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Case Report

Computer Navigation and Fixator-Assisted Femoral Osteotomy for Correction of Malunion After Periprosthetic Femur Fracture

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Abstract: Periprosthetic femoral fracture post–total knee arthroplasty can lead to malunion. This may lead to abnormal force transmission and accelerated wear of the prosthesis. Accurate femoral deformity correction depends on the combined correction of the mechanical axis alignment and the lateral distal femoral angle. Modern external fixation correction devices allow for simultaneous gradual corrections in multiple planes through one osteotomy site. Despite the accuracy of the devices, technical failures occur and are typically due to difficulty in assessing the exact intraoperative correction. Furthermore, conventional intraoperative measurements display high interobserver and intraobserver variations. Computer navigation has demonstrated great accuracy. Combining a mechanical corrective device and navigation should allow for increased precision and dynamic control intraoperatively. The current authors report on a clinical application of a novel minimally invasive fixator-assisted correction of a posttraumatic distal femoral varus deformity after total knee arthroplasty with combined navigated measurements. **Keywords:** limb correction, femoral osteotomy, navigation, alignment, deformity, external fixator corrections.

Angular deformities of the distal femur are often seen in patients after malunited fractures. Deformity leads to abnormal stresses across the knee and can lead to premature arthrosis [1]. Deformity after total knee arthroplasty (TKA) similarly produces abnormal force transmission and may cause premature failure.

Realignment of the knee joint can be performed to prevent this problem. Accurate correction of femoral deformity depends on a combined correction of the mechanical axis alignment and the lateral distal femoral angle [2]. Operative correction of the mechanical axis of the lower extremity can be accomplished through a distal femoral osteotomy.

Various successful surgical techniques for distal femoral osteotomy have been described. Recent trends *favor* use of less invasive techniques. Using temporary external fixation intraoperatively to obtain correction of deformity, followed by intramedullary nailing for ultimate fixation, has shown good results [3,4].

Despite the accuracy of these external fixation devices, technical failures occur and are often associated with assessment of the final intraoperative correction [5,6]. Traditional methods used to assess the mechanical axis intraoperatively have been shown to be cumbersome and inaccurate.

Recent integration of computer navigation technology into corrective osteotomy procedures allows precise intraoperative assessment of the mechanical axis and has been shown to improve accuracy and reduce exposure to radiation when compared with conventional techniques in high tibial osteotomies. Navigation allows for dynamic visualization of real-time reliable mechanical axis assessment throughout the duration of the operative procedure without a need for further radiographic imaging. The combination of an external fixator and navigation should allow for increased precision and dynamic control intraoperatively, particularly in the setting of complex distal femoral corrections.

The current authors report on a novel clinical application of fixator-assisted correction in combination

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with navigation of posttraumatic distal femoral varus realignment after periprosthetic fracture, post-TKA.

Patient and Technique

Patient

A 59-year-old female patient who had previously undergone a left TKA sustained a periprosthetic fracture of the distal femur. The fracture was malunited (Fig. 1). The interval between fracture and clinical presentation was 3 years.

The patient complained of pain over the medial aspect of the knee, above and below the prosthesis. The patient's uninterrupted walking distance was limited to 2 blocks, and stair climbing ability was also reduced. Clinical examination revealed a flexion contracture of 5° with ability to flex to 120°, grade 3 instability of the lateral collateral ligament (LCL), limb shortening of 1.8 cm, and varus malalignment of the lower limb axis. No rotational malalignment was noted. The patient also had a significant lateral thrust upon weight bearing.

Radiographic Evaluation

Preoperative 51″ standing bipedal anteroposterior (AP) radiographs were obtained. Conventional AP and lateral radiographs included the distal femur, knee joint, and proximal tibia of the affected left side. The deformity of the distal femur and the overall leg alignment was quantified by the malalignment test [2].

Measurements revealed a healed periprosthetic fracture, a stable knee prosthesis without radiolucency or signs of loosening, a mechanical lateral distal femoral angle of 104°, procurvatum (flexion) of the distal femoral fragment of 10°, a mechanical axis of 12° varus, a medial mechanical axis deviation (MAD) of 74°, and a medial proximal tibial angle of 88° (Fig. 1). Limb shortening of 1.8 cm was also noted. There was a joint line obliquity of 5° related to the LCL laxity in combination with a medial MAD.

Preoperative Planning

With reference to preoperative radiographs and a clinical assessment, the operative plan included the following corrective surgical steps after distal femoral osteotomy:

- Correction of the varus deformity to neutral
- Extension of distal femoral fragment of 10°
- Use of a neutral wedge correction to achieve some limb lengthening

A technical description of fixator settings and the accuracy of correction in combination with a locked plating technique are correlated with the computer-

Fig. 1. Conventional preoperative AP and lateral radiographs of the affected leg.

navigated measurements in this clinical case. The technique was performed on a sawbone model in the computer navigation laboratory and then implemented in the operating room.

In the computer navigation laboratory at the Hospital for Special Surgery, the procedure was performed on a sawbone model. The multiaxial correction frame (EBI Biomet, Parsippany, NJ) was applied to an intact femur. The hinge was placed over the osteotomy site at the distal femur. External fixation pins were placed so that their position would not hinder placement of the lateral plate; the proximal pins were placed anteriorly, and the distal pins were placed medially. After distal femoral osteotomy, stepwise 1° angular corrections of varus with up to a 10° overall correction were executed by adjusting the fixator. Simultaneous navigated measurements were performed and revealed corresponding 1° of respective changes of the mechanical axis. A high correlation between navigation and the EBI frame was found. However, translational movements of the femur could not be adequately measured because of technical limitations of the image-free navigation system.

Operative Technique

A combination of epidural and femoral block anesthesia was applied. The patient was positioned supine on a radiolucent table. An external fixator was applied to the distal third of the femur. Two 6.0-mm Schanz screws were inserted from anterior to posterior in the diaphysis, and 2 medial Schanz screws were inserted into the distal condyle under fluoroscopic control. The center of rotation of angulation was defined based on preoperative measurements and was localized on the patient using C-arm fluoroscopy. This was performed to accurately position the hinge of the fixator at the center of rotation of angulation.

Next, navigation was performed using Surgetics Station (Praxim, La Tronche, France) hardware and dedicated osteotomy reconstruction software. The required reference markers were attached to the frame's proximal Schanz screws, whereas at the proximal tibial site, 2 additional 3.0-mm Schanz screws were used for marker fixation.

Image-free leg alignment data acquisition included registration of the hip and ankle center and identification of percutaneous landmarks at the femoral and tibial epicondyles (Fig. 2). Passive flexion-extension motion sequences were also registered. Initial measurements with the system revealed a mechanical leg axis of 11° varus in full extension, which did not correlate with the preoperative weight-bearing x-ray varus angle of 12° (Fig. 3). This discrepancy was attributed to dynamic malalignment of joint laxity. Axial loading through the foot of the supine patient in the operating room increased the varus deformity to 15° as measured by the computer navigation system. Correspondingly, a prior study conducted by the current authors demonstrated that simulated weight bearing affects the measured navigated limb alignment in the coronal plane postosteotomy [7]. The osteotomy site was chosen to be the apex of the deformity. The osteotomy was performed using a percutaneous multiple drill hole and osteotome technique under fluoroscopic guidance.

After navigated registration had been completed, mechanical leg alignment correction was performed using external fixation for correction in the frontal plane. Stepwise corrections in 1° increments were performed while being simultaneously measured by the navigation system (Fig. 3). The fixator adjustments of each degree did not completely correlate with the degree correction noted by the navigation. Soft tissue tension caused some compromise in the skeletal response to fixator adjustment. Under constant visualization on the navigation screen, the completed coronal correction of 11° was controlled and finally documented

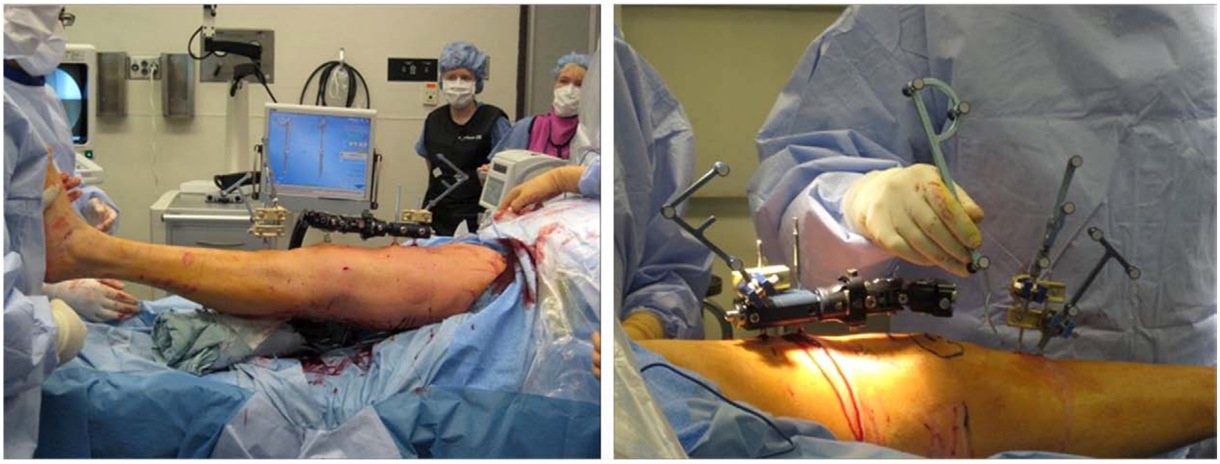

Fig. 2. Image-free leg alignment data acquisition included registration of defined percutaneous femoral and tibial landmarks intraoperatively.

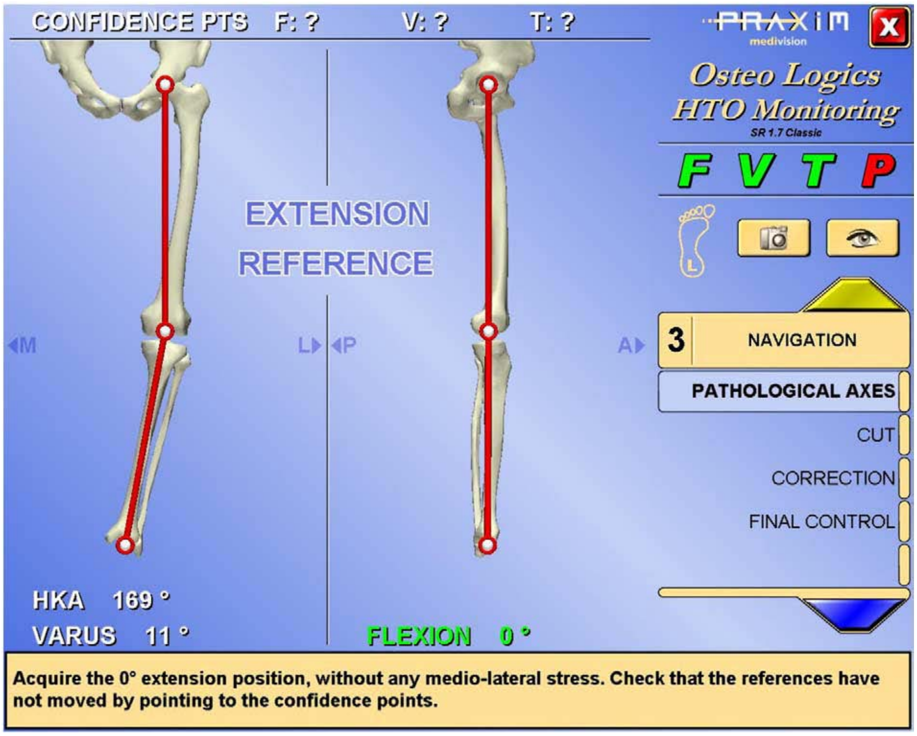

Fig. 3. Intraoperative screenshot of initial varus alignment of 11° after correction of the distal femoral flexion was done before the open wedge procedure. Stepwise corrections in 1° increments were done, simultaneously measured by the navigation system.

in a neutral leg alignment position. This required 13° of correction in the fixator. Although the degrees of correction measured by the navigation and the fixator were not 1:1, there was a strong correlation in measurements. Axial loading was again performed and showed no further deformity. This finding supports the concept that a well-aligned limb is more resistant to deformity from ligamentous laxity.

Final positioning was secured with the frame. A sterile tourniquet was placed on the upper thigh in preparation for plating. Definitive osteotomy fixation was performed under tourniquet control with a precontoured distal femoral locking plate (EBI Biomet) using a minimally invasive sliding technique under fluoroscopic control. The external fixator was then removed. Repeated navigated measurements of leg alignment and final intraoperative fluoroscopic images were taken and showed no change in position. The overall operative procedure was 138 minutes.

Postoperative Follow-up

The immediate postoperative course was uneventful. The patient left the hospital after 2 days, with partial weight-bearing status for 6 weeks. The patient was followed up clinically at 2 and 6 weeks of intervals. The range of knee motion was 0° to 120°. The lateral collateral ligament was persistently lax, but minimal thrusting was evident on examination.

Postoperative weight-bearing long radiographs revealed a mechanical leg axis of 2° varus with a MAD of 12 mm medially. This was attributed to LCL laxity causing a dynamic varus. The angle between distal femoral fragment and shaft revealed 1° of flexion. At actual time to heal, the ossification of the osteotomy site was seen, with a minimal persistent osteotomy gap (Figs. 4 and 5). Leg length measurements showed a leg length discrepancy of 0.5 cm in favor of the uninjured right lower limb. At 6 weeks postsurgery, the patient was bearing full weight and mobilizing without pain or need for assistance.

Discussion

It has been shown that coronal deformities of 10° and sagittal deformities of 20° can lead to a complex imbalance of the collateral knee ligaments and thus affect the stability and outcome of TKA [8]. Posttraumatic extra-articular femoral deformities after TKA can be difficult to correct adequately, depending on the location of malalignment. The major goal of this realignment procedure was to correct the existing coronal malalignment to provide knee stability and pain reduction and minimize overloading of the medial compartment, thus preventing early implant failure.

Modern external correction devices such as the Taylor spatial frame (Smith and Nephew, Memphis, TN) or the EBI multiaxial correction (EBI Biomet) frame allow for simultaneous gradual corrections in multiple planes through one osteotomy side. Consequently, corrections of coronal, sagittal, and axial plane

Fig. 4. Comparative preoperative and postoperative weight-bearing long-leg radiographs.

deformities can be performed by the defined hinge axis of those external devices. Based on exact preoperative long-leg standing radiographs and preoperative planning, correction can be obtained intraoperatively. These frames can temporarily secure the reduced bone allowing for further final fixation with locked plates or intramedullary nailing technique.

The operative use of temporary external correction devices in combination with final internal osteosynthetic devices postosteotomies at the distal femur has been widely established with evidence of successful clinical applications involving various techniques and implants [9].

Although general applications of the external fixator have shown good results, to date, the direct intraoperative measurement of limb alignment has used relatively unreliable techniques such as the Bovie cord method, a leg grid, or preoperative planning. All of these techniques demonstrated high interobserver and intraobserver variation. The oft-used "cable method" uses the Bovie cord and fluoroscopy showing where the cord crosses the knee joint. Alternative methods include using a grid placed beneath the patient with lead reference lines or measurement of correction angles on conventional radiographs intraoperatively. However, these techniques are known to have high interobserver and intraobserver variation, have low reproducibility and could be negatively influenced by limb rotation. According to a recent study, only 50% of tibial osteotomies achieved the desired correction [10]. Furthermore, the dynamic components of malalignment, often resulting from ligamentous laxity, cannot be assessed in an optimal fashion intraoperatively. Consequently, overcorrections and undercorrections have been described as the most common reason for failure after femoral and tibial osteotomies [10].

There is a need for a technique that can accurately measure the mechanical axis of the lower extremity intraoperatively and thus improve correction techniques. Such a technique will greatly improve acute correction techniques. The current authors were able to show a strong correlation between the degrees of angular correction achieved by navigation and the fixator in the coronal plane in a sawbone model and the clinical case

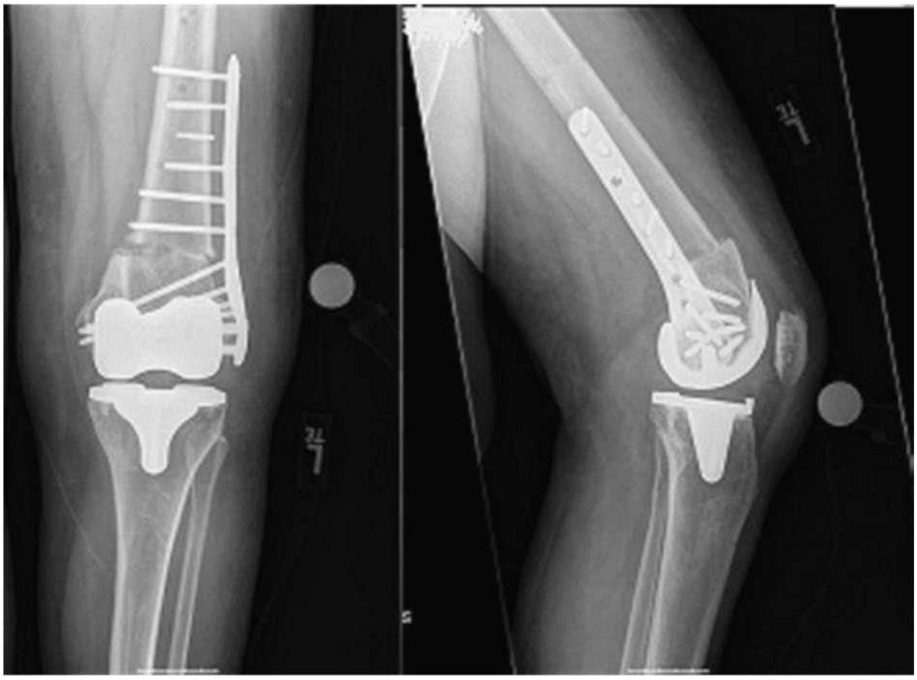

Fig. 5. Postoperative conventional AP and lateral radiographs.

described. Either technique would appear to provide a reliable intraoperative measurement system.

In the operating room, there was a differential response between fixator adjustment and navigation measurement. This may be explained by soft tissue tension. In addition, a greater magnitude of angular correction is needed at the distal femur osteotomy site than the recorded mechanical axis deformity. The further the osteotomy is away from the joint line, the less effect it has on changing the mechanical axis deformity. The navigation was particularly helpful at measuring the intraoperative correction.

However, this correlation was not observed for translational corrections in the coronal plane or for angular corrections in the sagittal plane. Navigation system is limited in its ability to track only 2 reference markers, one femoral and one tibial. Therefore, relative changes between the femoral fragments cannot be adequately assessed. Consequently, the authors limited the navigated measurements solely to the mechanical leg alignment.

Major limitations of the system include any complex multiplanar corrections, especially when translational deformity exists or translation is required to maintain the mechanical axis postosteotomy. Although the system could not track the translational movements accurately, reinitialization of the navigation system was possible at the end of the corrective procedure to reestablish the mechanical axis. Consequently, accurate simultaneous measurements of multiplanar deformities cannot be measured with the described navigation system and module. Future systems need to combine an image-based and image-free registration process to track all planes of deformity.

However, the ability of this system to demonstrate the mechanical axis at postcorrection makes it a very powerful intraoperative tool. The navigation system used in this study was originally designed for proximal tibial osteotomies where it has demonstrated the ability to track changes in all planes. Future developments in this system directed at redesigning the software for distal femoral osteotomy would greatly improve its accuracy and responsiveness. As it stands, this navigation system is very useful for direct tracking of angular coronal plane corrections and for finding the mechanical axis postcorrection to ensure that the desired mechanical axis has been established. Other systems *that exist* include those variables with combined use of a fluoroscopic registration process at the proximal and distal femoral regions. Descriptions for successful combined image-free navigated corrections were recently published [11].

Our findings correlate with previous studies for tibial and combined femoral-tibial corrections, which demonstrated a greatly improved rate of reproducibility (96%) in obtaining the proper axis while using navigation, compared with conventional techniques with only a 71% reproducibility rate for tibial and combined femoral-tibial corrections [12]. Another study also demonstrated lower variability in achieved correction using navigation, including significantly reduced fluoroscopic radiation times, compared with conventional techniques [9].

General drawbacks of the navigation system *also* include high initial and maintenance costs, increased operative time, and invasive fixation of the reference markers. Although some of those factors could not be adequately addressed for regular clinical applications to date, we believe that navigation provides a useful and reliable tool. It may increase the precision of femoral corrective osteotomies used in combination with an external correction device. This case demonstrates the combination with state-of-the-art mechanical and technical devices to accomplish distal femoral osteotomies.

References

1. Sharma L, Song J, Felson DT, et al. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. JAMA 2001;286:188.
2. Paley D, Herzenberg JE, Tetsworth K, et al. Deformity planning for frontal and sagittal plane corrective osteotomies. Orthop Clin North Am 1994;25:425.
3. Eralp L, Kocaoglu M, Cakmak M, et al. A correction of windswept deformity by fixator assisted nailing. A report of two cases. J Bone Joint Surg Br 2004;86:1065.
4. Gugenheim Jr JJ, Brinker MR. Bone realignment with use of temporary external fixation for distal femoral valgus and varus deformities. J Bone Joint Surg Am 2003;85-A:1229.
5. Noyes FR, Barber-Westin SD, Hewett TE. High tibial osteotomy and ligament reconstruction for varus angulated anterior cruciate ligament-deficient knees. Am J Sports Med 2000;28:282.
6. Dreher T, Wolf S, Braatz F, et al. Internal rotation gait in spastic diplegia—critical considerations for the femoral derotation osteotomy. Gait Posture 2007;26:553.
7. Kendoff D, Board TN, Citak M, et al. Navigated lower limb axis measurements: influence of mechanical weight-bearing simulation. J Orthop Res 2008;26:25.
8. Macule-Beneyto F, Hernandez-Vaquero D, Segur-Vilalta JM, et al. Navigation in total knee arthroplasty. A Multicenter Study. Int Orthop 2006;30:536.
9. Hankemeier S, Zheng G, Wang G, et al. Navigated open wedge high tibia osteotomy: advantages and disadvantages in comparison to the conventional technique in a cadaver study. Knee Surg Sports Traumatol 2006;14:917.
10. Marti CB, Gautier E, Wachtl SW, et al. Accuracy of frontal and sagittal plane correction in open-wedge high tibial osteotomy. Arthroscopy 2004;20:366.
11. Sastre S, Torner P, Macule F. Knee osteotomy: navigation guided and arthroscopy assisted. Knee Surg Sports Traumatol Arthrosc 2007;15:1215.
12. Saragaglia D, Roberts J. Navigated osteotomies around the knee in 170 patients with osteoarthritis secondary to genu varum. Orthopedics 2005;28(10 Suppl):s1269.