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# Application of Functional Alignment Principles and Stepwise Gap Balancing in Staged Bilateral Total Knee Arthroplasty for Severe Varus Knee Osteoarthritis With Lateral Femoral Bowing Using Conventional Instrumentation: A Case Report

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## Abstract

Severe varus deformity with apparent lateral femoral bowing can complicate component alignment and soft-tissue balancing during total knee arthroplasty (TKA) performed with conventional instrumentation. Functional alignment principles emphasize restoration of balanced soft tissues and stable knee kinematics rather than rigid correction to neutral mechanical alignment.

We report a case of bilateral Grade IV osteoarthritis with severe varus deformity managed using conventional jig-based TKA and rectangular gap balancing principles. A 70-year-old female presented with bilateral knee pain for more than 25 years associated with progressive deformity, difficulty in ambulation, and limitation of daily activities. Clinical examination revealed fixed varus deformity of approximately 20° on the right side and 15° on the left side, fixed flexion deformity of 20° bilaterally, medial soft tissue contracture, and relative lateral laxity. Flexion was preserved up to 110° and 115° in the right and left knees, respectively. Radiographs demonstrated bilateral Grade IV osteoarthritis with severe medial compartment degeneration and radiographic evidence of lateral femoral bowing. The patient, therefore, underwent staged bilateral TKA using conventional instrumentation, with the left knee replaced first, followed by the right knee during a subsequent admission after satisfactory recovery from the initial procedure. Femoral preparation was performed using a conventional intramedullary alignment guide. A 5° distal femoral valgus resection was performed on the left knee, while a 6° distal femoral valgus resection was used on the right knee. The resection angle was individualized according to the deformity characteristics and intraoperative assessment of coronal alignment and soft-tissue balance rather than applying a uniform valgus angle to both knees. Sequential balancing consisting of osteophyte excision, selective medial release, posteromedial release, and medial reduction osteotomy was performed to achieve balanced rectangular flexion and extension gaps. Postoperative radiographs demonstrated satisfactory component positioning and restoration of acceptable coronal alignment. Complex varus knee morphology and lateral femoral bowing may be successfully managed using functional alignment principles even when advanced technologies are unavailable. Careful deformity assessment and stepwise soft tissue balancing remain critical to achieving stable ligament tension and satisfactory knee kinematics. Functional alignment and rectangular gap balancing can be successfully achieved in severe bilateral varus knees with lateral femoral bowing using conventional instrumentation. Individualized balancing strategies may facilitate improved postoperative range of motion, Oxford Knee Scores (OKS), and clinically stable knees on examination without the need for robotic or navigation-assisted systems.

**Categories:** Pain Management, Orthopedics
**Keywords:** constitutional varus, conventional instrumentation, functional alignment, gap balancing, lateral femoral bowing, total knee arthroplasty

## Introduction

Total knee arthroplasty (TKA) is an established treatment for end-stage knee osteoarthritis in patients with persistent pain and functional limitation despite appropriate nonoperative management. Traditional mechanical alignment in TKA generally aims to restore the lower-limb mechanical axis toward neutral by orienting the distal femoral and proximal tibial resections according to their respective mechanical axes and predefined coronal targets. The resulting femoral and tibial component orientations contribute to, but are not synonymous with, the overall hip-knee-ankle (HKA) alignment [1,2].

Constitutional varus deformity may arise from increased distal femoral varus, decreased medial proximal tibial angle, extra-articular deformities such as lateral femoral bowing, or a combination of these factors. In

longstanding osteoarthritis, secondary intra-articular deformity, medial soft tissue contracture, and lateral ligament laxity may further complicate balancing during TKA [2,3].

Functional alignment is a patient-specific alignment philosophy that seeks to individualize femoral and tibial component positioning according to the patient's native lower-limb morphology and soft-tissue envelope while maintaining component orientation within predefined safe alignment boundaries. Unlike traditional mechanical alignment, which generally aims to restore a neutral mechanical axis, functional alignment does not require uniform correction of every patient to neutral alignment. Instead, component positioning is individualized to achieve appropriate coronal and sagittal alignment while preserving balanced ligament tension and physiological knee kinematics [4,5]. Modern functional-alignment workflows are frequently facilitated by navigation or robotic technology; however, the underlying principles of individualized alignment and soft-tissue preservation may also be applied using conventional instrumentation. Importantly, gap balancing is an intraoperative technique that may contribute to functional alignment but is not synonymous with functional alignment itself.

Although robotic and computer-assisted technologies have facilitated adoption of functional alignment concepts, conventional instrumentation remains the most widely utilized technique in many institutions. This report describes the management of severe bilateral varus knee osteoarthritis with apparent lateral femoral bowing on available preoperative radiographs using conventional jig-based TKA in which functional-alignment principles were applied through individualized component positioning and sequential soft-tissue balancing, with the aim of achieving stable knee mechanics without obligatory correction to a uniform neutral mechanical axis.

## Case Presentation

A 70-year-old female presented with bilateral knee pain for approximately 25 years. The symptoms had progressively worsened over time and were associated with increasing deformity, difficulty in walking, inability to climb stairs comfortably, and significant limitation of activities of daily living. Conservative treatment including analgesics, physiotherapy, and activity modification had failed to provide adequate relief.

Clinical examination revealed asymmetrical severe varus deformity involving both knees. Coronal alignment and ligamentous stability were assessed clinically in both full extension and approximately 90° of knee flexion. The patient demonstrated a fixed varus deformity with medial soft-tissue tightness and relative lateral laxity. The range of motion was 20°-110° on the right and 20°-115° on the left, indicating a fixed flexion deformity of approximately 20° in both knees. Assessment was performed despite pain associated with advanced osteoarthritis; although pain limited the extent of examination, the varus deformity and collateral ligament tension pattern were reproducible in both extension and flexion.

Preoperative radiographic evaluation demonstrated advanced Grade IV osteoarthritis involving both knees, characterized by complete medial compartment joint space loss, large marginal osteophytes, subchondral sclerosis, and severe varus alignment. Standing anteroposterior radiographs demonstrated apparent lateral femoral bowing bilaterally. The degree of femoral bowing was not quantitatively measured because the available preoperative radiographs did not permit reliable assessment. Preoperative full-length standing HKA radiographs were unavailable before surgery. Consequently, objective measurements of the hip-knee-ankle angle, mechanical lateral distal femoral angle, and medial proximal tibial angle could not be obtained for preoperative planning. Consequently, a formally quantified preoperative functional-alignment target could not be established. Alignment decisions were individualized intraoperatively based on deformity morphology, trial component position, flexion and extension gap balance, and collateral ligament tension. Preoperative full-length standing HKA radiographs were not available, limiting quantitative assessment of the overall mechanical axis and the individual femoral and tibial contributions to the coronal deformity. Therefore, the contribution of femoral and tibial deformities to the overall coronal malalignment could not be precisely quantified. Preoperative anteroposterior radiographs of the left and right knees were available and shown in Figure *1*. Composite lateral radiographs demonstrating advanced degenerative changes are shown in Figure *2*.

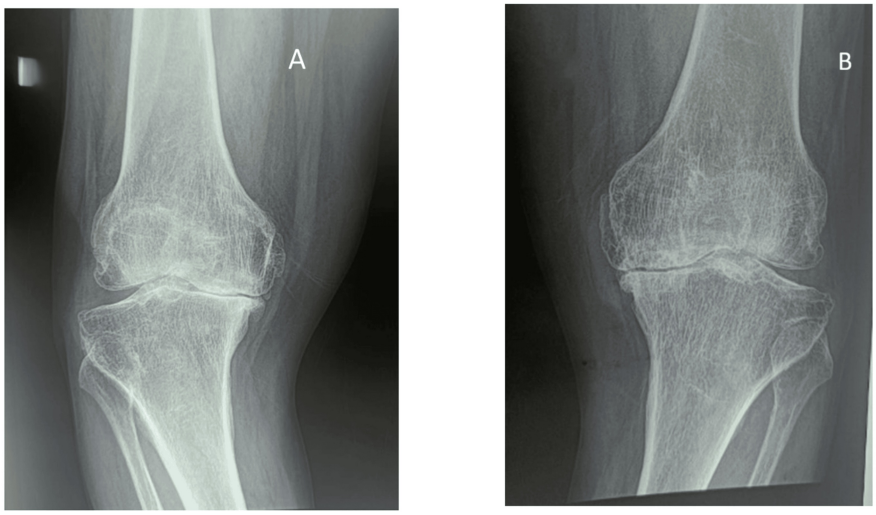



**FIGURE 1: Preoperative anteroposterior radiograph of the right knee (A) and left knee (B) demonstrating Grade IV osteoarthritis with severe medial compartment narrowing, osteophyte formation, subchondral sclerosis, and varus deformity.**

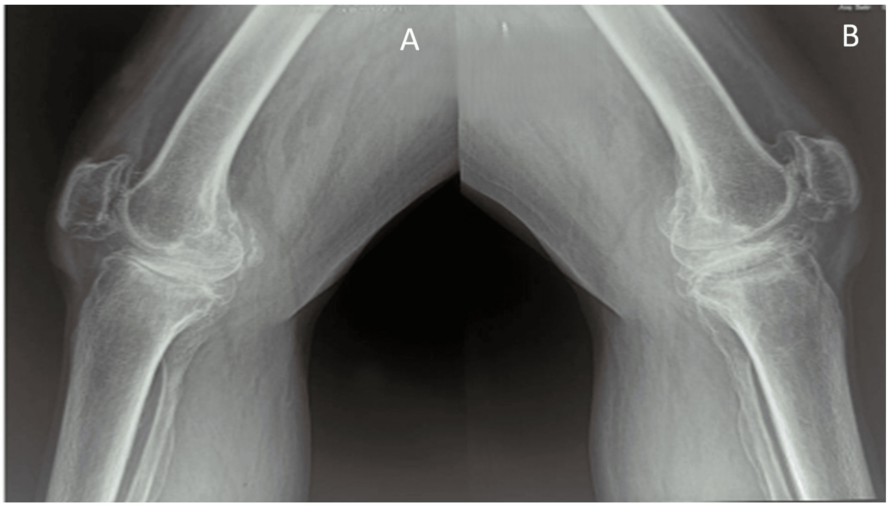



**FIGURE 2: Composite preoperative lateral radiographs of both knees (A: right knee, B: left knee) demonstrating advanced degenerative changes and osteophyte formation.**

Because of severe pain, progressive deformity, and substantial functional limitation, bilateral TKA was planned. However, a staged approach was adopted, with left TKA performed initially, followed by right TKA after a satisfactory recovery period of three months from the first procedure.

## Surgical technique

The left knee was operated first using a standard medial parapatellar approach under combined spinal epidural regional anesthesia. Extensive medial osteophytes were identified and excised. Femoral preparation was performed using a conventional intramedullary alignment guide. Distal femoral valgus resection was individualized according to intraoperative assessment rather than applying a uniform valgus angle to both knees. A 5° valgus cut provided satisfactory coronal alignment and balanced gaps in the left knee, whereas a 6° valgus cut was required in the right knee because of the more severe varus deformity and medial soft tissue contracture. The tibial resection was performed perpendicular to the mechanical axis in the coronal plane using an extramedullary alignment guide, with a posterior slope of approximately 3°. Femoral component rotation was determined using a combination of anatomical landmarks, including the

transepicondylar axis, Whiteside's line, and posterior condylar referencing, and was subsequently adjusted according to flexion gap balancing principles. Extension and flexion gaps were assessed intraoperatively using spacer blocks following bone resections. Sequential soft tissue balancing was performed with repeated gap assessment to achieve symmetrical rectangular gaps and balanced collateral ligament tension throughout the range of motion. This approach reflected the application of functional alignment principles using conventional instrumentation. The patella was not resurfaced. The decision was based on intraoperative assessment of the patellar articular surface and patellofemoral joint, with no specific indication for resurfacing identified. Patellar osteophytes were removed as required, and patellar tracking was assessed following trial component placement. Satisfactory tracking was confirmed before final implantation.

Following a satisfactory recovery period of three months from the first procedure, the patient underwent right TKA using the same surgical principles. Similar findings of severe medial contracture and varus deformity were encountered. Sequential soft tissue balancing was again performed to achieve symmetrical rectangular gaps and stable ligament tension.

Posterior-stabilized cemented prostheses were implanted in both knees. Patellar resurfacing was not performed. Final trial assessment demonstrated satisfactory coronal stability, restoration of extension, and flexion beyond 120° in both knees.

## Postoperative rehabilitation

Postoperative rehabilitation was initiated early, with assisted mobilization and progressive recovery of knee range of motion and function. Weight-bearing and ambulation were progressed according to the patient's postoperative clinical condition and ability to mobilize. Rehabilitation focused on regaining knee extension and flexion, improving quadriceps activation and lower-limb strength, and progressively increasing walking independence.

## Postoperative outcome

Postoperative recovery following both procedures was uneventful. Weight-bearing ambulation with assistance was initiated on the first postoperative day under supervision of the physiotherapy team.

A postoperative standing full-length lower limb radiograph obtained following completion of staged bilateral TKA demonstrated satisfactory restoration of overall coronal alignment with appropriate positioning of the femoral and tibial components bilaterally. Residual varus was accepted in accordance with functional alignment principles. No radiographic evidence of component malposition, loosening, or periprosthetic complication was identified (Figure 3).

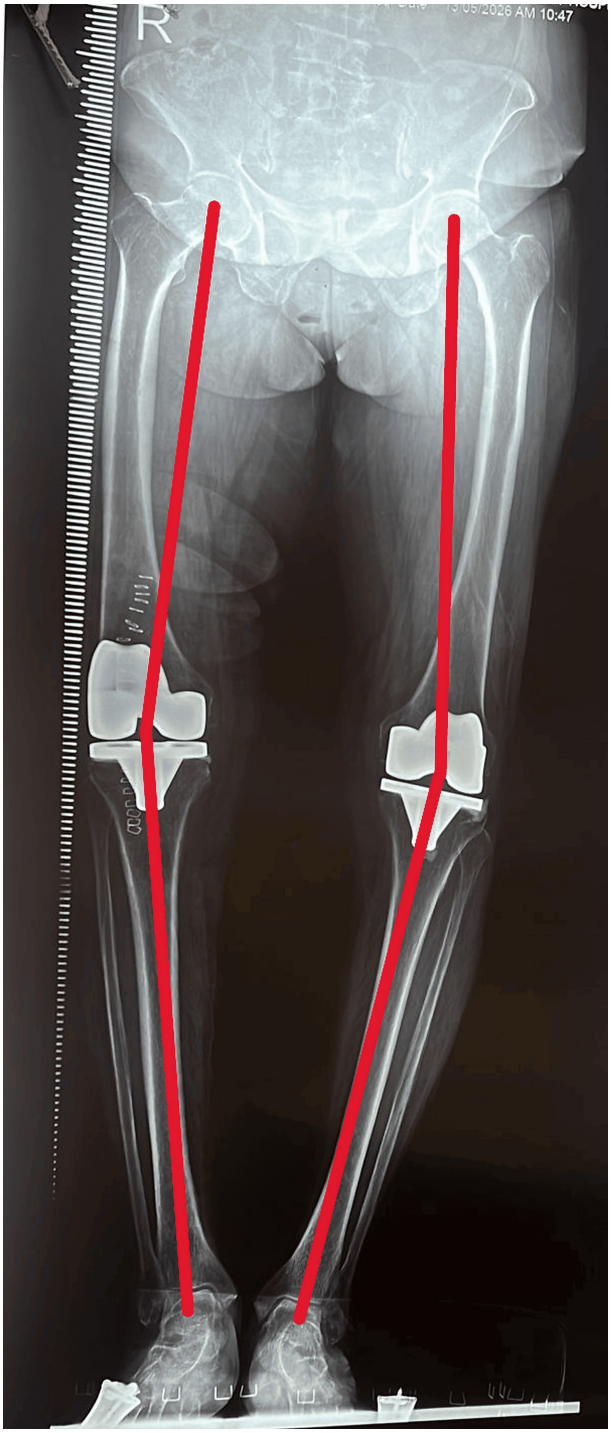



**FIGURE 3: A postoperative standing full-length lower limb radiograph was obtained following completion of staged bilateral total knee arthroplasty, demonstrating satisfactory coronal alignment, restoration of lower limb mechanical alignment, and well-positioned femoral and tibial components bilaterally. No radiographic evidence of component malposition, loosening, or periprosthetic complication was identified. This also demonstrates hip-knee-ankle angles of 168.4° on the right and 168.3° on the left, corresponding to approximately 11.6° and 11.7° of residual varus alignment, respectively.**

At final clinical assessment, performed six months after the second-stage right TKA, the right knee had six

months of postoperative follow-up, while the left knee had approximately nine months of postoperative follow-up because the procedures were performed three months apart. The patient reported substantial pain relief and improved ambulatory capacity. The 12-item Oxford Knee Score (OKS [6]; range, 0-48, with higher scores indicating better function and fewer symptoms) improved from 15/48 preoperatively to 40/48 postoperatively in the right knee and from 13/48 preoperatively to 40/48 postoperatively in the left knee. No coronal or sagittal instability, wound complications, or implant-related complications were identified. The patient was able to ambulate independently and expressed high satisfaction with the overall outcome. Clinical examination demonstrated a range of motion from 0° to 120° in the right knee and 0° to 125° in the left knee.

## Discussion

Management of severe varus knee deformity remains challenging because the observed deformity may reflect a combination of femoral morphology, tibial morphology, intra-articular bone loss, soft-tissue contracture, and longstanding osteoarthritis. Longstanding varus alignment often leads to medial soft tissue contracture, lateral laxity, and fixed flexion deformity, making soft tissue balancing an essential component of successful TKA [2,7,8].

Lateral femoral bowing may further complicate surgery because conventional intramedullary alignment systems assume a predictable relationship between the femoral anatomical and mechanical axes. Distortion of this relationship can potentially affect the accuracy of distal femoral resection. Despite these concerns, at follow-up, the patient demonstrated improved OKS and postoperative knee range of motion, with no documented instability or major implant-related complications. Postoperative radiographic alignment was assessed quantitatively as described above [3,9,10].

Functional alignment philosophy has gained increasing attention because it prioritizes restoration of balanced soft tissues and physiological knee kinematics [4,5,11]. In the present case, functional alignment principles were applied by accepting the limited residual varus alignment as part of the individualized alignment strategy rather than pursuing strict neutral mechanical alignment, while prioritizing balanced flexion and extension gaps and stable knee mechanics [2,4,5,11,12]. Rather than forcing all patients into neutral mechanical alignment, functional alignment recognizes constitutional anatomical variations and attempts to restore stable ligament tension within safe alignment boundaries [4,5,7,11]. In this patient, complete correction to neutral mechanical alignment was not considered necessary, as excessive correction could have required more extensive medial soft tissue release and potentially altered native ligament balance. Instead, functional alignment principles were applied by accepting the limited residual varus alignment as part of the individualized alignment strategy while prioritizing balanced rectangular flexion and extension gaps, physiological soft tissue tension, and stable knee mechanics. This strategy allowed satisfactory coronal stability and restoration of knee function without the need for constrained implants [11,12].

In the present case, sequential soft tissue balancing involving osteophyte removal, selective medial release, posteromedial release, and medial reduction osteotomy was critical in achieving balanced rectangular flexion and extension gaps [9,13]. This case demonstrates that conventional instrumentation can be used to individualize femoral coronal alignment based on intraoperative assessment. Rather than applying a uniform distal femoral valgus angle, the femoral resection was adjusted according to deformity severity, collateral ligament tension, and balanced flexion and extension gaps, thereby supporting stable knee mechanics while applying functional alignment principles [4,11,14]. Stable collateral ligament tension was obtained without excessive release or constrained implants [8,14].

The uniqueness of the present case lies in the coexistence of severe bilateral varus deformity, fixed flexion contracture, and extra-articular lateral femoral bowing, all of which increase the complexity of achieving balanced soft tissues and appropriate component positioning during TKA [4,5,11]. Furthermore, this case illustrates the feasibility of applying functional-alignment principles and stepwise gap balancing using conventional instrumentation in an individual patient with severe varus knee deformity and apparent lateral femoral bowing [11,15].

An additional feature of this case is the application of functional-alignment principles using conventional instrumentation in the absence of robotic or navigation-assisted technology. While robotic systems provide enhanced precision, many centers worldwide continue to rely on conventional techniques because of cost and resource limitations. Careful intraoperative assessment remains fundamental regardless of the technology employed. Although advanced imaging and computer-assisted planning facilitate precise deformity analysis, such resources may not be routinely available in many institutions [5,11,15,16].

## Conclusions

This case illustrates the feasibility of applying functional-alignment principles and stepwise gap balancing using conventional instrumentation in a technically challenging patient with severe bilateral varus knee osteoarthritis and apparent lateral femoral bowing. Individualized distal femoral resection and sequential soft-tissue balancing were used to achieve balanced flexion and extension gaps and stable knee mechanics,

with favorable clinical and radiographic findings at follow-up.

This single case does not establish the superiority or efficacy of functional alignment or support generalization to other complex knee deformities. The absence of preoperative full-length alignment measurements also limits quantitative assessment of the patient's pre-existing coronal alignment. Further comparative studies with objective alignment measurements and longer follow-up are required to determine the broader applicability of this approach.

# Additional Information

## Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

**Concept and design:** SK Julfikar Hossain , Anurag S. Sekhon, Basant Rai

**Acquisition, analysis, or interpretation of data:** SK Julfikar Hossain , Anurag S. Sekhon, Basant Rai

**Drafting of the manuscript:** SK Julfikar Hossain , Anurag S. Sekhon, Basant Rai

**Critical review of the manuscript for important intellectual content:** SK Julfikar Hossain , Anurag S. Sekhon, Basant Rai

## Disclosures

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