Editorial Commentary: Measurements for Successful High Tibial Osteotomy: Understanding Supine Versus Standing and Intraoperative Fluoroscopic Alignment Is Required

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Abstract: A high tibial osteotomy (HTO) that is used to correct varus malalignment, such as with medial arthrosis or before cartilage restoration or posterolateral reconstructions, represents an important and required surgery for clinical success. A major problem that occurs with HTO planning is that the preoperative measurements, with either lower limb supine or standing weight-bearing radiographs, will invariably show abnormal medial or lateral tibiofemoral compartment opening resulting from soft-tissue laxity or injury. It is imperative that this tibiofemoral joint opening be accounted for in the osteotomy correction calculations. There are well-described methods available that affect operative planning, such as the use of preoperative stress radiographs to determine the millimeters of tibiofemoral opening or closure. The use of intraoperative fluoroscopy with application of axial loading to the lower limb and verification of closure of the tibiofemoral joint is recommended. A careful fluoroscopic examination of the tibiofemoral compartments allows a final adjustment of the osteotomy correction and confirms the final weight-bearing line percent measurement and limb alignment. Post-operative radiographs are required to detect outliers resulting from unexpected soft-tissue laxity or inadequate correction.

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The diagnosis of a varus malalignment of the lower extremity in younger active patients and the associated surgery for correction with either opening wedge high tibial osteotomy (HTO) or closing wedge HTO have been the subject of multiple publications and clinical recommendations.[1-5] Authors have published advances in patient selection criteria, operative techniques to decrease complications, tibial slope correction, locking plate constructs to maintain the correction, and postoperative rehabilitation programs to regain knee motion and limb function.[5-9] Our center previously published on the importance of diagnosis of primary varus, double-varus (associated lateral joint opening with ligamentous laxity), and triple-varus (associated posterolateral ligament laxity with varus recurvatum) knees.[3,4] These advances have increased the overall success rates for HTO procedures for varus alignment and medial arthrosis and, as well, for varus-aligned knees before cartilage restoration, meniscus transplantation, and posterolateral ligament reconstruction.

Despite these positive advances, what remains missing in HTO surgical procedures are the techniques for precision and accuracy that are required to uniformly obtain the desired postoperative lower limb coronal correction. It is well established that the varus-aligned knee, with an abnormally high knee adduction moment, asymmetric weight bearing to the medial joint, and associated varus thrust with gait, requires correction to a valgus alignment for a successful clinical outcome.[4,10] I prefer the technique to avoid a major valgus correction with the intention to achieve a modest corrected weight-bearing line (WBL) in the 58% target area (rather than 62%). In knees without medial arthrosis, the target range is 54%, or 1° to 2° valgus, because the change in the knee adduction moment is minor with increasing WBL% and over-correction is avoided (Fig 1).

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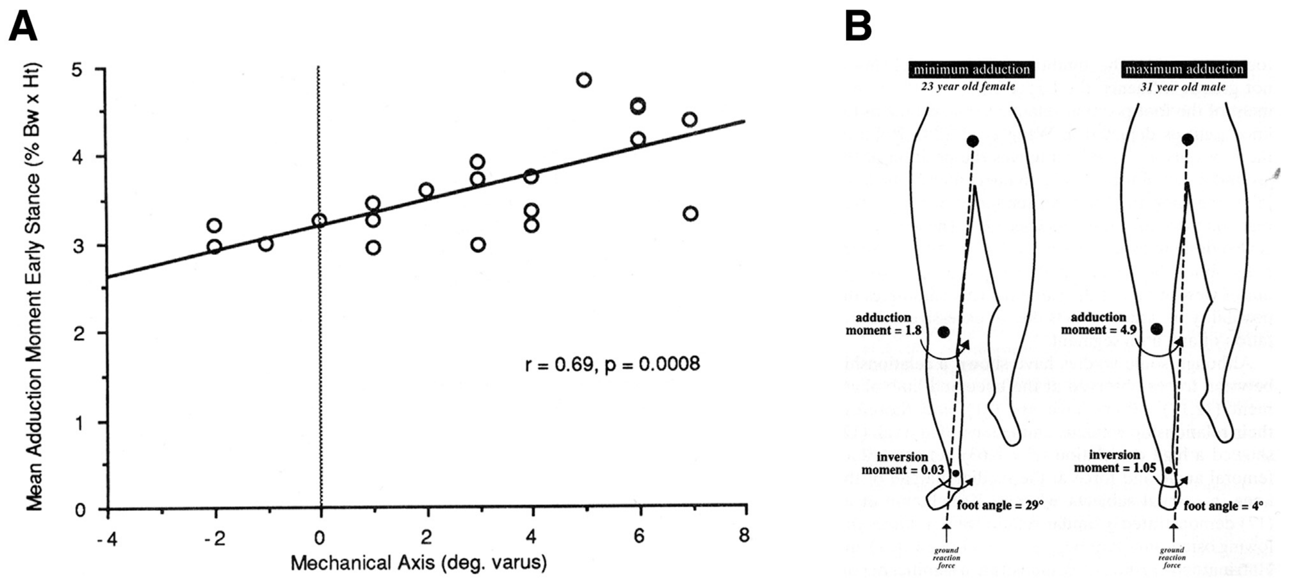

Fig 1. The knee adduction moment that produces medial tibiofemoral compartment loading and lateral joint tensile loads is dependent on both (A) the mechanical axis and (B) patient gait characteristics such as the rotation of the lower limb and the foot angle at stance phase. BW, body weight; Ht, height. (From Noyes FR, Barber-Westin SD. Tibial and femoral osteotomy for varus and valgus knee syndromes: diagnosis, osteotomy techniques, and clinical outcomes. In: Noyes FR, Barber-Westin SD (eds). Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes. 2nd ed. Elsevier, Philadelphia, PA:773-847.)

Throughout the past, multiple reports of failure to obtain the desired postoperative limb alignment correction have been published. There has been a high frequency of either under- or overcorrection that would be unacceptable for postoperative alignment after other operations such as total or partial knee replacement.[4] Many authors have questioned what are the missing factors that explain the high frequency of HTO correction errors postoperatively.[11-15]

Attempts to improve the accuracy of HTO corrections with computerized navigation have produced mixed results and recommendations. Stanley et al.[16] reported on 117 knees with varus angulation and medial arthrosis undergoing opening wedge HTO; 52 were corrected using computer navigation and 65 were corrected with conventional techniques and intraoperative fluoroscopy. Long-leg standing radiographs were obtained pre- and postoperatively. The authors reported no increase in overall accuracy in achieving lower limb alignment with computer-assisted navigation. In both groups, major outliers were present and, with a target WBL range of 53% to 63%, only 38.5% of the fluoroscopic group and 51.9% of the navigation group achieved the desired correction. In contrast, Reising et al.[17] reported in a group of opening wedge HTO knees no outliers in the navigated group (WBL 50%-70%) compared with 23% outliers in the fluoroscopic group. Iorio et al.[18] reported more accurate correction of lower limb varus alignment in a small group of 27 patients (11 conventional image, 13 navigated treatment). In this study, 86% achieved a postoperative mechanical axis of 182° to 186° with navigation, but only 23% achieved this correction with conventional treatment. Kyung et al.[12] concluded that, even with navigation, there may occur errors in limb alignment from medial or lateral soft-tissue ligamentous laxity and suggested that this unpredictability be addressed by axial compression in addition to valgus forces to simulate the weight-bearing condition.

Yan et al.[15] reported a systematic review of 34 studies of 2,216 HTOs (1,608 navigated, 608 conventional) and concluded that navigation resulted in improved alignment of the mechanical axis and posterior tibial slope, with both techniques providing equally improved patient outcomes. With navigation, there is a learning curve; however, this study reported pooled operative times of 96.4 minutes for navigated HTO and 87.7 minutes for conventional HTO. In agreement with other authors, this study noted the results reflect bony correction only and the non-weight-bearing conditions of both techniques require adherence to soft-tissue balancing and the influence of soft-tissue laxity.

In the study entitled, "Preoperative supine radiographs are more accurate than standing radiographs for preoperative planning in medial open-wedge high tibial osteotomy" by Kyun-Ho, Jae-Kyun, Jae-Jun, Ki-Mo, and Seung-Beom,[19] the preoperative supine whole-leg radiographs (WLR-SU) showed a more accurate prediction of the postoperative limb alignment hip-knee-ankle angle and mechanical axis deviation (WBL%) than standing weight-bearing radiographs (WLR-WB). Accordingly, these authors recommended preoperative

WLR-SU radiographs instead of WLR-WB measurements.

There are important points raised by this study that require comment. First, it is necessary in both standing and supine WLR that correct limb positioning be obtained with a symmetrical view of the intercondylar notch and eminences, one-third medial offset of the fibular head on the lateral tibial plateau, forward-facing patella, neutral lower limb rotation, and avoidance of knee hyperextension (highly important in standing WLRs).

Second, the issue of associated lateral soft-tissue laxity and increased lateral joint opening that add to the overall varus alignment is well known and recognized as a major source for overcorrection. In the current study, the WLR-WB showed the effect of increased lateral joint opening resulting from lateral soft-tissue laxity, with a WBL of 16.61 ± 12.99% compared with 23.01 ± 10.26%, indicating the WBL was displaced more medially in the tibiofemoral compartment. We described in prior publications[4,8] that after HTO, abnormal lateral joint separation is corrected because the WBL is transferred into the lateral compartment. In the current study, the joint line convergence angle (JLCA) was increased in the preoperative WLR-WB and not in the WLR-SU as expected, and the postoperative WLR-WB radiographs showed the corrected JLCA with closure of the lateral joint.

One of the problems I have encountered with WLR-SU views is that the medial joint space may not be fully compressed or closed as occurs with WLR-WB views. This effects preoperative planning and leads to the possibility of an undercorrection because the medial joint space would be closed after the HTO. If there is any question on the actual joint space narrowing, stress views are helpful for the medial and lateral tibiofemoral compartments. In addition, the measurement of the medial tibial plateau mechanical axis of the tibia provides an important checkpoint for the necessary osseous correction and may be more accurate than the WLR-SU views.

I agree with the authors' conclusions that the surgeon may correctly select supine radiographs and apply appropriate preoperative limb correction techniques for selection of the postoperative WBL percentage alignment. I compliment the authors on their study and application of these measurement parameters to their HTO patients. However, in addition to the mean values of the final WBL correction reported, the percent of outlier knees that were outside the tibial WBL target area was not reported. Of interest, the authors used the WBL technique we described in 1993,[3] which relied on selecting the target region of the new WBL percent intersection on the tibial plateau in addition to the measurement of the hip-knee-ankle mechanical axis. Tibial slope measurements and corrections are highly important and discussed in detail elsewhere.[4]

Another method to determine the limb alignment correction relies on WLR-WB of both lower extremities that has been used in a number of studies over the years. The advantage of using full standing radiographs is that the medial joint space is compressed and narrowed due to the medial arthrosis. In the WLR-SU, the medial joint space is not compressed in the absence of weight-bearing compressive loads. A major issue in

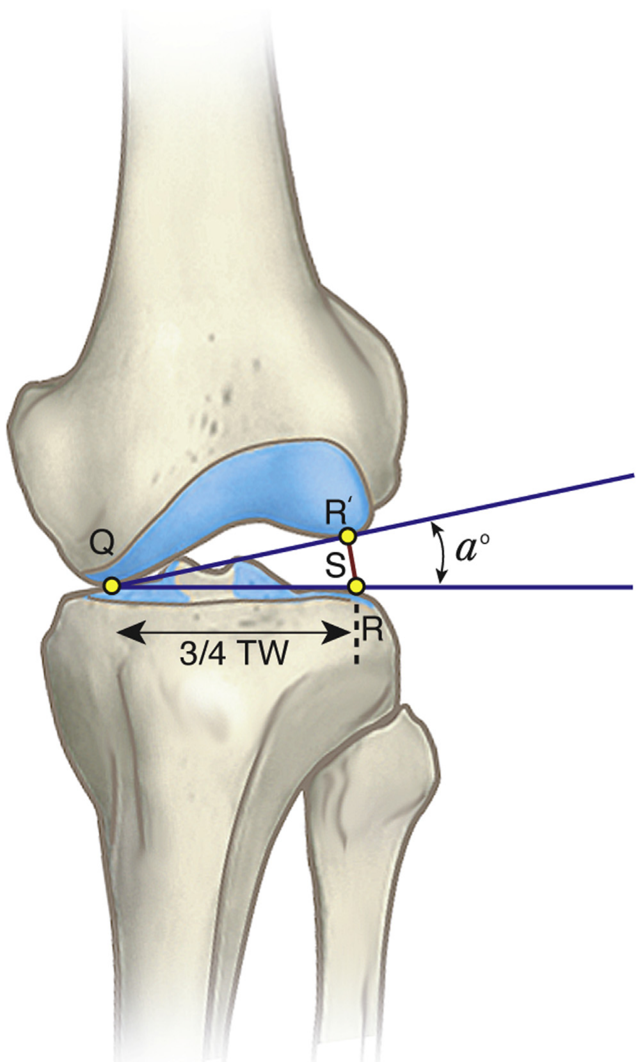

Fig 2. The effect of abnormal lateral joint opening on varus angular deformity. With a varus moment applied through a fulcrum, or center of rotation (Q), lateral joint space opening (S) occurs in the presence of slack lateral soft tissues resulting in an additional α degrees of varus angular deformity. TW, total width tibial plateau. (From Noyes FR, Barber-Westin SD. Tibial and femoral osteotomy for varus and valgus knee syndromes: diagnosis, osteotomy techniques, and clinical outcomes. In: Noyes FR, Barber-Westin SD (eds). Noyes' Knee Disorders: Surgery, Rehabilitation, Clinical Outcomes. 2nd ed. Elsevier, Philadelphia, PA:773-847.)

using bilateral WLR-WB is to measure the actual lateral joint opening and subtract this from the final calculated wedge correction at surgery. We previously published[3,4] that 1 mm of lateral joint opening equals close to 1° of angular correction (Fig 2). In the current study, there was no reference to this required correction in the preoperative WLR-WB views. Accordingly, the hypothesis of a difference in the 2 techniques of a supine versus a standing preoperative WLR may reflect not using the required corrections previously described.

I do have a concern with this study and quite frankly with many published HTO studies on the lack of a rigorous (enhanced) intraoperative technique that uses lower limb hip-knee-ankle fluoroscopy to verify the correction obtained at surgery. Granted, the fluoroscopy examination is supine and not under full weight-bearing conditions; however, we published a technique that we have used for many years that has been most helpful.[4] The technique for intraoperative fluoroscopy is not novel and involves axial compression and determination of closure of the medial and lateral compartments that are easily visualized under limb loading maneuvers.

The lower limb fluoroscopy examination is as follows:

1. A metal rod is used instead of a flexible cord.
2. The lower limb is positioned with neural rotation, with clear visualization of the intercondylar eminences and medial fibula offset, and forward-facing patella. During the final WBL measurement, the medial-to-lateral offset of the metal rod is easily shown with internal and external limb rotation because the rod is actually anterior to the center of rotation (and not at the central hip-knee-ankle functional axis). I prefer to make the final WBL in neutral to 10° of external rotation, which matches the normal foot progression angle of the patient.
3. A sponge-stick is used to maintain the rod over the central femoral head, which is marked on the drapes to verify that the rod position is maintained. A double drape is used between the hip joint and tourniquet that allows the rod to lie against the anterior knee joint without angulation.
4. A second assistant holds the rod distally at the predetermined mark on the ankle drape indicating the center of the talus.
5. The surgeon holds the lower leg and performs a gentle varus and valgus rotation that determines that the medial and lateral tibiofemoral compartments are CLOSED, recognizing the common occurrence of lateral soft-tissue laxity that effects the final lower limb alignment.
6. Holding the limb in this alignment with the knee at 5° to 10° flexion (a posterior knee pad may be used), apply a firm axial compression which maintains closure of both the tibiofemoral compartments.
7. The final WBL% intersection is determined with visual confirmation of closure of the tibiofemoral compartments and adjustments made in the opening wedge as required. After internal locking plate fixation, these steps are repeated to confirm maintenance of the desired WBL correction.

It may initially appear somewhat superfluous to describe the fluoroscopic technique with such detail. Sabharwal and Zhao[20] published a comparison between preoperative standing lower limb radiographs and supine intraoperative fluoroscopy and noted a mean of 13.4 mm in the WBL tibial measurements, which is a major discrepancy between the 2 techniques. There was no description of the effect of abnormal lateral joint opening on the standing preoperative radiographs. In addition, there was no evidence that axial loading and determination of the closure of the tibiofemoral compartments on the intraoperative fluoroscopy was done, which may account for the errors reported. The determination of the WBL percent tibial intersection by fluoroscopy has replaced the need for computer navigation at our center, although I still prefer navigation in varus-aligned knees with gross instability and major ligamentous deficits.

Lee et al.[21] recently discussed the concept of a latent medial laxity of the medial ligamentous structures. After HTO and transfer of weight-bearing to the lateral tibiofemoral compartment, there may occur opening of the medial tibiofemoral compartment, which increases the valgus alignment and leads to an overcorrection. These cases tend to occur in larger varus angular deformities with a higher JLCA.

In summary, the surgeon may select either supine or standing weight-bearing WLR views for preoperative planning measurements, recognizing that both radiographic techniques have inherent measurement errors in determining tibiofemoral compartment opening or closure. There are soft-tissue corrective errors that effect lower limb alignment before and after HTO in addition to the osseous correction. I have found in my operative HTO experience never to rely only on the preoperative radiographic measurements because there is almost always the necessity at surgery to make minor adjustments based on the described axial loaded fluoroscopic technique. A postoperative WLR-WB at 4 weeks is a necessity to prove the final limb alignment is within expected parameters. I advise my patients that even with all the appropriate planning, the operation does have the possibility of not achieving the expected correction of limb alignment and a postoperative correction, even though rare, may be required. An example of a repeat operative adjustment and need for correction would be a remaining varus alignment or an obvious valgus malalignment with a WBL >75%. An HTO is very similar to any planned total knee replacement with the necessity of understanding abnormalities in the medial and lateral ligamentous structures that effect joint opening (gap) assessment and correction along with overall osseous structural alignment.

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