

# Preoperative varus laxity correlates with overcorrection in medial opening wedge high tibial osteotomy

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## Abstract

**Purpose** Medial opening wedge high tibial osteotomy (HTO) is a realignment of the lower limb. Despite accurate preoperative planning and careful surgical techniques, many HTOs result in alignment correction errors. These alignment correction errors may be due to soft tissue laxity around the knee such as varus or valgus laxity. The purpose of this study was to examine the relationship of varus and valgus laxity of the knee and alignment correction errors, and to have a formula to predict the subsequent degree of these correction errors.

**Materials and methods** Fifty knees from 41 patients undergoing opening wedge HTO for knee osteoarthritis were involved. Standing full-length anteroposterior radiographs of the lower limb and the tibia, and varus and valgus stress radiographs of the knee were used to evaluate alignment and joint laxity. Parameters were global correction (the change in the hip–knee–ankle angle), bony correction (the change in the medial proximal tibial angle), and soft tissue correction (global correction – bony correction).

**Results** The average of global correction, bony correction, and soft tissue correction were  $12.8^\circ \pm 4.3^\circ$ ,  $9.4^\circ \pm 3.2^\circ$ ,

and  $3.4^\circ \pm 2.5^\circ$ , respectively. Preoperative varus laxity was moderately correlated with soft tissue correction ( $R = 0.58$ ), and in which the slope of the line in the scatter plot represented 0.59, implying that soft tissue correction increases by  $0.59^\circ$  for every  $1^\circ$  of preoperative varus laxity. **Conclusions** Preoperative varus laxity is correlated with soft tissue correction, suggesting that more accurate alignment correction could be achieved by surgical planning taking into account preoperative varus laxity as a factor of soft tissue correction.

**Keywords** High tibial osteotomy · Joint laxity · Overcorrection · Alignment correction

## Introduction

Medial opening wedge high tibial osteotomy (HTO) was first described in 1951 by Debeyre [1] and has become a more popular, well-established surgery for young active patients with medial compartment knee osteoarthritis (OA) [2]. Medial opening wedge HTO allows patients early weight bearing due to some specific internal fixator device such as TomoFix<sup>®</sup> (DePuy Synthes, West Chester, PA) and LOQTEQ<sup>®</sup> HTO plate (aap inpartate AG, Berlin, Germany) [3], and good mid-term results of medial opening wedge HTO and its conversion to total knee arthroplasty have been reported [4, 5]. 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. Clinical outcomes are dependent on an accurate preoperative analysis of the deformity, accurate preoperative planning, and careful surgical techniques [6–8]. Undercorrection and overcorrection have been shown to be

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associated with poor clinical outcomes [7, 9]. Adequate preoperative planning may be accomplished by a geometric methods proposed by Miniaci et al. which generates a preoperative correction angle for HTO with excellent reliability [10, 11], and adequate correction of lower limb alignment may be achieved using intraoperative techniques such as fluoroscopy or computer navigation systems [12].

Despite accurate preoperative planning and careful surgical techniques, many HTOs result in alignment correction errors such as undercorrection or overcorrection. These alignment correction errors may be due to soft tissue laxity around the knee such as varus or valgus laxity [13]. Recently, Lee et al. [14] reported that change in soft tissue laxity around the knee from before to after medial opening wedge HTO correlated with correction errors, and they concluded that coronal alignment overcorrection may be due to too large reduction in joint line convergence angle, which is formed by two articular tangential lines of the distal femur and the proximal tibia, from before to after surgery. This study implies that preoperative varus and valgus laxity of the knee joint may be related with alignment correction errors in HTOs. However, whether and to what extent varus and valgus laxity of the knee joint are related with alignment correction errors is unclear. The purpose of this study was to examine the relationship of varus and valgus laxity of the knee and alignment correction errors in medial opening wedge HTO, and to have a formula to attempt to predict the subsequent degree of these correction errors.

## Methods

This study was approved by the institutional review board of our university. All patients gave informed consent to allow use of their medical records for a retrospective case series study. This study involved a consecutive 50 knees from 41 patients undergoing medial opening wedge HTO for osteoarthritis of the knee in our institution between July 2012 and June 2015 (Table 1). There were 25 women and 16 men with a mean age of  $62.3 \pm 7.4$  years (range 48–72) at the time of surgery. All surgeries were performed by one of two surgeons (H.O. and K.M.). Inclusion criterion was medial compartment knee OA with a varus malalignment

of the lower limb with compartment pain and impaired activity of daily living. Exclusion criteria were severe OA of the patellofemoral joint, femorotibial angle over  $190^\circ$ , and flexion contracture over  $15^\circ$ .

## Surgical technique

During conventional preoperative planning using Miniaci's method [10], the valgus correction angle and the distance between the upper and lower edges of the opened posteromedial osteotomy site were measured on the radiograph used for prediction. The aim was to obtain a mechanical axis of the lower limb (Mikulicz line) that passes through Fujisawa point (a point at 62.5 % of the tibial plateau from the medial edge) [15]. Prior to medial opening wedge HTO, knee arthroscopy was performed to evaluate the extent of cartilage degradation, and microfracture was performed for degraded cartilage lesions to trigger cartilage regeneration. Thereafter, a longitudinal skin incision, approximately 6 cm in length, was made over the pes anserinus insertion at the antero-medial aspect of the tibia. The medial aspect of the proximal tibia was exposed by elevating the insertion of the pes anserinus, gracilis tendon, semitendinosus 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, 2.0 mm in diameter, were inserted into the tibia as an osteotomy guide under an image intensifier, and biplane 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 intensifier, 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. Two  $\beta$ -tricalcium phosphate wedges (OSferion60, Olympus Terumo Biomaterials, Tokyo, Japan) were trimmed to the size of the opening gap during surgery. The wedges were then inserted into the osteotomy gap horizontally, after which the elevated hamstrings were

**Table 1** Patient demographics

Patients (number)	41
Knees (number)	50
Age (years; mean $\pm$ SD)	$62.3 \pm 7.4$
Sex (female, number)	28
Operative side (right, number)	25

SD standard deviation

repaired. The medial osteotomy site was then rigidly fixed using a TOMOFIX Osteotomy system (DePuy Synthes, Switzerland) over the osteotomy site.

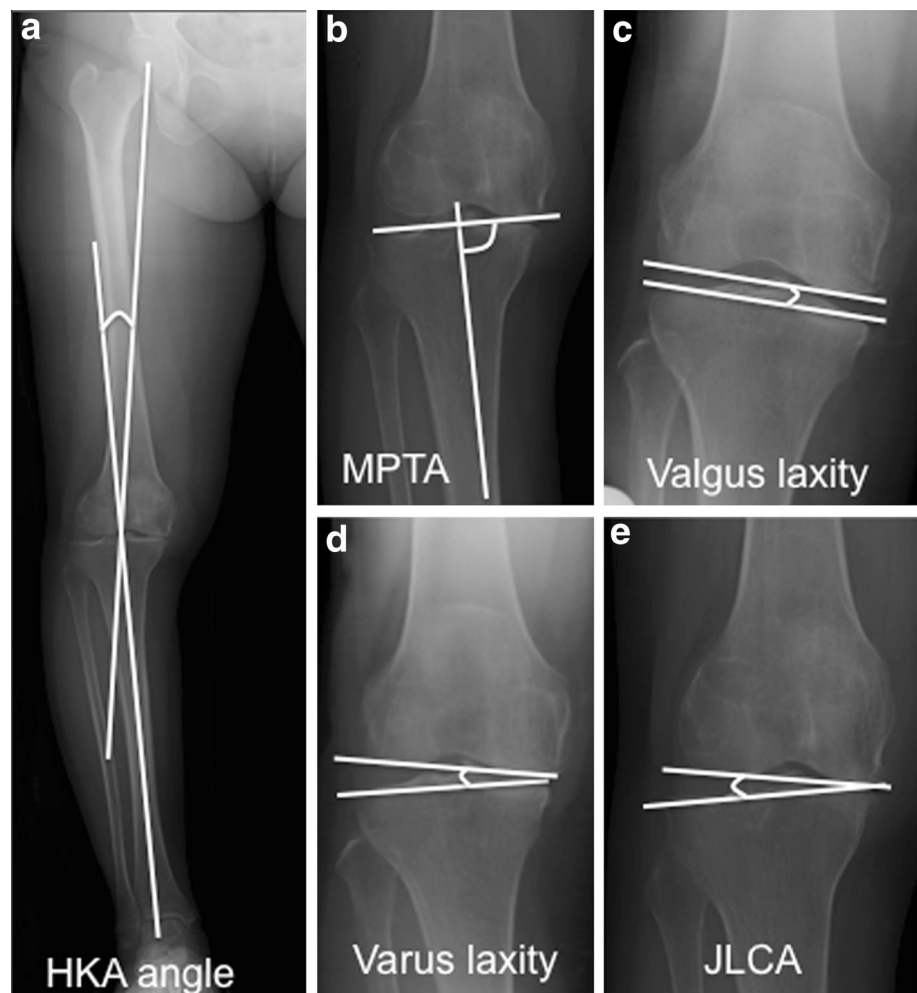
### Radiographic measurements

Double legs standing full-length anteroposterior radiographs of the lower limb with the patella facing directory anterior and full-length anteroposterior radiographs of the tibia were taken preoperatively and 6 months postoperatively, and short anteroposterior radiographs of the knee with the patella facing directory anterior under maximal manual varus and valgus stress were taken preoperatively. The following parameters were measured using these radiographs: the hip–knee–ankle (HKA) angle (defined as the angle between the femoral and tibial mechanical axes; varus, negative; valgus, positive) (Fig. 1a), the mechanical medial proximal tibial angle (MPTA) (defined as the angle between the tibial plateau and the tibial mechanical axis) (Fig. 1b), the valgus laxity angle (defined as an angle between a distal femoral joint line and a proximal tibial

joint line under valgus stress) (Fig. 1c), the varus laxity angle (defined as an angle between a distal femoral joint line and a proximal tibial joint line under varus stress) (Fig. 1d), and the joint line convergence angle (JLCA) (defined as the angle formed by two articular tangential lines of the distal femur and the proximal tibia) (Fig. 1e). JLCA was measured on double legs standing full-length anteroposterior radiographs of the lower limb. The overall realignment was evaluated by HKA angle, and the change in HKA angle ( $\Delta$ HKA angle; postoperative HKA angle – preoperative HKA angle) was defined as “global correction”. The change in MPTA ( $\Delta$ MPTA; preoperative MPTA – postoperative MPTA) was defined as “bony correction”. Realignment by other than bony correction was evaluated by the deduction of bony correction ( $\Delta$ MPTA) from global correction ( $\Delta$ HKA angle), which was defined as “soft tissue correction” (soft tissue correction =  $\Delta$ HKA angle –  $\Delta$ MPTA). The change in JLCA (preoperative JLCA – postoperative JLCA) was defined as  $\Delta$ JLCA.

All radiographic measurements were performed by two independent observers, who were one of surgeon related

**Fig. 1** Radiographic assessments. **a** The hip–knee–ankle angle (HKA angle): the angle between the femoral and tibial mechanical axes; varus, negative; valgus, positive. **b** The mechanical medial proximal tibial angle (MPTA): the angle between the tibial plateau and the tibial mechanical axis. **c** Valgus laxity: the angle between the tibial and femoral margin tangents under valgus stress; valgus, positive; varus, negative. **d** Varus laxity: the angle between the tibial and femoral margin tangents under varus stress; varus, positive; valgus, negative. **e** Joint line convergence angle (JLCA): the angle formed by two articular tangential lines of the distal femur and the proximal tibia; varus, positive; valgus, negative



with the surgeries (H.O.) and the other is not related to the surgeries, in a blinded fashion. To ensure measurement accuracy, the interobserver variance was assessed using kappa statistics. No significant differences were found between observers. Arthritic changes in the knee joint were evaluated using Kellgren–Lawrence (KL) grades.

### Statistical analysis

All radiographic measurements were performed by two independent observers, including one of the authors (H.O.) and an orthopedic surgeon not involved in the surgeries, in a blinded manner. The intra- and inter-rater reliability was expressed as intra-class correlation coefficients (ICC), which varied from zero (no agreement at all) to 1 (total agreement).

Statistical comparisons of the results were performed using SPSS version 13.0 software (SPSS Inc., Chicago, IL, USA). A paired *t* test was used to evaluate differences in all of the measured preoperative and postoperative parameters. The correlation between preoperative varus laxity, preoperative valgus laxity, a combined angle of both, soft tissue correction, and  $\Delta$ JLCA was evaluated by simple linear regression analysis. *p* values of less than 0.05 were considered significant.

### Results

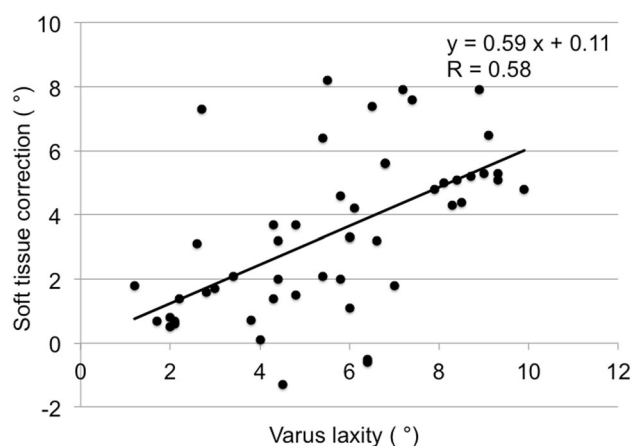
Results were summarized in Table 2. The average HKA angle significantly improved from  $-9.6^\circ \pm 4.0^\circ$  preoperatively to  $3.2^\circ \pm 2.3^\circ$  postoperatively ( $p < 0.01$ ), resulting in an average global correction ( $\Delta$ HKA angle) of  $12.8^\circ \pm 4.3^\circ$ .

**Table 2** Radiographic parameters

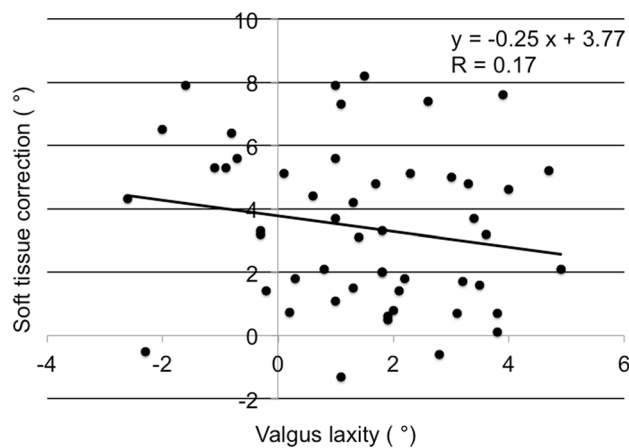
Parameter	Average ( $^\circ$ )
Preoperative HKA angle	$-9.6 \pm 4.0$
Postoperative HKA angle	$3.2 \pm 2.3$
Global correction ( $\Delta$ HKA angle)	$12.8 \pm 4.3$
Preoperative MPTA	$84.9 \pm 3.0$
Postoperative MPTA	$94.3 \pm 3.2$
Bony correction ( $\Delta$ MPTA)	$9.4 \pm 3.2$
Soft tissue correction (global correction – bony correction)	$3.4 \pm 2.5$
Valgus laxity	$1.5 \pm 1.8$
Varus laxity	$5.6 \pm 2.4$
Preoperative JLCA	$4.6 \pm 2.2$
Postoperative JLCA	$2.7 \pm 1.6$
$\Delta$ JLCA	$2.0 \pm 1.5$

HKA hip–knee–ankle, MPTA medial proximal tibial angle, JLCA joint line convergence angle,  $\Delta$  the difference between preoperative and postoperative values

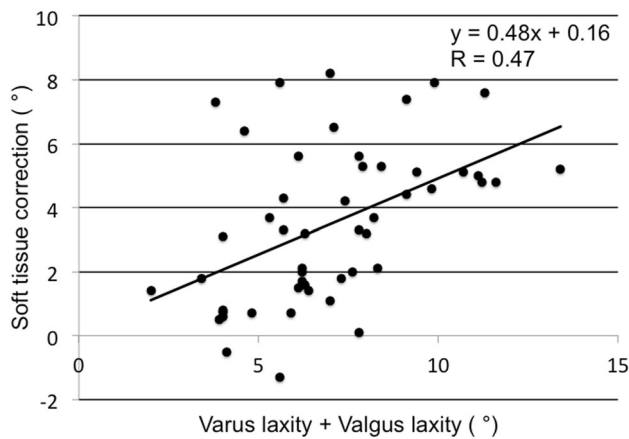
The average MPTA also significantly changed from  $84.9^\circ \pm 3.0^\circ$  preoperatively to  $94.3^\circ \pm 3.2^\circ$  postoperatively ( $p < 0.01$ ), which resulted in an average bony correction ( $\Delta$ MPTA) of  $9.4^\circ \pm 3.2^\circ$ . The average JLCA also significantly changed from  $4.6^\circ \pm 2.2^\circ$  preoperatively to  $2.7^\circ \pm 1.6^\circ$  postoperatively ( $p < 0.01$ ), which resulted in  $\Delta$ JLCA of  $2.0^\circ \pm 1.5^\circ$ . The average soft tissue correction, determined by the subtraction of an average bony correction ( $\Delta$ MPTA) from an average global correction ( $\Delta$ HKA angle), was  $3.4^\circ \pm 2.5^\circ$ . Preoperative valgus and varus laxity was  $1.5^\circ \pm 1.8^\circ$  and  $5.6^\circ \pm 2.4^\circ$ , respectively. The regression analysis showed moderate correlation between preoperative varus laxity and soft tissue correction [correlation coefficient (*R*), 0.58; Fig. 2], little correlation between preoperative valgus laxity and soft tissue correction (*R*, 0.17; Fig. 3), low



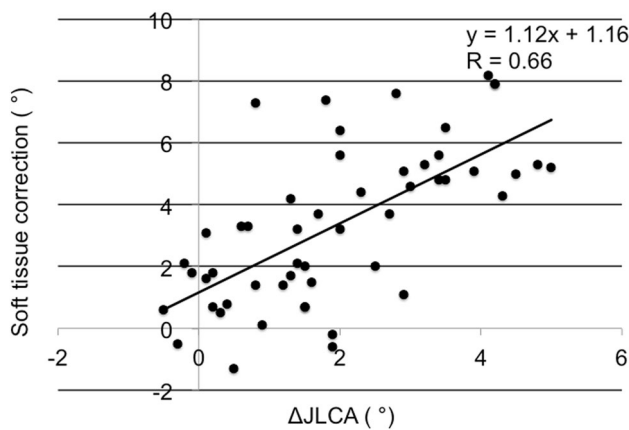
**Fig. 2** The relationship between preoperative varus laxity and soft tissue correction (overcorrection). The scatter plot shows a moderate correlation between varus laxity and soft tissue correction ( $R = 0.58$ ). A slope of the line in the scatter plot for the correlation of varus laxity and soft tissue correction represented 0.59



**Fig. 3** The relationship between preoperative valgus laxity and soft tissue correction (overcorrection). The scatter plot shows little correlation between valgus laxity and soft tissue correction ( $R = 0.17$ )



**Fig. 4** The relationship between a combination of preoperative varus and valgus laxity and soft tissue correction (overcorrection). The *scatter plot* shows a low correlation between the combined laxity and soft tissue correction ( $R = 0.47$ )



**Fig. 5** The relationship between  $\Delta$ JLCA and soft tissue correction (overcorrection). The *scatter plot* shows a moderate correlation between  $\Delta$ JLCA and soft tissue correction ( $R = 0.66$ )

correlation between the combined varus and valgus laxity and soft tissue correction ( $R$ , 0.47; Fig. 4), and moderate correlation between  $\Delta$ JLCA and soft tissue correction ( $R$ , 0.66; Fig. 5). In the scatter plot for the relation of varus laxity and soft tissue correction, the slope of the line in the scatter plot for varus laxity and soft tissue correction represented 0.59 (Fig. 2). Evaluation of the severity of osteoarthritis in the medial compartment showed that 3 knees could be classified as KL grade 2, 39 as KL grade 3, and 8 as KL grade 4. In the lateral compartment, 22 knees could be classified as KL grade 0, 25 knees were classified as KL grade 1 and 3 as KL grade 2.

The intra-class correlation coefficient (ICC) of the radiographic parameters is shown in Table 3. In all measurements the ICCs were reasonable, and for the all assessments intra- and inter-rater agreement was similar throughout.

**Table 3** Intra-class correlation coefficient (ICC) of preoperative radiographic parameters

	Intra-rater	Inter-rater
HKA angle	0.99	0.98
MPTA	0.99	0.89
Valgus laxity	0.96	0.95
Varus laxity	0.98	0.94
JLCA	0.98	0.94

HKA hip–knee–ankle, MPTA medial proximal tibial angle, JLCA joint line convergence angle

## Discussion

The most important finding of the present study is that preoperative varus laxity was moderately correlated with soft tissue correction (overcorrection) in medial opening wedge HTO. Therefore, it may be possible to accurately predict soft tissue correction by taking into account preoperative varus laxity, which consequently leads to a decrease in overcorrection.

Recently, the efficacy and of digital planning of osteotomy with a high interrater reliability [16] and the usefulness of a computer navigation system to provide a better target angle with a reduced risk of undercorrection and overcorrection [17, 18] were reported. On the other hand, achievement of planned alignment corrections after surgery still remains challenging. The primary reason may be the unpredictable influence of soft tissue on postoperative alignment, such as knee joint laxity and compensatory change of ankle joint alignment [8]. A retrospective observational study evaluating relationship between joint line convergence angle (JLCA), which is formed by two articular tangential lines of the distal femur and the proximal tibia, and alignment correction errors revealed that a greater difference pre- and postoperative JLCA was associated with greater overcorrection of lower limb alignment [14]. However, as the change in JLCA could not be predicted preoperatively; thus, overcorrection could not be predicted as associated with JLCA. In addition, they founded that as the postoperative limb alignment became more valgus, the postoperative JLCA became more parallel, and that as preoperative limb alignment became more varus, the preoperative JLCA became more convergent. As they documented, the close relationship between JLCA and limb alignment may be explained by the change in adduction moment of the medial compartment. Because the adduction moment is closely related with varus laxity, it is really plausible that varus laxity of the knee correlates with limb alignment, overcorrection. In fact, the result of the present study showed that preoperative varus laxity and  $\Delta$ JLCA were both significantly correlated with soft tissue

correction (overcorrection). The close relationship we found between preoperative varus laxity and soft tissue correction is clinically relevant because more accurate alignment correction could be achieved by surgical planning taking into account preoperative varus laxity as a factor of soft tissue correction.

Accurate preoperative prediction of the influence of soft tissue on postoperative alignment is important to obtain planned postoperative alignment as well as exact practice of the planned osteotomy [19]. In the present study, we focused on preoperative varus and valgus laxity of the knee as factors affecting postoperative alignment, which stem primarily from the laxity of the medial collateral ligament (MCL) and lateral collateral ligament (LCL). MCL is usually relaxed and LCL is tensed in varus deformity of medial compartment knee OA, while MCL is relatively tensed and LCL is relaxed following a lateral shift of the weight-bearing axis due to medial opening wedge HTO. As known that MCL and LCL are affected in knee OA, evaluation of varus/valgus laxity seems important to predict influence of soft tissue on alignment correction. Therefore, in the clinical practice, you have to be careful and keep soft tissue influence in mind. The more soft tissue correction you have, the more  $\Delta$ JLCA you get and the more you are in danger for an overcorrection.

There are some limitations in this study. Although we showed that 61 % of preoperative varus laxity is predicted as soft tissue correction, we have not verified whether this formula could work correctly. Further investigation is required in order to verify the application of our concept that “soft tissue correction” leads to more accurate alignment correction in medial opening wedge HTO. Soft tissue treatment such as hamstring elevation and superficial layer of MCL by surgical approach may affect the joint laxity and further postoperative lower limb alignment; so the effect of these soft tissue treatment on postoperative alignment of the lower limb should be investigated.

#### Compliance with ethical standards

**Conflict of interest** There are no conflict of interest to declare.

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