

# Comparison of Radiological and Clinical Efficacy of Normal and Overcorrected Varus Deformity After Medial Open Wedge High Tibial Osteotomy: A Two-Year Follow-up Investigation

Kui-shuai XU

The Affiliated Hospital of Qingdao University

Liang ZHANG

The Affiliated Hospital of Qingdao University

Rui SHEN

Affiliated hospital of Qingdao University

Jie SUN

Qilu Hospital of Shandong University Qingdao

Jian WANG

qingdao 971 Naval hospital

Xia ZHAO

the affiliated hospital of qingdao university

Yi ZHANG

affiliated hospital of qingdao university

Teng-bo YU (✉ [ytb8912@hotmail.com](mailto:ytb8912@hotmail.com))

The Affiliated Hospital of Qingdao University <https://orcid.org/0000-0003-1134-0134>

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## Research article

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## Abstract

**Objective** To study the clinical efficacy of over-correction of varus deformity 2 years after Open wedge High tibial osteotomy (OWHTO), and by using radiographic indicators, the compensatory changes of the hip, patellofemoral, and ankle joints were observed.

**Methods** Since February 2016, were retrospectively analyzed in August 2019 in our hospital during the period of treatment and included in the standard of 63 cases of patients with medial compartment osteoarthritis knee joint data, according to the postoperative measuring weight bearing line ratio (WBLR), rectify all patients were divided into normal group, 52 cases ( $50\% < \text{WBLR} < 67\%$ ) and excessive correct set of 11 cases ( $\text{WBLR} \geq 67\%$ ), Measured at the end of the two groups of patients with preoperative and follow-up sessions Hip-knee-ankle angle (HKA), medial proximal tibial angle (MPTA) and lateral distal femoral angle (LDFA), joint line convergence Angle (JLCA), Posterior tibial slope (PTS) after evaluating the effect of postoperative lower limb power line correction, measurement of Hip abduction angle (HAA), tibial plafond inclination (TPI), Talar inclination Angle (TIA), Carton index, Lateral patellar tilt (LPT), Lateral patellar shift (LPS), medial patellofemoral space, and lateral patellofemoral space were used to evaluate the postoperative compensatory changes of the adjacent joints in the two groups. The American Hospital for Special Surgery score (HSS), The Western Ontario and McMaster University Osteoarthritis Index (WOMAC) for the patients with knee arthrosis before and at the last follow-up, and the incidence of complications in patients at the last follow-up.

**Results** In the over-corrected group, the postoperative WBLR averaged ( $74.43 \pm 4.05$ ) %, with 4 cases (36.36%) of postoperative complications, while in the normal corrected group, the postoperative WBLR averaged ( $55.76 \pm 4.88$ ) %, with 6 cases (11.54%) of complications. The difference in postoperative complications between the two groups was statistically significant ( $P = 0.041$ ). After OWHTO HKA compare two groups of patients at the end of the time, ( $7.39 - 1.61$ ) ° for excessive correction group, ( $3.28 - 1.59$ ) ° for normal correction group, difference was statistically significant ( $P = 0.000$ ), compared two groups of patients at the end of the second MPTA, excessive correction group is ( $94.95 + 1.01$ ) °, ( $91.1 - 2.87$ ) ° for normal correction group, difference was statistically significant ( $P = 0.001$ ), compared two groups of patients at the end of the time HAA, excessive correction group is ( $2.96 + 1.58$ ) °, normal correction for ( $0.97 + 2.31$ ) °, The difference was statistically significant ( $P = 0.026$ ), while the comparison of other imaging indicators showed no statistically significant difference. The results of surgical correction of the two groups were satisfactory, and the differences in the score of American Hospital for Special Surgery and the osteoarthritis index of The Western Ontario University and McMaster University were significant compared with those before surgery in the last follow-up ( $P < 0.05$ ), and there was no statistical difference between the two groups in the last follow-up.

**Conclusions** Overcorrection of varus deformity (postoperative WBLR  $\geq 67\%$ ) did not affect the clinical outcome within 2 years after OWHTO, but increased the incidence of postoperative complications and resulted in increased compensatory adduction of the hip joint.

## 1. Introduction

Open wedge high tibial osteotomy (OWHTO) has become a common treatment for medial compartment arthritis of the knee in recent years [1-4]. The key factor for the long-term success after OWHTO is the transfer of the lower limb line and load-bearing axis to the outside, so as to achieve the uniform distribution of knee mechanical load [2,11,12]. The selection of force line correction point is the key to this operation. It has been reported that the force line after surgical correction can obtain the best effect by Fujisawa point, which is 62.5% point on the lateral tibial plateau [3,9,26]. For patients with severe varus deformity of the knee, intraoperative osteotomy Angle needs a lot of correction, according to the multiple stages of knee osteoarthritis, according to different degrees of degeneration of the medial interventricular cartilage injury of the knee, the implementation of different force line orthopedic programs. After the follow-up found that some patients OWHTO exists in lower limb power line corrective postoperative WBLR (67% or higher), to evaluate the short-term clinical efficacy and postoperative complications in patients with such and adjacent joint compensatory changes, therefore, this study by imaging and related clinical function score, to explore the diagnosis and treatment OWHTO excessive correct varus deformity the short-term curative effect of the medial compartment knee osteoarthritis. Until now, compensatory changes in hip, patellofemoral and ankle joints after OWHTO overcorrected varus deformity have been rarely studied.

The purpose of this study was to assess whether overcorrection of varus malformation affects early clinical outcomes after OWHTO and to assess compensatory changes in the hip, patellofemoral, and ankle joints. We hypothesized that due to compensatory changes in hip and patella positions and ankle joints, some degree of overcorrection would not adversely affect clinical outcomes after OWHTO.

## 2. Materials And Methods

A retrospective analysis was performed on 92 patients with osteoarthritis who underwent initial unilateral OWHTO in Affiliated Hospital of Qingdao University from February 2016 to August 2019. Inclusion criteria were as follows: Clinical diagnosis was consistent with early anterior medial compartment osteoarthritis of knee; The follow-up time was at least 1 year. No neuromuscular disease; X-ray examination of the knee joint showed clear structure; Accompanied by varus genus deformity <15°(proximal tibia deformity mainly), flexion contracture <10°; The range of motion of the knee is >110°. Exclusion criteria: osteoarthritis or inflammatory arthritis in the lateral compartment of the knee; The follow-up time was less than 1 year. OWHTO was performed at the same time as other joint operations; OWHTO was performed on both sides. Incomplete imaging data and missing persons; Knee ligament injury or functional insufficiency; Corrective insufficiency (WBLR≤ 50%); A total of 22 patients were excluded from the study according to the exclusion criteria. Among them, there were 5 patients who received bilateral OWHTO, 7 patients with postoperative loss, 8 patients with incomplete imaging data, and 9 patients with corrective insufficiency (WBLR < 50%). Therefore, the final study consisted of 63 patients with an average age of (58.32±5.26) years old, including 12 males and 51 females. According to postoperative WBLT, the patients were divided into the following two groups: 52 patients in the normal correction group (50%

$\leq$ WBLR < 67%) and 11 patients in the over-correction group (WBLR $\geq$  67%). The radiological index measurement, complications and functional recovery of affected limb were compared between the two groups after OWHTO operation. Preoperative and postoperative imaging indexes of all patients were measured by the same person for 3 times at different time periods to reduce errors, and then the mean value was taken. All operations were performed by the same senior medical officer. All patients agreed to participate in this study and signed informed consent, and the study plan was approved by the ethics Committee of our hospital.

## 2.1 Operative technique

All patients were in supine position during the operation under general anesthesia. Tourniquet was routinely used at the root of the operative side thigh. A longitudinal incision of 6-8cm was made along the medial proximal tibia and gradually exposed to the foot of the goose. Two 3.0mm kirschner needles were inserted horizontally toward the upper tibiofibular joint on the outer edge of the tibia, and the direction of kirschner needles was the same as the retrograde direction of the tibia. The ascending and horizontal planes of biplane osteotomy were at an Angle of about 110°. After the completion of osteotomy, the osteotomy Angle needed to be corrected was determined according to the preoperative lower extremity line, and the osteotomy space was opened with bone knife and retainer, so as to avoid lateral cortical fracture by careful operation. After c-arm fluoroscopy showed satisfactory force lines, TomoFix locking plate was used for fixation, and tranexamic acid injection was administered 20min before surgery. The tourniquet is also applied locally before completion of suturing.

## 2.2 Postoperative rehabilitation

After surgery, the affected limb was lifted, all patients were pressurized with elastic bandage, the drainage tube was clamped for 4 h after surgery, and then drainage was opened. Drainage could be removed if the postoperative drainage volume was less than 50mL.Antibiotics and anticoagulant drugs were used in a standardized manner within 24 hours after the operation. Quadriceps femur exercise and ankle pump exercise were performed within 24 hours after the operation. Partial weight-bearing walking with crutches was performed within 6 weeks after the operation, and full weight-bearing walking was performed after gradually abandoning crutches. The patient was followed up on time after discharge.

## 2.3 Clinical Assessment

All patients received preoperative and final knee functional follow-up: ☐The American Hospital for Special Surgery score (100 points) : pain 30 points, function 22 points, activity 18 points, muscle strength 10 points, flexion deformity 10 points, stability 10 points and subtractive items; the higher the score, the better the function; ☐The Western Ontario and McMaster University Osteoarthritis Index: a 0-4 grading method is used to evaluate 5 aspects of pain, 2 aspects of stiffness, and 17 aspects of difficulty in daily activities. A higher score means a worse function. The motion range of the knee was measured using a long arm goniometer. All patients were followed up for at least 1 year, and postoperative complications including subcutaneous congestion, neurovascular injury, lateral hinge fracture, infection, deep venous

thrombosis of the lower extremity, delayed or nonunion, and joint stiffness were obtained through outpatient review and telephone follow-up.

## 2.4 Radiological assessment

Radiological measurements included Hip-knee-ankle angle (HKA), Weight-bearing line ratio (WBLR) medial proximal tibial angle (MPTA) lateral distal femoral angle (LDFA), joint line convergence Angle (JLCA), Posterior tibial slope (PTS) Hip abduction angle (HAA), tibial plafond inclination TPI, Talar inclination Angle (TIA) ,Carton index, Lateral patellar tilt(LPT), Lateral patellar shift (LPS), medial patellofemoral space and lateral patellofemoral space PTS were measured using knee lateral radiographs. LPT, LPS, Carton index, and medial patellofemoral space and lateral patellofemoral space were measured using patella 30° axial radiographs, and other radiological parameters were measured using full-length loaded radiographs of the lower extremities. HKA is the included Angle (varus, negative value) formed between the mechanical shaft of the femur and the mechanical shaft of the tibia (**Fig. 2A**). WBLR was defined as the horizontal distance between the load bearing line and the medial edge of the tibial plateau divided by the width of the tibial plateau (**Fig 2B**). PTS is defined as the Angle between the proximal tibial central anatomical axis and the tangent of the tibial plateau (**Fig 2C**). JLCA was defined as the Angle between the tangent of the femoral condyle and the tibial plateau, and the positive value of JLCA represented the opening of the lateral joint (**Fig. 3A**). MLDFA is defined as the lateral Angle formed between the mechanical shaft of the femur and the tangent of the femoral condyle (**Fig. 3B**). MPTA is the medial Angle formed between the mechanical shaft of the tibia and the tangent of the tibial plateau (Fig 3C). TIA is defined as the included Angle between the articular surface of the talus and the horizontal line, and the varus is positive [11] (**Fig 4A**). TPI is the Angle between the tangent and the horizontal of the distal tibia, and varus is positive (**Fig.4b**). HAA is the included Angle between the mechanical shaft of femur and the straight line perpendicular to the ground, and abduction is defined as positive value [14] (**Fig. 4C**). LPT is the Angle formed by the line between the highest point of the internal and external condyles of the femur and the extension line of the maximum transverse diameter of the patella (**Fig.5A**). LPS was defined as a straight line drawn from the highest point of the internal and external condyle of the femur, the measured distance was B, and the lateral edge of the patella was perpendicular to the line (**Fig.5B**). Make a vertical line through the highest point of the lateral condyle of femur, and the distance between the two perpendicular lines is a, then  $LPS = A/B$ . Medial and lateral interspaces of patellofemoral joints [16] are the distance from the center of the joint surface to the patella by drawing vertical lines to measure the medial and lateral interspaces of patellofemoral joints (**Fig 5C**). The Carton index is the ratio of the distance between the lower pole of the patella joint surface and the anterior upper Angle of the tibia plateau to the length of the patella joint surface. The normal value is 0.6~1.2(**Fig. 5D**).

## 2.5 Statistical analysis

Statistical data were analyzed by SPSS 25.0 software. Normal distribution was detected for the two groups of data, and the measurement data in line with normal distribution was expressed as mean  $\pm$

standard deviation. Comparison of measurement data using T test or non-parametric test; Statistical data were measured by chi-square test, and the difference was statistically significant at  $P \leq 0.05$ .

## 3. Results

### 3.1 General patient information and radiological parameters

According to the inclusion and exclusion criteria, 63 patients finally participated in this study. According to postoperative WBLT, 52 patients in the normal correction group ( $50\% \leq WBLR < 67\%$ ) and 11 patients in the over-correction group ( $WBLR \geq 67\%$ ) were divided into the following two groups, as shown in Figure 1.63 patients for at least 12 months of follow-up, excessive correct group and normal correction for age, sex, side, body mass index, duration, operation time, bone cutting Angle, and follow-up time knee K - L grade, specific data are shown in **table 1**, 2 set of preoperative tibiofemoral Angle, proximal tibial medial Angle, the U.S. special surgical hospital ratings, WOMAC osteoarthritis index there was no significant difference compared with significance ( $P > 0.05$ ), which is comparable. See **Table 2-4 and Table 6** for the specific data of each group.

### 3.2 Comparison of postoperative radiological parameters between the two groups

After OWHTO, the last HKA was compared between the two groups. The overcorrected group was  $(7.39 \pm 1.61)^\circ$ , and the normal corrected group was  $(3.28 \pm 1.59)^\circ$ , with statistically significant difference ( $P=0.000$ ). The last MPTA of the two groups was  $(94.95 \pm 1.01)^\circ$  in the overcorrected group and  $(91.1 \pm 2.87)^\circ$  in the normal corrected group, and the difference was statistically significant ( $P=0.001$ ). Comparison of the last HAA between the two groups showed that the overcorrected group was  $(-2.96 \pm 1.58)^\circ$  and the normal corrected group was  $(-0.97 \pm 2.31)^\circ$ , with statistically significant difference ( $P=0.026$ ). The degree of postoperative correction of TPI and TIA in the over-corrected group was higher than that in the normal corrected group, but the difference was not statistically significant ( $p > 0.05$ ). The comparison of other imaging indicators showed no statistically significant difference. The results are shown in **Table 2-4**.

### 3.3 Comparison of postoperative complications between the two groups

Excessive correct set of postoperative complications occurred in 4 cases, including 1 case with subcutaneous ecchymosis large area, delayed union of fracture in 1 case  $\pm$  1 case incision infection, 1 cases of lateral hinge fracture, the incidence of 36.36% $\pm$ Normal correct set of 6 cases of postoperative complications, including 1 case with subcutaneous ecchymosis large area, stiff joints in 1 case, fracture healing, 1 case of incision infection, 1 case, the lateral hinge fractures in 2 cases, the incidence of 11.54%, compared two groups of postoperative complications, difference was statistically significant ( $p = 0.041$ ). For complications, none of the patients underwent a second operation, and after active conservative treatment, all of the patients recovered from these complications. Therefore, we believe that these complications are not related to the final clinical efficacy, as shown in **Table 5**.

### **3.4 Postoperative clinical results were compared between the two groups**

At the last follow-up, the hospital score of American Special Surgery in the 2 groups was significantly increased compared with that before surgery, with significant difference ( $P < 0.05$ ), and WOMAC osteoarthritis index was significantly decreased compared with that before surgery, with significant difference ( $P < 0.05$ ). There was no significant difference between the hospital score of special surgery and WOMAC osteoarthritis index in the 2 groups ( $P > 0.05$ ). Shown in **table 6**.

## **4. Discussion**

Medial open wedge high tibial osteotomy is generally suitable for patients with medial compartment osteoarthritis of the knee and is an effective joint conservative treatment method [3,4,9]. New alignment of lower limb weight-bearing machinery axle weight is an important determinant of clinical efficacy after medial tibial high osteotomy [5]. Accurate line-of-force correction is the key to the success of OWHTO, and the control of orthopedic Angle is an important risk factor affecting prognosis [6]. Fujisawa et al. [3] believed that when the lower limb line passed through the tibial plateau 60% to 70% after surgery, cartilage damage would not progress, and cartilage growth was the best at 62.5%. Dugdale et al. [7] suggested that the force line after osteotomy should pass through the area near 60% of the lateral tibial plateau on the coronal plane. In order to obtain a better long-term effect, Myrnerts [8] found in the study on the optimal correction of varus deformity in high tibial osteotomy that between 3 and 7 degrees of orthotopic valgus (three-point technique) can lead to the optimal subjective evaluation of the results by patients. Recently, scholars have also confirmed through the finite element analysis of knee joint that the lower limb force line near 62.5% of the medial side of knee joint can obtain the minimum difference in area and pressure value of stress concentration area in the medial and lateral compartment of knee joint, and can obtain a more uniform distribution of force on the tibial surface [9]. Lee analyzed that in 34 patients undergoing medial open wedge high tibial osteotomy, the changes in JLCA may be greater in patients with underlying medial relaxation or severe varus deformity requiring greater correction, which may lead to accidental overcorrection of HTO [10]. In this study, the imaging changes and clinical efficacy of OWHTO in overcorrection of varus deformity were studied in patients with excessive lateral displacement of lower limb bearing axis after surgery.

Respectively from two groups of patients in this study TPI (6.23-3.9) ° and preoperative (5.29 + 5.75) ° down to the last follow-up (0.74 + 5.4) ° and (2.46-4.33) °, TIA, respectively from the preoperative (8.3-4.3) ° and the (5.75 + 6.05) ° down to the last follow-up (1.95 + 5.71) ° and (2.81-4.62) °, differences were statistically significant ( $p < 0.05$ ), and further verified the OWHTO exhibit a lateral ankle positioning levels tend to be more even outer, This conclusion is also consistent with previous literature [11,12]. As for the relationship between HTO's posterior ankle joint and knee joint, Takeuchi et al. also reported the successful treatment of ipsilateral knee and ankle osteoarthritis by HTO [13]. In this study, it was found that the degree of postoperative correction of TPI and TIA in the over-corrected group was higher than that in the normal corrected group, but the difference was not statistically significant ( $p > 0.05$ ), and there were few relevant literatures. Therefore, future studies need to expand the sample size and conduct

longer follow-up. Previous similar studies found that patients in the over-corrected MPTA group (MPTA > 95° after surgery) showed no statistically significant difference in postoperative talus inclination Angle compared with those in the normal correction group ( $p=0.777$ ) [14].

The main findings of this study were that varus deformity was overcorrected after OWHTO, and patients with lower extremity linear load bearing axis greater than 67% were followed up at the last time, with a high incidence of postoperative complications, but the postoperative clinical efficacy was not affected. After measurement of lower extremity load position tablets, compensatory adduction of the affected side hip joint was found to be increased. Comparison of the last HAA between the two groups showed that the overcorrected group was  $(-2.96\pm1.58)$  ° and the normal corrected group was  $(-0.97\pm2.31)$  °, with statistically significant difference ( $P=0.026$ ). Previous studies have shown that compared with normal patients, patients with varus after high tibial osteotomy had significantly higher adduction moments of the hip and knee before surgery, and after surgery, the adduction moments decreased to below the knee level and the hip joint to the normal level. When the knee becomes slightly everted, the frontal plane torque around the hip can be reduced to a normal level, and the reduced load may be beneficial to patients with ipsilateral osteoarthritis of the hip and knee [15]. Goshima found that KJLO was maintained parallel to the ground after OWHTO due to compensatory movement of the hip joint, and that a certain degree of overcorrection for MPTA (postoperative MPTA > 95°) did not affect clinical outcomes after OWHTO [14]. Ishimatsu et al. also reported that the intraoperative and lateral space of patellofemoral joint after OWHTO was reduced compared with that before OWHTO, with statistically significant differences ( $P < 0.05$ ) [16]. Due to the excessive displacement of the weight-bearing axis of the affected limb, it is reasonable to believe that compensatory adduction of the hip joint is increased to maintain the stability of the lower limb and re-remodeling the line of force.

In this study, according to imaging analysis, no changes in the relative position of patellofemoral joint after OWHTO were found between the overcorrection group and the normal correction group, and patellar height decreased to varying degrees in both groups, but the difference between the two groups was not statistically significant ( $P =0.139$ ), which may be related to the short follow-up time. Previous studies have also been controversial. It was found that 69 patients (69 knees) who received OWHTO treatment did not change patella height when the knee axial correction was less than 15 degrees and had good short-term clinical results [22]. Otsuki study found that OWHTO could induce patella depression and decrease Caton-Deschamps index by 1.7%. Preoperative Caton-Deschamps index  $< 0.8$  should be considered as a risk factor [17]. In other studies, 16 patients with 18 knees were followed up for an average of 54.2 months (25 to 96 months), and patella height was reduced by an average of 15% ( $P <0.05$ ) [18]. Correction of a major deformity of the medial wedge high tibial osteotomy may result in degeneration of patellofemoral articular cartilage [19,20]. Yang treated 62 cases of knee joint (61 patients) with MOWHTO for single intervenors osteoarthritis of knee joint. Bone index was measured by postoperative radiological assessment. The average changes of patella height and tibial posterolateral Angle were statistically significant, but the tilt and displacement of patella were not significantly changed [21]. However, recent studies have found that the lateral inclination of patella (LPT) decreased from

$8.67 \pm 2.60$  degrees before surgery to  $6.13 \pm 2.30$  degrees after surgery, respectively. Patella still has lateral displacement, and internal rotation of the distal tibia is an important reason for LPT reduction [22].

The incidence of postoperative complications between the two groups was statistically significant ( $P = 0.041$ ). The average osteotomy gap was  $11.16 \pm 1.81$  mm in the over-corrected group and  $8.86 \pm 2.07$  mm in the normal corrected group, with statistically significant differences ( $P = 0.008$ ). The enlargement of the osteotomy space and the increase of bone defect mean that the incidence of non-union or delayed union of the postoperative osteotomy is higher. Previous studies have also confirmed [23] that open clearance (opening width exceeding 13.0mm, OR=1.61,  $P=0.02$ ) can lead to delayed bone healing after open wedge high tibial osteotomy. In addition, with an increased osteotomy gap, there is an increased risk of hinge fracture. This is consistent with the conclusion of Seo [24] that the size of the medial opening ( $>11$ mm) is an important risk factor for lateral cortical fractures (OR=4.98). In addition, the increase of osteotomy space, the increase of intraoperative fluoroscopy, and bone grafting in some patients all increased the operation time. The prolonged operation time, along with the increase of intraoperative bleeding, and the prolonged exposure of the operative area to air, also increased the risk of infection. Combined with the above factors, the incidence of postoperative complications in the over-corrected group was higher than that in the normal corrected group.

This study time at the end of the two groups of patients with postoperative follow-up clinical curative effect comparison, excessive correct set of HSS score and WOMAC index average ( $87.63 + / - 3.62$ ) and (9.50-1.60) points, normal correction HSS score and WOMAC score averaged (89.77-3.63) and (8.91-3.31) points, excessive correction HSS score below the normal orthodontic group, but there was no statistically significant difference ( $p = 0.139$ ), excessive correction WOMAC score higher than normal correction group, but there was no statistically significant difference ( $p = 0.501$ ). There is still controversy about the influence of degree of correction on clinical efficacy. Myrnerts[8] believed that the efficacy of patients with overcorrection was significantly better than that of normal orthodontists. Dugdale et al. [25] believed that when the lower extremity negative gravity line passed 50%~75% of the width of the tibial plateau (average 62.5%) after medial tibial high osteotomy, the postoperative clinical efficacy was the most satisfactory. Another study evaluated the hip, knee, and ankle angles, and corrected the affected limb to an average of  $-4.3^\circ$  to  $3.7^\circ$ , enabling patients to regain excellent function and daily physical activity ability through micro-orthosis [26]. At present, it is generally believed that setting different intraoperative force lines according to different knee wear conditions can reduce the pressure in the medial compartment of the knee to the greatest extent, thus reducing knee pain [27,28]. There was no statistical significance in HSS score between the two groups, which may be because knee HSS score was affected by factors such as joint range of motion and muscle strength, and the pain improvement and daily motor function were more affected by lower limb line and cartilage repair, so the improvement in HSS score was not statistically significant [29,30]. In this study, there was no statistically significant difference between THE HSS score and WOMAC score in patients with OWHTO posterior extremity line over-migration compared with the normal correction group so far. If the orthopedic Angle is too large and the lower limb force line is overcorrected, it is bound to cause excessive knee eversion, resulting in the wear and degeneration of the lateral compartment cartilage, and increasing the probability of postoperative lateral compartment

degeneration of the knee. Therefore, the long-term clinical efficacy of postoperative knee arthroplasty and whether to increase the possibility of knee replacement should be followed up for a longer period of time.

## 5. Limitations

There are some limitations in our study, which should be considered as follows: 1. The full-length X-ray images of lower extremities in our hospital were taken by using conventional photographic parameters in 3 neutral positions of the whole lower extremities and were imaged, which resulted in the errors of the X-ray images themselves. 2. The absolute neutral position cannot be guaranteed by any knee joint X-ray, and minor rotation, tilt, and pronation will lead to huge errors in the subsequent measurement. 3. The Angle measurement of ankle joint stability was not based on the anteroposterior and lateral ankle radiographs, but based on the preoperative and postoperative X-ray radiographs, which had some errors. 4. The follow-up time was short, and the degree of correction after TPI and TIA in the over-corrected group was higher than that in the normal corrected group, but the difference was not statistically significant, requiring long-term follow-up results. 5. As a single-center retrospective study, this study still has limitations such as a small sample size, so it still needs to further expand the sample size and conduct a prospective multi-center study. 6. This study did not carry out preoperative and postoperative arthroscopic repair of medial cartilage damage and wear of lateral cartilage.

## 6. Conclusions

Overcorrection of varus deformity (postoperative WBLR $\geq$  67%) did not affect the clinical efficacy of OWHTO within two years, but increased the incidence of postoperative complications and resulted in increased compensatory adduction of the hip joint.

## Declarations

### Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the affiliated hospital of Qingdao University. Written informed consent was obtained from all patients. No children (under 16 years old) were included in this study.

### Consent for publication

Not applicable.

### Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

### Competing interests

We declare that we have no Conflict of Interest.

## Funding

We received no external funding for this study.

## Authors' contributions

Authors Kui-shuai XU , Liang ZHANG and Rui SHEN designed the study; Liang ZHANG, Jian WANG analyzed the data; Kui-shuai XU , Jie SUN and Liang ZHANG wrote the manuscript; Yi ZHANG, Xia ZHAO and Teng-bo YU supervised the study.

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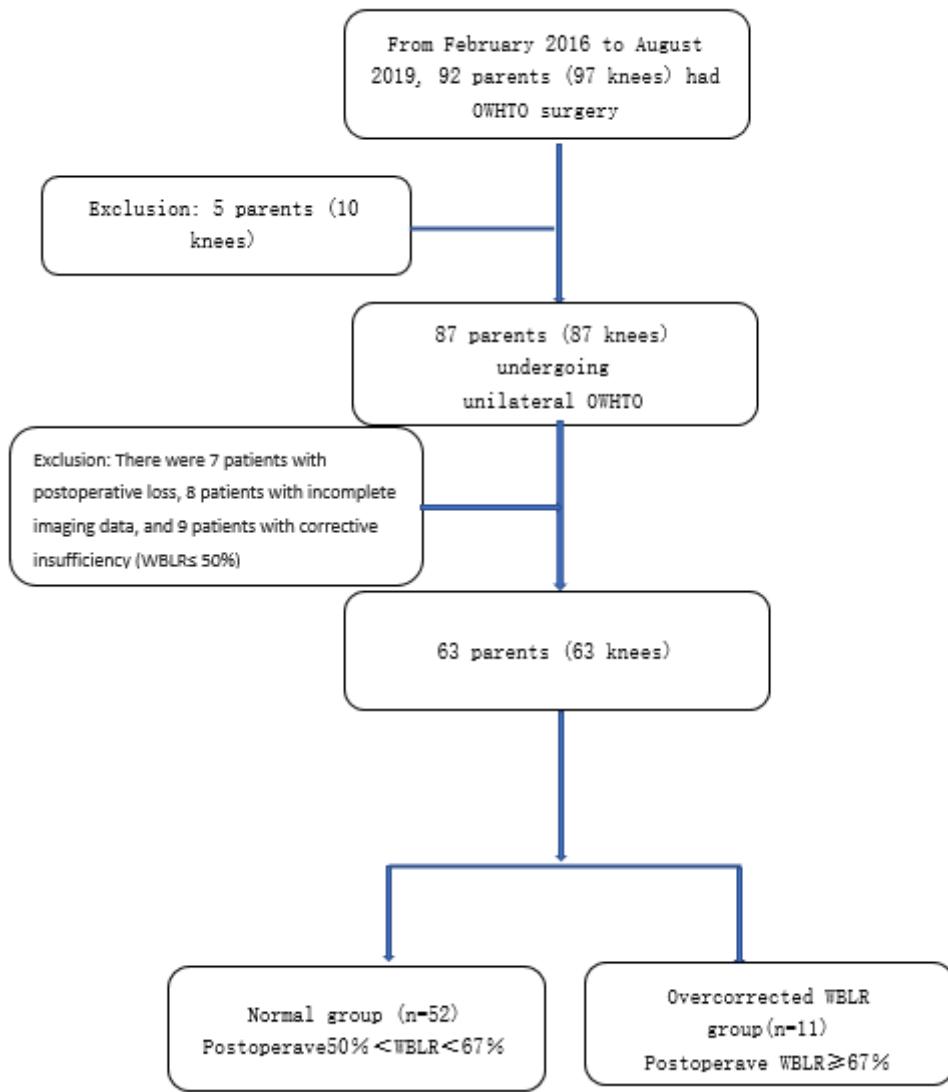
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## Tables

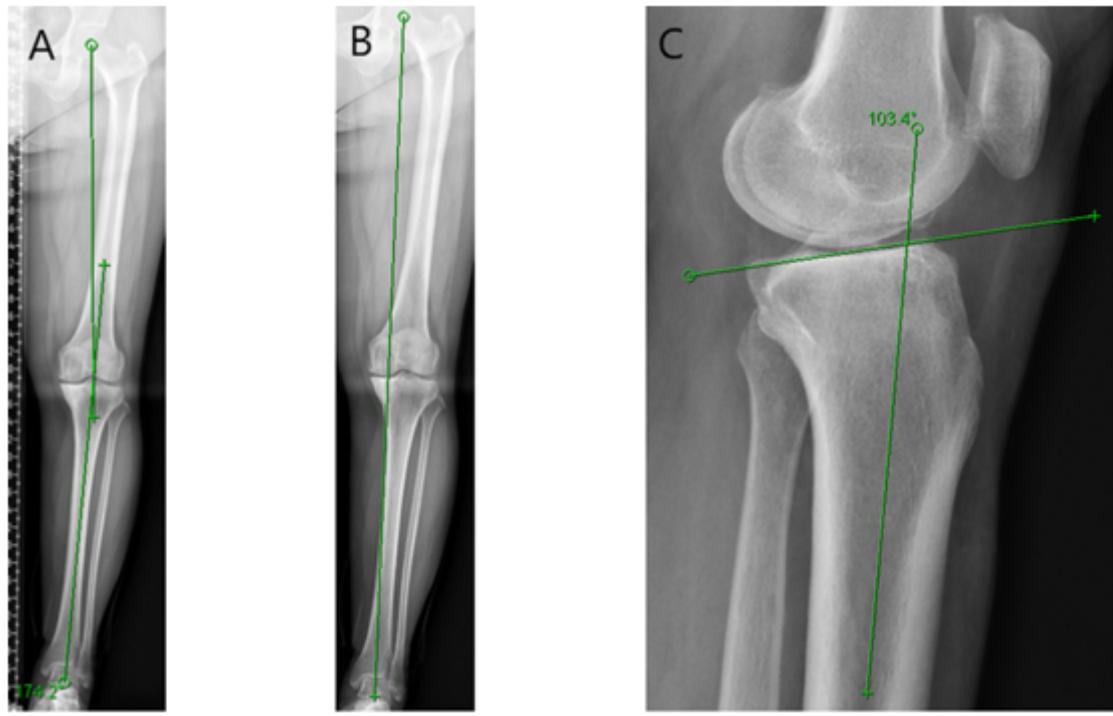
Due to technical limitations, table 1 to 6 is only available as a download in the Supplemental Files section.

## Figures



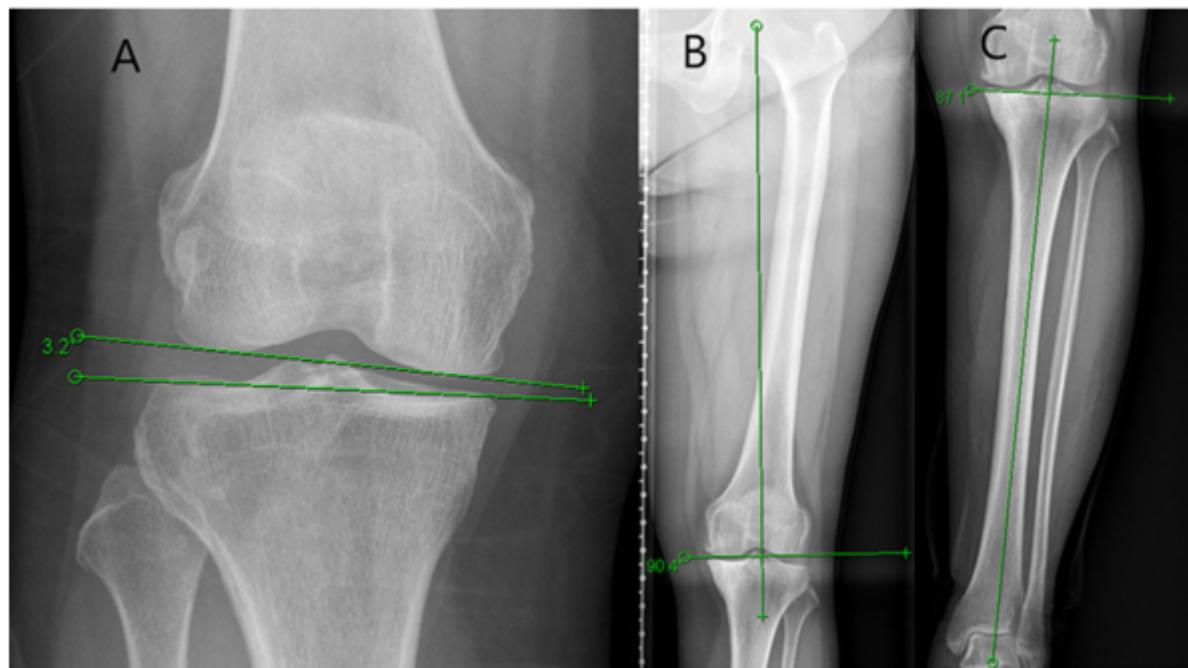
**Figure 1**

A flowchart showing the reasons for the exclusion



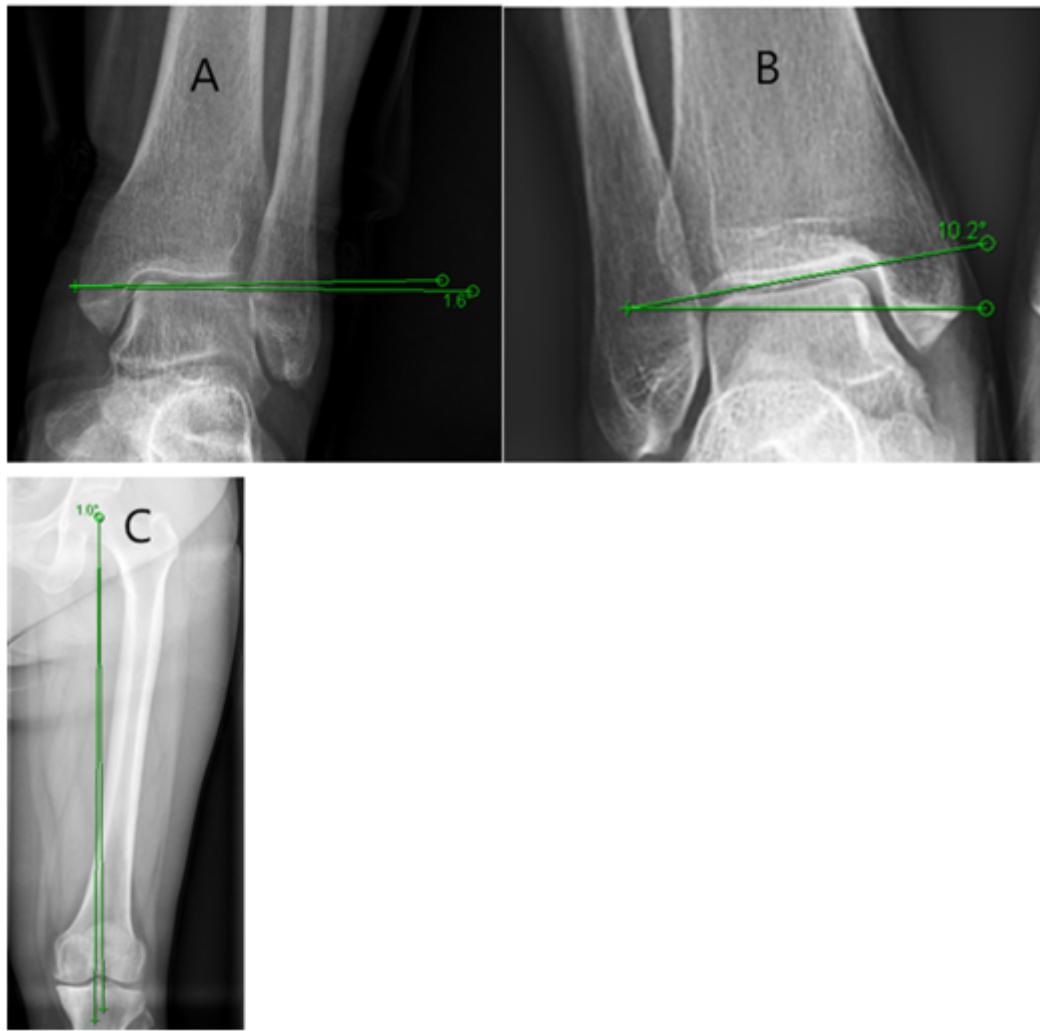
**Figure 2**

Measurement of imaging indexes of lower limb lines. (A) Hip-knee-ankle Angle (HKA). HKA is the Angle formed between the mechanical shaft of the femur and the mechanical shaft of the tibia (varus, negative).(B) Weight-bearing line ratio (WBLR). WBLR is defined as the horizontal distance from the load-bearing line to the medial edge of the tibial plateau divided by the width of the tibial plateau.(C) Posterior tibial slope (PTS). PTS is defined as the Angle between the line perpendicular to the proximal tibial center anatomical axis and the tangent of the tibial plateau.



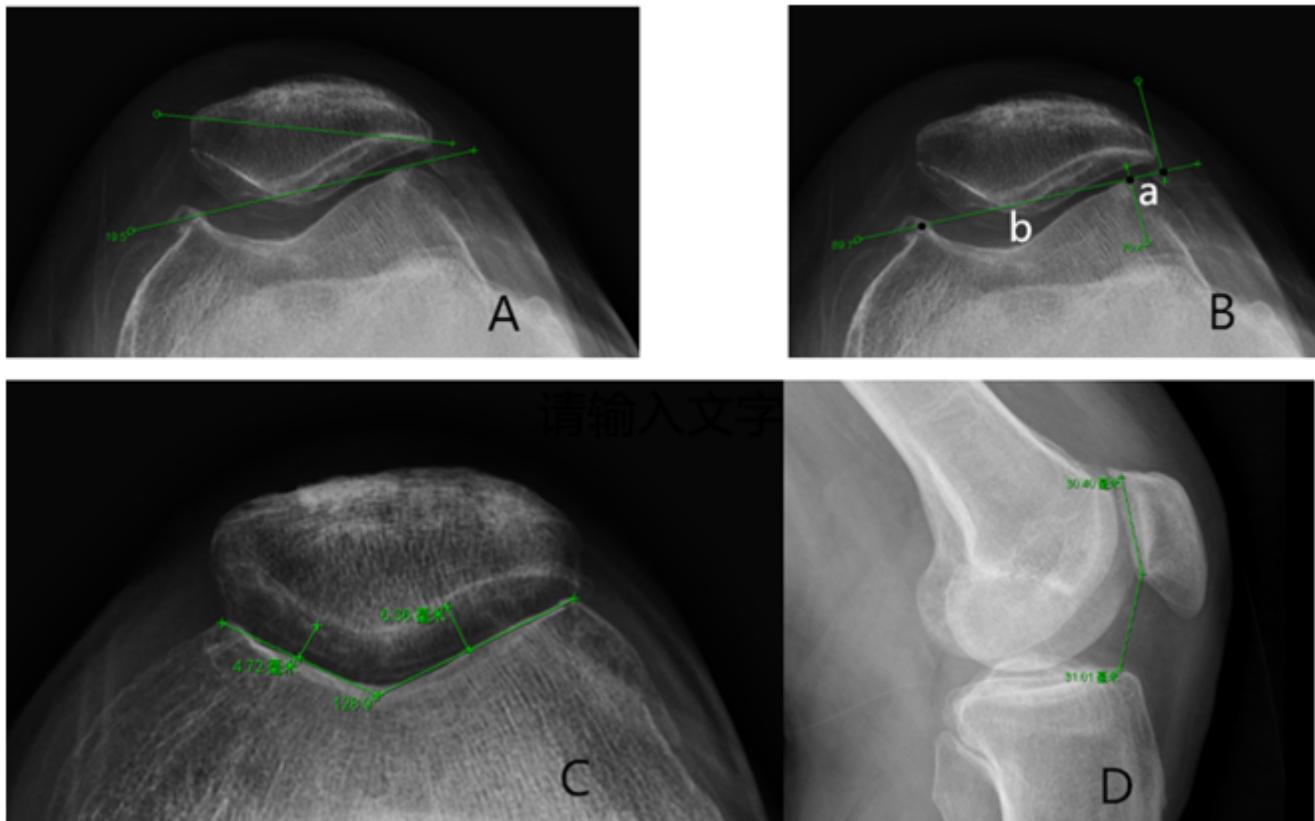
**Figure 3**

Measurement of imaging indexes of lower limb lines.(A) Joint line convergence Angle (JLCA).JLCA was defined as the Angle between the femoral condyle and the tibial plateau, and the positive value of JLCA represented the opening of the lateral joint.(B) Distal lateral femoral Angle (mLDFA).MLDFA is defined as the lateral Angle formed between the mechanical shaft of the femur and the tangent of the femoral condyle.(C) Medial proximal tibial angle (MPTA).MPTA is the medial Angle formed between the mechanical shaft of the tibia and the tangent of the tibial plateau.



**Figure 4**

Imaging measurement of ankle joint line dip and hip abduction Angle.(A) Talar inclination Angle (TIA).TIA is defined as the Angle between the articular surface of the talus and the horizontal line, and varus is positive.(B) tibial plafond inclination (TPI).TPI is the Angle between the tangent line of the distal tibia and the horizontal line, and varus is positive.(C) Hip abduction angle (HAA).AA is the Angle between the mechanical shaft of femur and the straight line perpendicular to the ground, and abduction is defined as positive value.



**Figure 5**

Measurement of imaging indexes of patellofemoral joint stability.(A) Lateral patellar tilt (LPT).LPT is the Angle formed by the line between the highest point of the femoral condyle and the extension line of the maximum transverse diameter of the patella.(B) Lateral patellar shift (LPS).LPS is defined as a straight line drawn from the highest point of the internal and external condyle of the femur, the measured distance is B, and the lateral edge of the patella is perpendicular to the line. Make a vertical line through the highest point of the lateral condyle of femur, and the distance between the two perpendicular lines is a, then  $LPS= A/B$ .(C) Medial patellofemoral space and Lateral patellofemoral space. The medial and lateral interspaces of patellofemoral joints are the distance from the center of the joint surface to the patella measured by drawing vertical lines (Fig 5C).(D) Carton index .Carton index is the ratio of the distance between the lower pole of the patella joint surface and the anterior upper Angle of the tibial plateau to the length of the patella joint surface. The normal value is (0.6 ~ 1.2).

## Supplementary Files

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