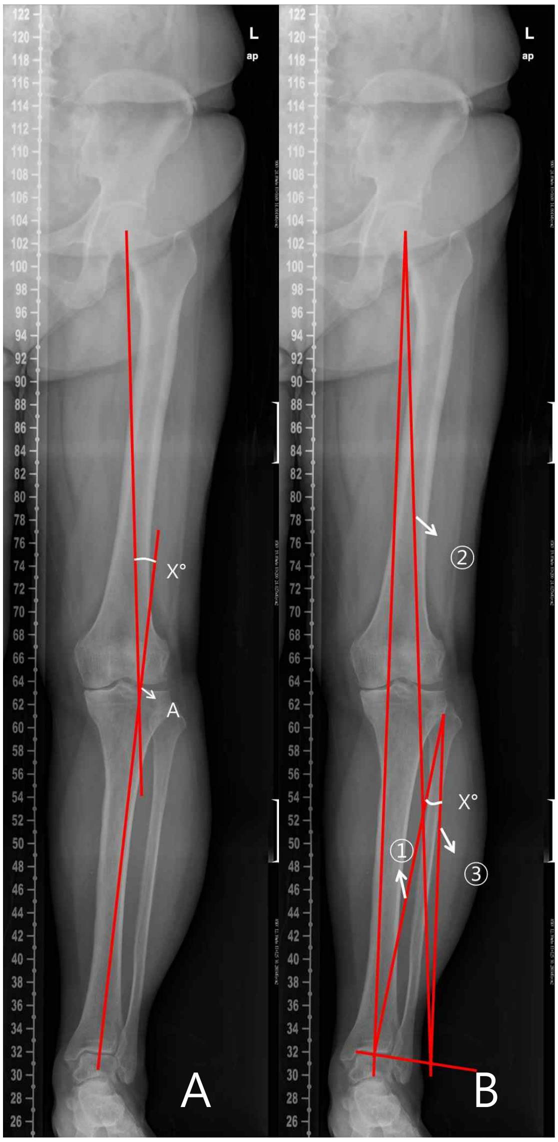

Figure 2A. Application of Dugdale method for preoperative planning(Left)

Figure 2B. Application of Miniachi method for preoperative planning(Right)

We defined postoperative status as acceptable correction if the difference from the target angle was 5% or less, under−correction in case the difference from the target angle was less than 5% and over−correction in case that angle difference was more than 5%(28).

To determine intra− and inter−observer reliabilities of radiographic assessments, two orthopedic surgeon performed radiographic assessments in 20 randomly selected knees twice with an interval of 3 week. The intra−and inter−observer reliabilities of assessments of all radiographic measurements were evaluated using intraclass correlation coefficients (ICCs). The ICCs of intra− and inter−observer reliabilities of all measurement showed highly satisfactory reliability (range: 0.89 − 0.98). Thus, measurements taken by a single investigator (one of the authors) were used in the analyses.

Surgical technique

A longitudinal skin incision, approximately 6cm in length, was made over the pes anserinus insertion at the anteromedial aspects of the tibia. The medial aspect of the proximal tibia was exposed by elevating the insertion of the pes anserinus, gracilis tendon, semitendinous muscle tendon, and the superficial layer of the medial collateral ligament. The neurovascular structures underlying the knee joint were protected by retracting them with a blunt retractor. Two Kirschner wires were inserted into the tibia as an osteotomy was performed. First, an osteotomy was performed in the frontal plane, from 5 mm proximal to the insertion of the patellar tendon to the second osteotomy plane, maintaining a tibial tubercle thickness of approximately 10 mm. The osteotomy in the second plane was initiated at the medial cortical margin approximately 5 cm distal from the tibial plateau and stopped at a distance of approximately 5 mm from the lateral cortical margin, targeting at the proximal one-third part of the fibular head. With the help of an image intensified, the osteotomy line was gradually opened to the axis on the lateral cortex by the stepwise insertion of a set of five chisels. The posteromedial gap distance was measured to confirm the predicted opening width while the gap was temporarily fixed using a bone spreader. The posteromedial gap distance was measured to confirm the predicted opening width using a bone spreader, which was inserted into the tibia as close to the coronal plane as possible with the patella face upright. The medial osteotomy site was then rigidly fixed using a TOMOFIX Osteotomy system (Depuy Synthes, Switzerland) over the osteotomy site(29).

Statistical analysis

All the statistical analyses were carried out with SPSS for Windows version 20.0 (SPSS Inc., Chicago, Illinois), and p-values < 0.05 were considered significant throughout. Comparisons of values of the three anatomical parameters and amounts of their contributions to overall mechanical TFA were carried out using analysis of student t-test. Changes in the proximal tibia inclination and the knee joint space tilt angle between pre- and post-HTO were calculated and examined using paired t-test. The factors associated with amount of joint space tilt angle changes by HTO were investigated by use of the multivariate regression analyses with stepwise method. The factors evaluated were preoperative mechanical TFA and preoperative values of the three anatomical parameters, height and weight as covariates. Multiple regression analysis results were summarized by use of standardized coefficients, that is, β-coefficients, *P* values, and coefficients of determination (R^2). The factors associated with over-correction were investigated by use of logistic regression analysis. The factors evaluated were age, BMI and preoperative value of the anatomical parameters (M-TFA, TPI, FCO and JTA). Logistic regression analysis results were summarized by use of odds ratio and p-value.

Results

Comparison between two groups showed significant differences in the value of alignment parameters, more varus in HTO group (Table 1). In the evaluation of the alignment parameters change, naturally, there were significant differences between preoperative and postoperative in the value of m−TFA, TPI and WLL. But, there were also significant change in JTA which we did not intend to correct (Table 2).

Among sixty−six patients, 19 patients (28.8%) showed change of joint tilt angle more than 3˚ (Fig. 3). After HTO, the tibial plateau inclination increased by 8.9˚ aand the joint space tilt angle decreased by 2.0° on average, which resulted in 11.1° changes of mechanical TFA on average. When comparing the target angle according to the method of preoperative planning method, there were significant difference between Dugdale and Miniachi methods, respectively 8.6° and 9.7°(p−value = 0.028). The mean correction angle was 8.9° which was closer to Dugdale method.

Multivariate regression analyses revealed that the greater preoperative joint tilt angle and more severe varus preoperative TFA were significantly associated with a greater postoperative decrease in the joint space tilt angle after HTO (β = −0.20, p = 0.006 and β = −0.28, p = 0.001, respectively; R^2 for regression model = 0.361). Surgical target (within 5% from the target WLL) was achieved in 37 knees (56%). However, 29 knees (44%) were overcorrected (more than 5% valgus from the target WLL) and there were no knees under corrected. There were no significant difference between acceptable and over correction groups in patients' demographics and parameters of anatomical alignments. But, the change of joint tilt angle differed significantly between two groups (respectively 1.5° and 3.0°, p<0.001) (Table 3).

Conditional logistic regression analysis showed that an increased incidence of overcorrection was associated with the amount of JTA changes (odds ratio=3.04, p−value =0.002).

Table 1. Comparison of mechanical tibiofemoral angle(TFA) and three anatomical parameters between two groups.

	Group		p-value
	HTO(n=66)	Normal(n=160)	
M-TFA(degree)	−8.8°(SD=2.8)	−2.2°(SD=3.2)	<0.001
FCO(degree)	1.3°(SD=2.0)	3.1°(SD=2.6)	<0.001
TPI(degree)	−5.9°(SD=2.1)	−4.0°(SD=2.5)	<0.001
JTA(degree)	4.1°(SD=2.3)	1.2°(SD=1.7)	<0.001

*Abbreviations

M-TFA : Mechanical tibiofemoral angle

FCO : Femoral condylar orientation

TPI : Tibia plateau inclination

JTA : Joint tilt angle

SD : Standard deviation

Negative values means varus angle in three parameters (M-TFA, FCO, TPI, JTA)

Positive values means varus angle in joint tilt angle

Table 2. Comparative results of the mechanical tibiofemoral angle(TFA), weight loading line(WLL), the tibial plateau inclination(TPI) and knee joint space tilt angle(JTA) before and after high tibial osteotomy(HTO)

Parameters	Pre-HTO	Post-HTO	Diff.	p-value
WLL(%)	10.9%	63.2%	52.3%(SD=14.6)	<0.001
M-TFA(degree)	-8.8°	2.7°	11.1°(SD=3.2)	<0.001
TPI(degree)	-5.9°	3.4°	8.9°(SD=0.4)	<0.001
JTA(degree)	4.1°	2.1°	2.0°(SD=0.2)	<0.001

*Abbreviation

SD(standard deviation)

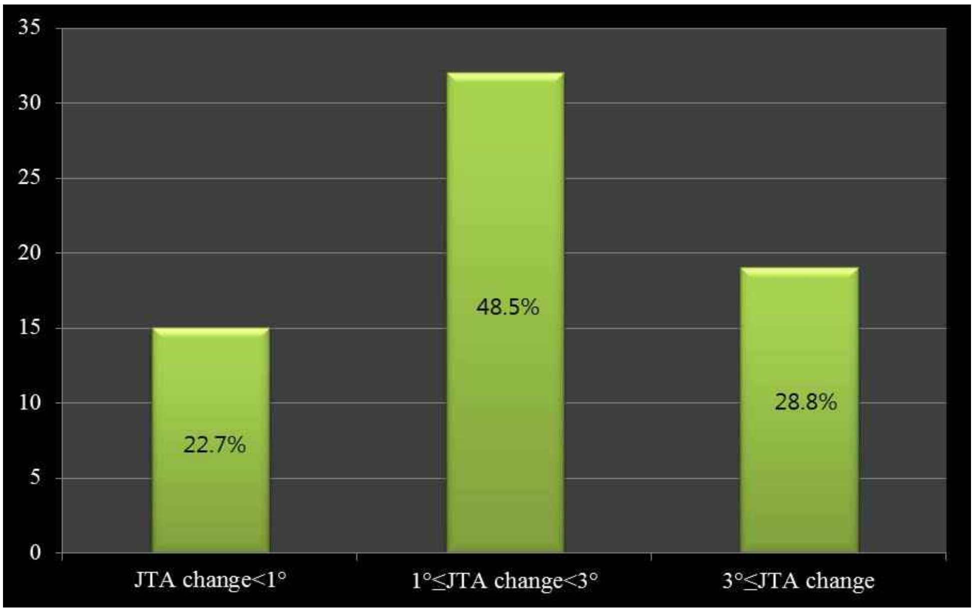

Figure 3. Frequency according to the change in angle of the joint surface(%)

Table 3. Comparison of patients' demographics and alignment parameters between acceptable−correction and over−correction group

Parameters	Acceptable−correction(n=37)	Over−correction(n=29)	Difference	p−value
Age(years)	53.7(SD=7.9)	53.3(SD=4.9)	0.4	0.788
BMI(kg/m2)	27.4(SD=3.9)	26(SD=2.8)	1.4	0.108
M−TFA(degree)	−8.5°(SD=2.4)	−9.1°(SD=3.3)	0.6°	0.383
WLL(%)	12.4%(SD=9.8)	9.1%(SD=13.6	3.3	0.257
FCO(degree)	1.3°(SD=1.9)	1.2°(SD=1.9)	0.1°	0.788
TPI(degree)	−6.1°(SD=2.2)	−5.5°(SD=2.0)	0.6°	0.279
JTA(degree)	−3.7°(SD=2.3)	−4.5°(SD=2.3)	0.8°	0.183
Post−MTFA(degree)	2.1°(SD=2.4)	2.8°(SD=3.5)	0.7°	0.313
Post−FCO(degree)	1.3°(SD=1.9)	1.2°(SD=1.9)	0.1°	0.788
Post−TPI(degree)	2.9°(SD=2.9)	3.1°(SD=3.0)	0.2°	0.792
Post−JTA(degree)	−2.1°(SD=2.0)	−1.5°(SD=1.9)	0.6°	0.174
Post−WLL(%)	60.8%(SD=5.5)	66.4%(SD=9.8)	5.6	0.009
JTA	1.5°(SD=1.4)	3.0°(SD=1.6)	1.5°	<0.00

Discussion

Open wedge HTO is becoming more popular as precise and valuable realignment procedure for relatively younger patients with symptomatic varus knee OA or lateral thrust.(6) Accurate correction of limb alignment is very important to achieve satisfactory clinical outcomes after HTO.(8, 9) But, all patients who undergo HTO do not achieve adequate correction, despite careful surgical techniques, because of the narrow goal of limb alignment correction. Limb alignment correction errors, including undercorrection and overcorrection, are due to inaccurate preoperative planning of correction amount and inappropriate intraoperative correction as planned due to lack of reliable tool to assess limb alignment during surgery.(30-33) In addition, this procedure purely changes the geometry of the proximal tibia. Therefore, abnormal knee joint line inclination, i.e. valgus inclination of joint line, can be made after the procedure. In particular, if HTO was performed to a patient whose varus malalignment did not mainly stem from proximal tibia, this valgus inclination of the knee joint becomes more significant. Furthermore, because of reduced adduction moment around the knee joint after HTO, changes of joint space tilt angle can occur, which would affect postoperative limb alignment. So, we sought to address these issues in HTO.

In this study, we compared the normal knee group with HTO group, and all the 3 parameters are more varus. Particularly JTA was more than 3 fold of those in normal knee. Besides the change of TPI, JTA was also decreased by 2 degree after HTO. In normal patients, the articular surface of the distal femur is parallel to the tibia plateau, with JTA ranging from 0° to 2°.(34) The amount of JTA change would be larger in patients with more varus alignment and larger JTA, preoperatively. The parallel JTA differed in patients with medial osteoarthritis because of the pseudolaxity of the lateral side with varus alignment, resulting from substantial amounts of intra-articular cartilage and subchondral bone loss in the medial compartment.(35) JTA is more likely to be restored to a parallel position after than before HTO, because the pseudolaxity of the lateral side could disappear due to valgus alignment following HTO.(28)

In comparison between Dugdale and Miniachi method, the correction amount computed by Miniachi method was significantly larger than that of Dugdale method. Historically, bony configurations were measured with caliper(36) and osteotomy correction were judged by eye(37), later John Insall advised against this practice(38). The early application of radiographs for HTO planning was restricted to short knee films(39), but later Harris recognized the benefit of long-leg weight-bearing films(40). Preoperative planning became increasingly important because the degree of correction influenced HTO longevity(41). Planning methods have been described using the anatomical or mechanical axes. Alternatively, planning methods that employ MiKulicz's weight-bearing line are advantageous because the surgeon can appreciate the point of mechanical loading in relation to the known degenerative condition of the knee. Miniaci's method of planning was broadly used for this reason. Miniachi's original description is a lateral closing wedge osteotomy, geometrically planned using the weight-bearing line of Mikulicz. However, the principle of an angle generated at the hinge point subtending the current and proposed ankle centers is readily applicable to an opening wedge osteotomy. Even though, Miniach methods is theoretically more sound, correction based on that method could result in overcorrection when JTA is not considered. But, in this study, correction amount was almost identical with that computed by Dugdale method, 44% of the patients were overcorrected without case of undercorrection. We thought that if we followed the Miniachi method, there could be more cases of overcorrection. It was shown that amount of joint space tilt angle change was significantly higher in over-correction group with odds ratio of 3.04. Another retrospective observational study evaluating relationship between JTA and alignment correction errors also revealed that a greater difference pre- and postoperative JTA was associated with greater overcorrection of lower limb alignment.(28) So, we should consider joint space tilt angle change when performing HTO. But, until now, there is no method to consider it. So, we suggest Dugdale method as preoperative planning for HTO to minimize the risk of overcorrection. Eventually, further study would be required for the development of modified method which consider not only tibial inclination but also joint tilt angle change.

Conclusion

We found that three major variables determining overall coronal alignment was more varus in the HTO group than the control group. Particularly, JTA of the HTO group significantly contributed to the varus limb alignment, and the JTA decreased by 2° on average after HTO which could result in additional valgus realignment effect after HTO. Even though more preoperative varus alignment and more preoperative tilt of JTA were found to be associated with larger change of the JTA after HTO, accurate estimation of the JTA change may not be possible due to low R^2 value. Planning of target angle by Miniachi method showed significantly larger angle than that of Dugdale method. Therefore, if JTA change was not considered, Miniachi method could increase risk of overcorrection after HTO. Development of new method which could estimate the change of JTA more accurately would be warranted via further studies.

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국 문 초 록

배경

본 연구는 개방형 경골 근위부 절골술을 시행받는 환자에서 1) 관상면 하지 정렬에 기여하는 3가지 주요 변수를 평가하고, 2) 수술 후 3가지 변수의 변화 및 실제 교정 각도와 술 전 Dugdale 방법과 Miniach 방법을 이용하여 계산한 계획 각도의 차이를 비교하며, 3) 술 후 관절간격의 기울기의 변화 정도와 관련된 인자들을 분석하고, 4) 수술 후 하지의 최종 정렬 상태와 연관된 인자를 알아보고자 한다.

대상 및 방법

내측 개방형 경골 근위부 절골술을 시행받은 66명의 환자와 정상 대조군으로 160명의 환자를 대상으로 하여 연구를 진행하였다. 기립 전하지 전후면 방사선 사진을 이용하여 체중 부하선과, 원위 대퇴 경사도, 경골 고평부 경사도, 슬관절간격의 기울기를 측정하였고, 환자군에서 수술 전 상태와 수술 후 상태, 그리고 환자군에서 수술 전 상태와 정상 대조군의 상태를 비교하였다. 수술 후 슬관절간격의

기울기에 변화에 기여하는 인자들에 대해 분석을 시행하였다. 또한, 수술 전 Dugdale 방법과 Miniach 방법을 이용하여 교정각도를 계산하였고, 이를 실제 교정된 각도와 비교하였다. 수술 후 체중 부하선이 원래 목표했던 체중 부하선과의 차이가 5% 이내인 경우를 적절한 교정으로 보았고, 목표했던 체중 부하선에 비해 5% 이상 외반인 경우를 과교정, 5% 이상 내반인 경우를 저교정으로 정의하였으며, 이상교정된 경우에 이에 기여하는 인자들에 대해 분석하였다.

결과

정상 대조군과 비교하였을 때 3가지 변수가 환자군에서 모두 유의하게 내반되어 있었다. 특히 관절간격의 기울기는 대조군에 비해 3배가 넘는 차이를 보였다. (환자군: 4.1°, 대조군 : 1.2°, P<0.001) 수술 후에는 경골 고평부 경사도의 변화 외에도 관절간격의 기울기가 평균 2도 감소하였다. 수술 전 교정각도의 계산을 위한 Dugdale 방법과 Miniach 방법을 비교하였을 때, Miniachi 방법으로 계산한 교정각이 Dugdale 방법으로 계산한 값에 비해 유의하게 컸다.(각각 9.7° 와 8.6°, p = 0.028). 또한 실제 교정각도는 8.9°로 Dugdale 방법으로 계산한 값에 더 근접하였다. 관절간격의 기울기는 수술 전에 내반 정도가 클수록

그리고, 수술 전 관절간격의 기울기가 더 내반되어 있을수록 수술 후의 그 변화량이 더 큰 경향을 보였다(β = −0.19, p = 0.006 and β = −0.28, p = 0.001, respectively; R^2 for regression model = 0.361). 수술 후 정렬 상태를 평가하였을 때 총 29 명의 환자(44%)에서 과교정이 되었으며, 저교정된 환자는 없었다. 적절하게 교정된 군과 과교정된 군간에 인구학적 요소들과 하지의 정렬에 기여하는 해부학적 인자들에는 유의한 차이가 없었으나, 관절간격의 기울기의 변화량에는 유의한 차이가 있었으며, 과교정된 군에서 그 변화량이 유의하게 더 컸다(각각 1.5° 와 3.0°, p<0.001). 회귀분석을 시행하였을 때, 관절간격의 기울기 변화량이 클수록 과교정의 위험도가 유의하게 증가하였다(Odds ratio = 3.04, p = 0.002)

결론

본 연구에서는 대조군에 비하여 환자군의 3가지 주요 관상면 정렬 기여 변수가 모두 다 내반되어 있었으며, 특히 관절간격의 기울기가 환자군에서 내반 정렬에 상대적으로 큰 기여를 하고 있음을 알 수 있었다. 내측 개방형 경골 근위부 절골술 후에 관절간격의 기울기가 감소하여 결국 평균 2도의 추가적인 외반 교정효과가 발생함을 알 수

있었으며, 이는 수술 전 내반 변형의 정도와 관절간격의 기울기와 연관이 있었다. 하지만 추정 회귀식의 수정된 결정 계수 값이 낮아 관절간격 기울기 변화를 만족스럽게 예측할 수는 없었다. 수술 전 교정각도를 계산할 때 Miniachi의 방법으로 계산한 값이 Dugdale 방법으로 계산한 값보다 유의하게 컸으며, 이론적으로는 Miniachi 방법이 더 타당해 보이지만 관절간격의 기울기를 고려하지 않는 경우 과교정의 위험이 더 큰 것으로 사료된다. 따라서, 과교정의 위험성을 조금이나마 줄이기 위해서는 관절간격의 변화에 대한 고려가 필요하다. 향후 관절간격의 기울기의 변화를 보다 정확하게 추정할 수 있는 방법에 대한 연구가 필요할 것으로 사료된다.

주요어 : 경골 근위부 절골술, 개방형 절골술, 과교정, 관절간격

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