

# Analysis of the effects of high tibial osteotomy on tibial rotation

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## Abstract

**Purpose** Limited literature reports on internal and external rotation of the distal fragment in the context of valgus open wedge (OW) high tibial osteotomy (HTO). In the authors clinical observation, the distal fragment

was always rotated internally in relation to the proximal fragment by the end of the surgical procedure. The purpose was to evaluate the influence of valgus OW-HTO on post-operative tibial torsion.

**Study design** Prospective case series.

**Methods** Fifty patients (10 female, 40 male; mean age  $42.1 \pm 9.4$  years) underwent valgus OW-HTO. The osteotomy was spread and fixed with a locking plate at the posteromedial aspect of the proximal tibia. The osteotomy of the tibial tuberosity was performed either proximally or distally dependent on the patello-femoral findings. Two independent observers measured axial tibial rotation using K-wires placed into the anterior margin of the tibia proximal and distal to the osteotomy.

**Results** An overall mean of  $4.4 \pm 2.8^\circ$  internal rotation of the distal tibia has been shown. In four patients with additional single step double bundle ACL-replacement after harvesting ipsilateral autologous hamstring grafts, the distal tibia rotated internally by  $0.1 \pm 0.3^\circ$ , accordingly in the other 46 patients by  $4.8 \pm 2.6^\circ$ .

**Conclusions** Valgus OW-HTO produces significant internal axial rotation of the distal tibia. This might be caused by soft tissue tension of the medial hamstrings/soft tissue structures and the location of the lateral tibial hinge.

**Clinical relevance** Surgeons have to take into consideration that valgus OW HTO might result in significant 3D changes of the tibia. Higher degrees of internal torsion of the tibia might influence overall gait mechanics and specifically alternate patellofemoral kinematics.

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**Keywords** High tibial osteotomy · Open wedge · Tibial torsion

## Introduction

Valgus high tibial osteotomy (HTO), focusing on medial knee OA, is known to achieve pain relief for a period of five to 20 years post-operatively [1–4, 6, 7]. This long-term joint preservation is based on the effect of valgus HTO in the frontal plane, transferring the mechanical load from the overloaded and worn medial (medial OA) to the more intact lateral knee compartment.

In the authors' clinical experience, the distal tibia is commonly rotated internally in relation to the proximal fragment at the end of the very standardized surgical procedure of open wedge (OW) HTO. Excessive changes of the physiologic tibial torsion may adversely affect the frontal knee moments and therefore influence gait mechanism and patellofemoral kinematics. Additionally such changes could finally result in an increased risk of patellofemoral OA [9, 17, 21, 22].

To our knowledge, only two in-vivo considered tibial torsion in that context. One year after a hemi-callosistis procedure for treatment of medial OA due to varus malalignment no change of torsion was found [18]. Another study by Jang et al. [13] demonstrated a mean of  $3^\circ \pm 7^\circ$  of internatal rotation when performing a HTO. All other data result from cadaveric in-vitro studies describing both internal and external rotation of the tibia distal to the osteotomy or data from studies using animal bone models [5, 15]. None of these studies evaluated additional effects of soft tissue procedures (e.g., harvesting of hamstring tendons for ACL reconstruction) and their effect on such rotational changes.

Surgeons have to take into consideration that valgus OW HTO might result in significant 3D changes of the tibia. Thus the purpose of our prospective analysis was to verify this concomitant change in single step valgus producing OW-HTO. Our hypotheses were that: 1) valgus producing OW-HTO does result in internal rotation of the distal tibia with respect to the proximal tibia and 2) the extent of rotation does not depend on the amount of frontal plane correction.

## Materials and methods

### Patients data

For this prospective case series, 50 knee joints in 50 consecutive patients were enrolled. As inclusion criteria, all patients had an opening wedge HTO performed by one of the authors (S.H.) for varus malalignment and symptomatic medial compartment disease (localized cartilage damage in the medial compartment or subtotal resection of the medial meniscus in previous surgery each with medial pain but good motion) between August 2008 and April 2011. The group consisted of ten females (20 %) and 40 males (80 %) with a mean age at surgery of  $42.1 \pm 9.4$  years. Due to the fact that the indications

were not only based on OA, the patients' age was young and the average correction was less than the recommended  $3\text{--}4^\circ$  of mechanical valgus. All patients consented to participate in this observational study. All patients not matching the inclusion criteria and undergoing surgery in this period were not incorporated in this case series. HTO was a single procedure in 39 (78 %) knees, combined with osteochondral transplantation in two (4 %) knees, microfracturing in four (8 %) knees and implantation of a collagen meniscus implant in two (4 %) knees. Combined one-stage double bundle (db) ACL-replacement was performed in four (8 %) patients with varus malalignment and concomitant ACL-insufficiency. One of these patients also required microfracturing of the medial femoral condyle.

### Diagnostics

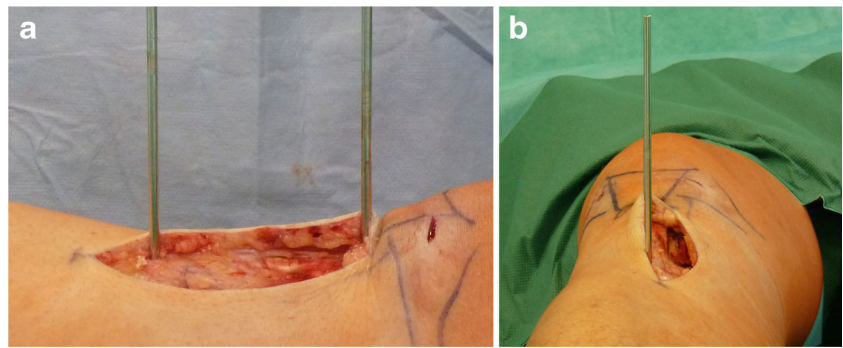
The routine pre-operative diagnostic studies consisted of conventional anteroposterior (AP) and lateral radiographs, a full length standing AP radiograph of the affected leg and an MRI of the affected knee. Leg alignment (mechanical varus of the lower extremity) as given by the hip-knee-ankle axis was determined with long standing films [12].

### Surgical procedure

Surgery was performed in supine position on a straight operating table. The detailed procedure was described recently [11]. In short, a 10 cm anteromedial incision exposed the proximal tibia. Two reference K-wires were drilled into the anterior margin, one above the osteotomy directly proximal to the insertion of the patellar ligament and a second wire 8 cm below the osteotomy. Both were placed strictly parallel in the sagittal and axial plane (Fig. 1a and b). The osteotomy site (starting 4–5 cm below the joint line) was exposed after detachment of the gracilis tendon insertion and incision of the anterior and mobilization of the posterior portion of the medial collateral ligament.

A biplanar osteotomy was performed leaving the tibial tuberosity on the distal fragment if no patello-femoral complaints were reported preoperatively (such as: pain behind the patella during activities of daily living (walking or climbing stairs), or sports in the medical history and clinical exam showed no pain behind the patella on pressure or medio-lateral translation under pressure during the physical examination) and the correction did not exceed  $5^\circ$  (25 patients received a proximal osteotomy, 50 %,  $39.3 \pm 8.2$  years). The frontal plane osteotomy was aimed distally leaving the tuberosity on the proximal fragment to avoid altering patellofemoral kinematics in the remaining 25 patients (50 %,  $45.3 \pm 9.8$  years). While the osteotomy was spread as close to the posterior medial corner of the tibia as possible and the leg was in a sagging position the two reference K-wires were kept parallel in the sagittal plane (Fig. 2a). Thus

**Fig. 1** Intra-OP view of the osteotomy site from medial. **a** at the beginning of the operation the two K-wires proximal and distal of the osteotomy are strictly parallel. **b** seen from distally the K-wires impose as one structure

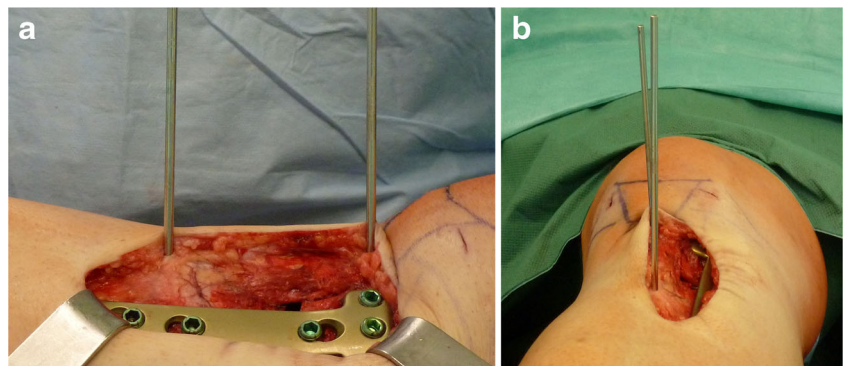


maintenance of the original tibial slope was insured. The position of the two K-wires in the axial plane was controlled (Fig. 2b). The frontal correction angle was calculated preoperatively for each patient individually based on the preoperative leg alignment and the specific extent of either degenerative changes or cartilage lesions in the medial and lateral compartment. Finally the open wedge osteotomy was fixed with a selflocking plate (TomoFix®, Synthes, Umkirch, Germany) and the tuberosity was fixed with one or two screws if the osteotomy was aimed distally. The pre- and post-operative X-rays for both types of tuberosity osteotomy are shown in Fig. 3. At the end of the procedure the two K-wires were measured again (Fig. 2) and finally they were removed.

#### Frontal plane correction measurement

Measuring the angle between the proximal and distal border of the osteotomy on the post-operative AP radiograph was used to evaluate the magnitude of correction in the frontal plane (digital X-ray software, PACS, Philips EasyVision, Best, Netherlands). All measurements were performed in a digital technique by one of the authors (K.B.). In the process of measurement, the radiographs were magnified to increase accuracy of line placement without resulting changes of measured angles.

**Fig. 2** Intra-OP view of the osteotomy site from medial. **a** at the end of the operation the two K-wires proximal and distal of the osteotomy are still strictly parallel. **b** seen from distally the two wires indicate the internal rotation of the distal tibia with respect to the proximal aspect



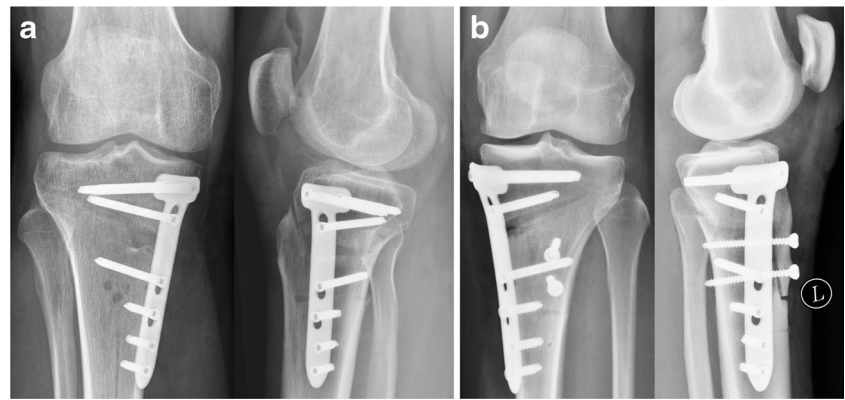
#### Torsion measurement

Two independent surgeons (K.B., J.P.) confirmed the strict parallelism of the mentioned landmark K-wires at the beginning of each surgical procedure. After finalized osteotomy and fixation of the plate, both surgeons measured the torsion of the two K-wires again independently by using a sterile goniometer (Fig. 2b).

#### Statistical analysis

The statistical software used for all analyses was SPSS 15.0 (SPSS, Chicago, USA). We used a paired Student's *T*-test for comparison of pre-OP and post-OP tibial torsion. A *P*-value of less than 0.05 was regarded as indicative of statistical significance. The inter-observer variability of the tibial torsion measurement was assessed by calculating the mean absolute differences between the two examiners. A power analysis was performed and revealed a minimum of 35 patients for adequate power of this study. This was calculated using an expected degree of rotation observed in previous surgeries. The difference to detect was set to  $2 \pm 3^\circ$  of tibial rotation with an alpha value of 0.05 ( $\alpha$ ) and power of 0.80 ( $1 - \beta$ ).

**Fig. 3** X-ray ap and lateral showing open wedge high tibial osteotomy and Tomofix® plate fixation before and directly after the operation. **a** the tibial tuberosity is left at the distal tibia. **b** the tibial tuberosity is left at the proximal tibia and distally fixed with two additional cortical screws



## Results

### Frontal plane correction

All surgeries were performed without any major complications or intra-operative alternations of the routine procedure. The full standing ap radiographs revealed a pre-operative mean varus deformity of  $6.1 \pm 2.9^\circ$ . The mean angle of correction in the coronal plane after the osteotomy was  $7.7 \pm 2.7^\circ$  (Table 1).

### Torsion measurement

Valgus producing OW-HTO in average led to significant internal axial rotation (mean of  $4.4 \pm 2.8^\circ$ ) of the distal tibia with respect to the proximal tibia ( $P < 0.01$ ). The mean absolute difference for rotational measurement between the two examiners was  $0.8 \pm 0.6^\circ$ . In four patients with additional single step db-ACL-replacement using autologous ipsilaterally harvested hamstring grafts, the internal axial rotation of the distal tibia was  $0.1 \pm 0.3^\circ$ . The remaining 45 patients without simultaneous harvesting of the hamstring tendons showed  $4.8 \pm 2.6^\circ$  internal axial rotation of the distal tibia. The overall magnitude of internal tibial rotation showed no correlation with the magnitude of frontal plane HTO correction ( $R = 0.23$ ) (Table 1).

**Table 1** Mean tibial rotation change and frontal plane correction in valgus producing OW-HTO

Tibial Rotation Change (A)	$4.4 \pm 2.8^\circ$ * IR
Frontal Plane Correction (B)	$7.7 \pm 2.9^\circ$
Correlation A with B	0.23

\* indicates  $P < 0.05$  compared to pre-operatively. “IR” indicates internal rotation of the distal tibia with respect to the proximal aspect

## Discussion

The aim of this prospective study was to evaluate the amount of axial tibial rotation resulting after valgus producing OW-HTO. With regard to our hypotheses the main findings of this study are: Valgus producing OW-HTO leads to internal rotation of the distal tibia in correlation to the proximal tibia of about  $5^\circ$  (if the hamstring tendons are intact). No direct correlation exists between the amount of rotation and the magnitude of frontal plane correction.

Tibial torsion after valgus producing OW-HTO has hardly been examined to date [5, 13, 15, 18]. To our knowledge, the only human study used radiostereometric analysis in a randomized protocol and compared conventional CW-HTO with OW-HTO by hemi-callostasis. One year post-operatively no change of rotation in OW-HTO was found [18]. This study only reported on these observations but failed to discuss possible reasons for their observed data. Jang et al. [13] in 2015 demonstrated a unintended internal rotation of  $3 \pm 7^\circ$  in their study of 35 HTOs. In this study, only the observation of these changes was reported and a correlation was seen to the opening angle of the osteotomy and the angle of osteotomy. This study did not evaluate the effects of the soft tissue structures on the rotational changes [13].

Another study, which was comparable to the presented but performed under *in vitro* conditions, describes external rotation of the distal tibial fragment in ten out of 13 limbs (all over  $2.7 \pm 6.3^\circ$ ,  $12^\circ$  max external;  $9.5^\circ$  max internal) [15]. Baumgarten et al. [5] compared coronal plane- with OW-osteotomy in a cadaveric study using tibia-fibula constructs without soft tissue. In OW-osteotomy all specimen showed external rotation of the proximal tibia that is equal to internal rotation of the distal tibia correlating with the amount of OW-correction. These rotational changes in OW-HTO are comparable to our data. Coronal plane osteotomy showed insignificant external rotation of the distal tibia. Coronal plane HTO altered axial tibial rotation less than the OW-osteotomy. The authors explained the changes observed in these cadaveric



experiments by the intact fibula and intact tibia–fibula joint. The intact fibula would resist angular correction and increased tension developed in the tibia–fibula construct, which would be relieved by the tibia rotating around the intact fibula. However, one must be aware of the fact, that Baumgarten et al. [5] measured the rotation of the proximal fragment relative to the distal whereas the amount of rotation was measured vice versa in the current study. Consequently, identical results are described with different methods in both manuscripts. Notably this study evaluated cadaveric specimen in an in-vitro setting with no attached soft tissue and therefore no possible effects of soft tissue tension. Our observations seemed to correlate with the status of the tendons of the medial hamstring insertion: patients with missing semitendinosus and gracilis tendons (due to ACL surgery) showed less rotational changes. Though these results have to be seen critical, since the number of observed patients is low. The causing effect cannot finally be answered due to our experimental set up. However both theories seem to contribute to the observed effect of increased internal rotation while performing OW-HTO.

Two anatomic conditions may be considered causative for our observations: The first would be seen in the medial soft tissue structures. In open wedge valgus HTO the pes anserinus is just mobilized and the specific insertion of the semitendinosus tendon is left distal to the osteotomy. With opening of the osteotomy the increased tension of these tendons seems to result in an internal tibial rotation. We conclude that patients with harvested semitendinosus and gracilis tendons show rather no tibial rotation due to the absence of this internally acting force. Additionally the authors believe that it is not the semimembranosus muscle alone, that is the main soft tissue structure responsible for the resulting internal rotation.

The second reason is supposed to be the orientation of the osteotomy in the complex 3-dimensional structure of the proximal tibia. In OW-HTO preserving a lateral cortical bridge is intended. First, because the planning of the operation is based on that hinge for valgisation of the distal tibia, and second an intact lateral column is essential for primary stability of the osteotomy gap. However, the soft tissue preparation at the posterior aspect of the tibia is often performed not properly due to concerns about muscle and vessel injuries [20]. Thus the osteotomy of the posterior and posterior-lateral cortex is difficult to perform and the hinge axis direction can hardly be foreseen. This variation of hinge axis location and direction might vary distinctly from case to case and influence the distal tibial rotation. However, the hinge axis effect has been described only for PTS and PH changes until now [23].

Previous studies have shown a significant interaction between the rotational alignment of the lower extremity and medial tibiofemoral compartment contact pressures [8, 14, 19]. Thus the more medial position of the tibial tubercle in OW-HTO with the tuberosity left at the distal fragment may alter patellofemoral kinematics. Although the authors of this

study detected an overall internal rotation which is commonly intended for treatment of patellofemoral instability, an excessive internal rotation should be prevented to eliminate the risk of increased pressure on the medial patellofemoral joint with resulting risk of OA progression [10, 16]. If surgeons intend to prevent such changes (e.g., in case of already existing medial patellofemoral OA), a distal osteotomy of the tibial tubercle may avoid excessive effects on the kinematics of the patellofemoral joint.

To avoid excessive postoperative torsional changes of the 3D tibia architecture, we recommend intra-operative control with the described method of K-Wire measurement. This feasible and cheap technique enables the surgeon to estimate the rotation of the distal fragment intra-operatively and correct excessive amounts before performing the final osteosynthesis. However, the surgical experience of the authors showed that externally rotating the lower leg or increased flexion of the patients' knee to relax the hamstrings while performing the osteotomy did not result in changes of the observed rotation effects.

Our study was mainly focused on geometrical values. A limitation is, that it lacks the correlation between the torsion-changes and the clinical outcome. This should be caught up in a planned prospective study comparing clinical and geometrical changes. Further limitations of our study include the accuracy of the intra-operative measurement. We used a simple method with two K-wires, which was easy to handle and did not cause additional radiation or prolonged surgical time for the patient. However, using this approach we cannot compare our values with CT data, which is regarded as the gold standard in torsion measurement. Due to requirements by the local ethics committee we were not allowed to perform a CT-scan before or after the operation. This would have given further information regarding overall changes in tibial torsion. Nevertheless the agreement of the measurements by the two independent surgeons was so high that an immanent mistake must have been rather low.

## Conclusion

Valgus ow-HTO produces significant internal axial rotation of the distal tibia as long as the medial hamstrings can be preserved. The effect of that rotation change is still unknown. Surgeons have to be aware of possible 3D changes of tibia torsion in OW-HTO and minimize these effects intra-operatively.

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