Article

Oblique Vertical Component and Dual Anteroposterior Fixation in Sagittal "L"-Shaped High Tibial Osteotomy: Technical Considerations and Biomechanical Reasoning

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AIM: To describe an oblique vertical modification of the sagittal "L"-shaped high tibial osteotomy combined with dual anteroposterior fixation and to present the biomechanical reasoning supporting its potential application.
METHODS: A technical note was developed based on the previously described sagittal "L"-shaped high tibial osteotomy (HTO). The proposed modification consists of introducing a slight obliquity (10°–20°) in the vertical osteotomy component posterior to the tibial tubercle while maintaining supplementary parallel anteroposterior fixation. The surgical technique, preoperative planning, indications, and biomechanical reasoning were reviewed and described.
RESULTS: The proposed modification was designed to increase the available metaphyseal cancellous contact area without substantially altering the original osteotomy geometry. Based on geometric principles and previously published biomechanical studies evaluating osteotomy configurations, the oblique orientation may theoretically improve contact surface characteristics and facilitate load transfer across the osteotomy interface. Dual anteroposterior fixation is maintained as an adjunct stabilization strategy previously described for this osteotomy configuration.
CONCLUSIONS: The oblique vertical modification represents a technical refinement of the sagittal "L"-shaped high tibial osteotomy. Although its proposed biomechanical advantages remain theoretical and require experimental and clinical validation, the modification may provide a useful geometric framework for increasing metaphyseal contact area while preserving the established principles of sagittal alignment control, posterior tibial slope preservation, and maintenance of patellar height.

Keywords: high tibial osteotomy; varus knee; posterior tibial slope; patellar height; tibial tubercle; anteroposterior fixation

Introduction

In young and active patients with symptomatic varus knee, proximal tibial osteotomy remains a joint-preserving option aimed at unloading the medial compartment and restoring coronal alignment. However, sagittal plane changes remain a relevant concern, as conventional osteotomy techniques may modify patellar height or posterior tibial slope, with potential consequences for patellofemoral mechanics and ligament balance.

The sagittal "L"-shaped configuration described by Monllau et al. [1] was developed to address these limitations by preserving the relationship between the extensor mechanism and the proximal tibial fragment while allowing controlled sagittal correction and facilitating preservation of posterior tibial slope through its characteristic osteotomy geometry and tibial tubercle configuration [1,2,3]. Subsequent clinical experience supported its feasibility in selected patients with medial compartment disease and low patellar height [1,2]. In complex joint-preservation scenarios, the procedure may also be combined with cartilage restoration techniques when required [3].

The sagittal "L"-shaped configuration represented an important advancement by preserving patellar height and facilitating posterior tibial slope control. However, as with any technically demanding osteotomy, specific intraoperative considerations remain relevant. The vertical limb is usually performed as a straight cut posterior to the tibial tubercle, which may limit the available metaphyseal cancellous contact surface and may increase reliance on fixation stability during opening maneuvers. In addition, maintenance of tibial tubercle fragment position and preservation of posterior tibial slope may require careful intraoperative control during valgus distraction, particularly when larger corrections or concomitant joint-preservation proce-

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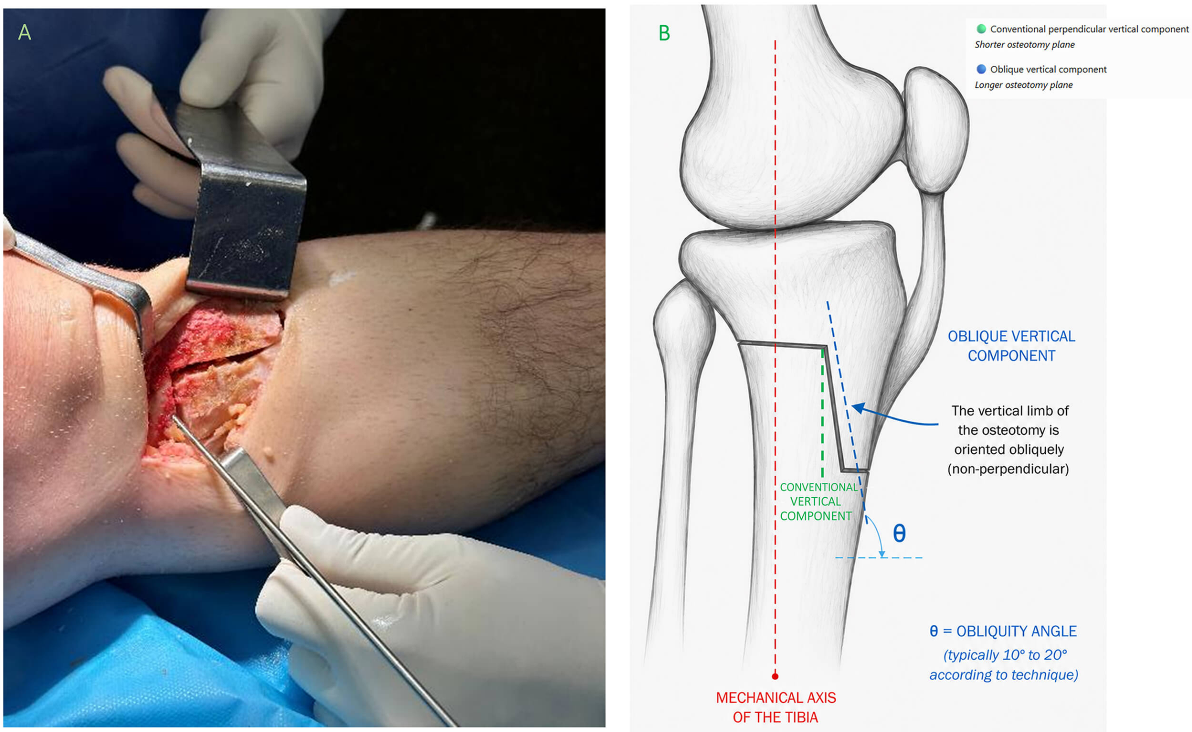

Fig. 1. Intraoperative and schematic representation of the oblique vertical component in sagittal "L"-shaped high tibial osteotomy. (A) Intraoperative view demonstrating the oblique orientation of the vertical osteotomy component posterior to the tibial tubercle. (B) Schematic sagittal illustration showing the oblique vertical limb. The proposed oblique orientation illustrates the geometric concept of a longer osteotomy plane within the same metaphyseal region. The red dashed line represents the mechanical axis of the tibia. Figure adapted from reference [3], available under the Creative Commons Attribution 4.0 International License.

dures are required. These technical considerations support the exploration of minor technical refinements aimed at improving contact geometry, construct control, and surgical reproducibility.

In response to these technical considerations, the aim of this technical note is to describe a further refinement consisting of an oblique vertical osteotomy component in sagittal "L"-shaped high tibial osteotomy. While supplementary anteroposterior fixation has previously been incorporated as a stabilization strategy during surgical application of the technique [3], the primary focus of the present report is the geometric modification of the vertical osteotomy component and its potential implications for sagittal control, metaphyseal contact geometry, and surgical reproducibility.

Biomechanical Reasoning

In symptomatic varus knee, valgus-producing proximal tibial osteotomy allows realignment of the lower limb mechanical axis and redistribution of load away from the overloaded medial compartment. Although medial open-wedge techniques are commonly used because they allow gradual correction without fibular osteotomy, they may also induce undesired sagittal plane modifications, particularly changes in patellar height and posterior tibial slope, with possible implications for patellofemoral mechanics and cruciate ligament loading [1,2,3,4].

Several technical strategies have therefore been developed to reduce sagittal imbalance during correction and preserve extensor mechanism function. Distal osteotomy configurations relative to the tibial tubercle (TT) may help prevent postoperative patellar lowering; however, fixation in these scenarios frequently depends on predominantly cortical bone surfaces, which may increase mechanical demands on the construct and potentially impair biological consolidation [4].

Within this framework, the "L"-shaped proximal tibial osteotomy was conceived to combine coronal alignment correction with improved sagittal control while preserving continuity between the extensor mechanism and the proximal tibial fragment. Control of posterior tibial slope in this configuration is not attributed to the opening pattern alone, but rather to the combined effect of osteotomy geometry, controlled posterior opening, and stabilization of the tibial tubercle fragment as originally described [1].

The present technical modification introduces a slight sagittal obliquity of the vertical osteotomy component, designed to increase the effective length of the osteotomy plane, which may theoretically expand the available metaphyseal cancellous contact surface (Fig. 1, Ref. [3]). From a theoretical biomechanical perspective, this geometric configuration may contribute to more homogeneous load transfer across the osteotomy interface during opening maneuvers.

Table 1. Indications and contraindications for proximal tibial osteotomies.

Technique	Indications	Contraindications, relative limitations and technical considerations
Conventional high tibial osteotomy (HTO) – medial opening wedge HTO (MOWHTO)	Medial compartment osteoarthritis associated with varus alignment; commonly considered in middle-aged and physiologically active patients and may also be considered in carefully selected older individuals; anteromedial osteoarthritis (AMOA) with overlapping indications, showing functional outcomes comparable to unicompartmental knee arthroplasty (UKA) at 18 months [5,6,7].	Low patellar height or patella infera (higher risk of patellar descent); need for strict control of posterior tibial slope; consider potential future conversion to total knee arthroplasty in selected cases [6,7].
Conventional HTO – Lateral closing-wedge HTO (LCWHTO)	Commonly considered in younger and physiologically active patients with medial compartment osteoarthritis; durable option with low overall complication rates in long-term follow-up [5].	Standard selection criteria for HTO; assessment of alignment, range of motion (ROM), and ligament status; caution in non-correctable multiplanar deformities [5].
Biplanar sagittal "L"-shaped HTO (distal tibial tubercle configuration)	Patients with symptomatic varus alignment and predominant medial compartment disease; reduced patellar height or risk of postoperative patellar lowering; need for preservation of sagittal alignment parameters; associated patellofemoral involvement [1,2,3].	Technical considerations may include severe multiplanar deformity; major bone loss of the femoral condyle or tibial plateau; advanced lateral compartment degeneration; inflammatory or infectious arthritis; severe functional limitation [2,3]. Additional relative contraindications include: limited metaphyseal bone support compromising stable fixation; high technical complexity [1,2,3].

When combined with dual anteroposterior fixation, this configuration may provide additional resistance to fragment displacement and facilitate more controlled sagittal alignment during correction [3].
The objective of correction is to redistribute the mechanical load-bearing axis toward the Fujisawa zone (approximately 62% of the tibial plateau width measured from the medial edge), while restoring physiological lower limb alignment and minimizing unintended modifications in patellar height and posterior tibial slope [1,2,3].

Indications and Contraindications

Patient selection criteria and the principal limitations of different proximal tibial osteotomy configurations are summarized in Table 1 (Ref. [1,2,3,5,6,7]).

Preoperative Planning

Preoperative evaluation requires detailed analysis of lower limb alignment and joint morphology through standing radiographic studies. Full-length weight-bearing radiographs are used to identify coronal malalignment and estimate the desired correction angle. Lateral knee radiographs obtained at approximately 30° of flexion allow assessment of patellar position, sagittal tibial alignment, and posterior tibial slope measurements, including evaluation of patellar height indices such as the Caton-Deschamps index, which are particularly relevant when preservation of patellar height and posterior tibial slope is a primary surgical objective [1,2,3].

Complementary imaging modalities may further define associated intra-articular abnormalities and guide combined reconstructive strategies. Magnetic resonance imaging is especially valuable for detecting concomitant chondral, meniscal, osteochondral, or ligament-related lesions that could influence intraoperative decision-making or require additional procedures during the same intervention [1,2,3,4]. The oblique vertical modification does not alter the established indications for the original sagittal "L"-shaped osteotomy and should be regarded as a technical refinement intended to optimize osteotomy geometry while maintaining the established principles of sagittal alignment preservation.

Preoperative measurements of posterior tibial slope, patellar height, correction magnitude, tibial tubercle position, and metaphyseal bone stock are incorporated into a sequential decision-making process. Posterior tibial slope and patellar height are first evaluated to determine whether preservation of sagittal alignment and extensor mechanism position represents a relevant surgical objective. This consideration is particularly important in patients with reduced patellar height, in whom additional distalization of the tibial tubercle should be avoided whenever possible. Correction magnitude is then assessed to confirm that the planned valgus opening can be achieved while maintaining control of posterior tibial slope and the tibial tubercle fragment. Finally, tibial tubercle position and metaphyseal bone stock are evaluated to determine whether the vertical limb can be safely performed posterior to the tibial tubercle while preserving adequate metaphyseal bone support for fixation. Compared with infratubercle cortical osteotomy configurations, the sagittal "L"-shaped configuration preserves a larger metaphyseal cancellous region available for fixation while allowing supplementary anteroposterior screw fixation as previously described [3].

The oblique vertical modification is therefore not indicated as an independent procedure but rather as a technical refinement in patients already considered suitable for sagittal "L"-shaped high tibial osteotomy. The proposed 10°–20° inclination does not represent a validated biomechanical threshold or a patient-specific angle derived from radiographic measurements. Instead, it was established as a pragmatic intraoperative range intended to modestly increase the effective length of the osteotomy plane while preserving the original "L"-shaped configuration, tibial tubercle support, lateral hinge safety, and technical reproducibility.

Surgical Technique

The patient is positioned supine under combined regional and general anesthesia. A pneumatic tourniquet is applied at the proximal thigh with a pressure of 350 mmHg. Diagnostic arthroscopy is routinely performed before the osteotomy to assess intra-articular status and treat associated chondral, synovial, or meniscal abnormalities when indicated.

A longitudinal incision of approximately 5 – 7 cm is made over the proximal anteromedial aspect of the leg, centered over the planned osteotomy region. After dissection through the anatomical planes, the extensor mechanism and medial soft tissues are carefully exposed, including distal detachment of the superficial medial collateral ligament and careful protection of the patellar tendon, thereby exposing the proximal metaphyseal region of the tibia for osteotomy planning and fixation.

Fluoroscopy is used to define the osteotomy trajectory and confirm safe orientation toward the lateral hinge. A reference Kirschner wire may be positioned at the metaphyseal–diaphyseal region with an ascending obliquity of approximately 30°, serving as a guide for orientation of the main osteotomy plane while preserving the proximal tibiofibular region. The planned "L"-shaped osteotomy is then outlined over the medial proximal tibial cortex, and the cuts are completed using standard osteotomy instruments under fluoroscopic control.

While the horizontal osteotomy follows principles similar to those of standard medial open-wedge high tibial osteotomy, the descending limb of the osteotomy is intentionally positioned posterior to the TT.

Coronal correction is obtained through an oblique medial-to-lateral osteotomy with an ascending obliquity of approximately 30°, preserving the lateral cortical hinge to maintain controlled opening stability. From the sagittal perspective, the initial horizontal osteotomy cut is planned perpendicular to the longitudinal axis of the tibia in order to avoid excessive modification of posterior tibial slope during osteotomy opening.

The vertical component of the osteotomy extends distally behind the TT, allowing separation of the anterior tibial cortex from the tibial shaft while preserving continuity of the extensor mechanism with the proximal fragment. Unlike the original description [1], in which the vertical limb follows a straight orientation that defines the classic "L"-shaped osteotomy, the present technical modification allows this segment to be performed with a slight sagittal obliquity from posterosuperior to anteroinferior, typically ranging between 10° and 20° relative to the tibial longitudinal axis. This range does not represent a validated biomechanical threshold but rather a pragmatic surgical recommendation intended to increase metaphyseal contact area while preserving the overall geometry of the original osteotomy configuration. This variation may theoretically increase the available metaphyseal contact surface and cancellous bone exposure. From a geometric perspective, the proposed obliquity was designed to maximize the available metaphyseal contact area without substantially modifying the fundamental architecture of the original "L"-shaped osteotomy.

The distal thickness of the TT is maintained at a minimum of 1 cm to reduce fracture risk and allow secure fixation using two compression screws. Finally, the osteotomy is completed through an additional distal anterior horizontal cut, while maintaining the TT attached to the proximal osteotomized segment (Fig. 2).

After completion of the cuts, gradual valgus opening is performed according to the planned correction. A posterior wedge is positioned along the dorsal cortex to create a controlled trapezoidal opening pattern with greater posterior height of the osteotomy gap. The purpose of this maneuver is to facilitate control of the posterior tibial slope during correction. In the original technique, this opening pattern is combined with preservation of the tibial tubercle within the proximal fragment and anteroposterior fixation of the tibial tubercle segment. This fixation was intended to counteract anterior elevation of the proximal fragment during correction and thereby contribute to preservation of the posterior tibial slope. Therefore, control of the posterior tibial slope should be interpreted as the result of the combined effect of osteotomy geometry, controlled distraction, and stabilization of the tibial tubercle, rather than as a consequence of the trapezoidal opening pattern alone [1].

Prior to definitive plate fixation, two parallel 3.5-mm cortical screws are inserted in an anteroposterior direction across the TT as a supplementary stabilization strategy. The use of

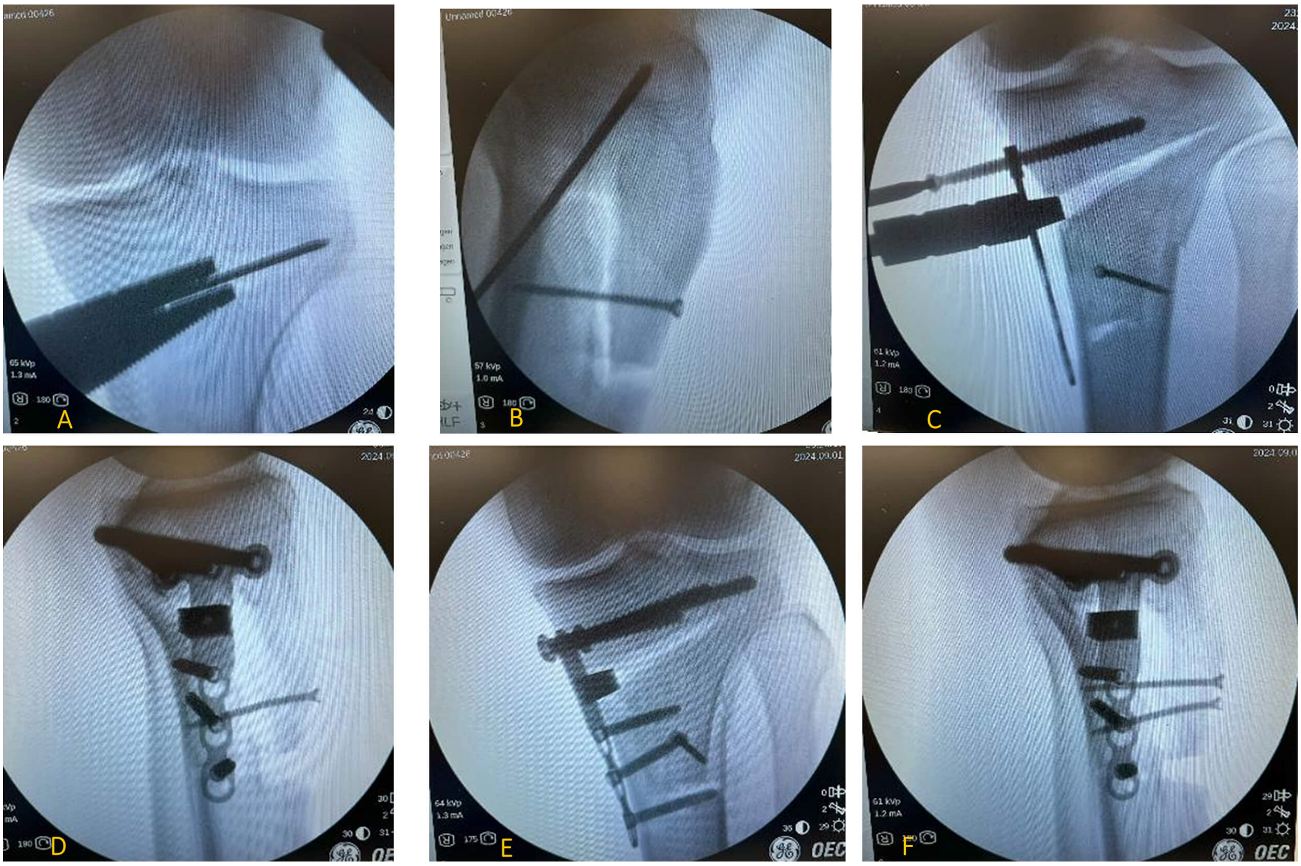

Fig. 2. Sequential fluoroscopic representation of sagittal "L"-shaped proximal tibial osteotomy with oblique vertical modification and dual anteroposterior fixation. (A) Fluoroscopic orientation of the primary osteotomy plane. (B) Development of the slightly oblique vertical osteotomy component posterior to the tibial tubercle, typically oriented 10°–20° relative to the tibial longitudinal axis. (C) Controlled valgus distraction during correction. (D) Fluoroscopic sagittal view after placement of the first anteroposterior screw across the tibial tubercle fragment during the fixation sequence. An incidental screw deformation is visible in this illustrative image; however, this isolated finding was not the basis for the dual anteroposterior fixation strategy. (E) Definitive stabilization using medial plate fixation. (F) Final construct configuration incorporating supplementary parallel anteroposterior fixation.

two parallel screws is intended to increase construct stability during opening maneuvers and definitive fixation.

Dual anteroposterior fixation is maintained as part of the current technique and had already been incorporated during the clinical application of the original "L"-shaped osteotomy [3]. Although no specific biomechanical testing was performed, this measure is retained as a pragmatic strategy intended to improve stability of the osteotomized fragment during correction.

Definitive stabilization is performed using a Puddu-type plate or an anatomical proximal tibial plate combined with locking screws. The osteotomy gap may subsequently be filled with biological augmentation, including autograft, allograft, or bone substitutes, depending on surgeon preference and local bone conditions. Fresh-frozen non-irradiated cancellous allograft may represent a useful option to support bone healing.

Soft tissue repair is then completed by reattaching the medial stabilizing structures over the plate before layered closure. When indicated, additional cartilage, meniscal, or ligament reconstructive procedures may be performed during the same surgical setting.

Fig. 3 presents an illustrative radiographic example before and after correction using the described technique. The figure is intended to demonstrate the radiographic appearance of the procedure and does not constitute a clinical or radiographic outcome analysis (Fig. 3).

Discussion

The sagittal biplanar "L"-shaped osteotomy represents a useful technical alternative in clinical practice when preservation of patellar height and posterior tibial slope is a priority. Compared with conventional medial open-wedge osteotomies, it may offer potential advantages in sagittal alignment control and mechanical load redistribution, potentially reducing the biomechanical alterations associated with traditional supratuberosity techniques [1,2,3].

Previous reports demonstrated the feasibility of this osteotomy configuration in patients with symptomatic varus knee and reduced patellar height [1,2]. A subsequent clin-

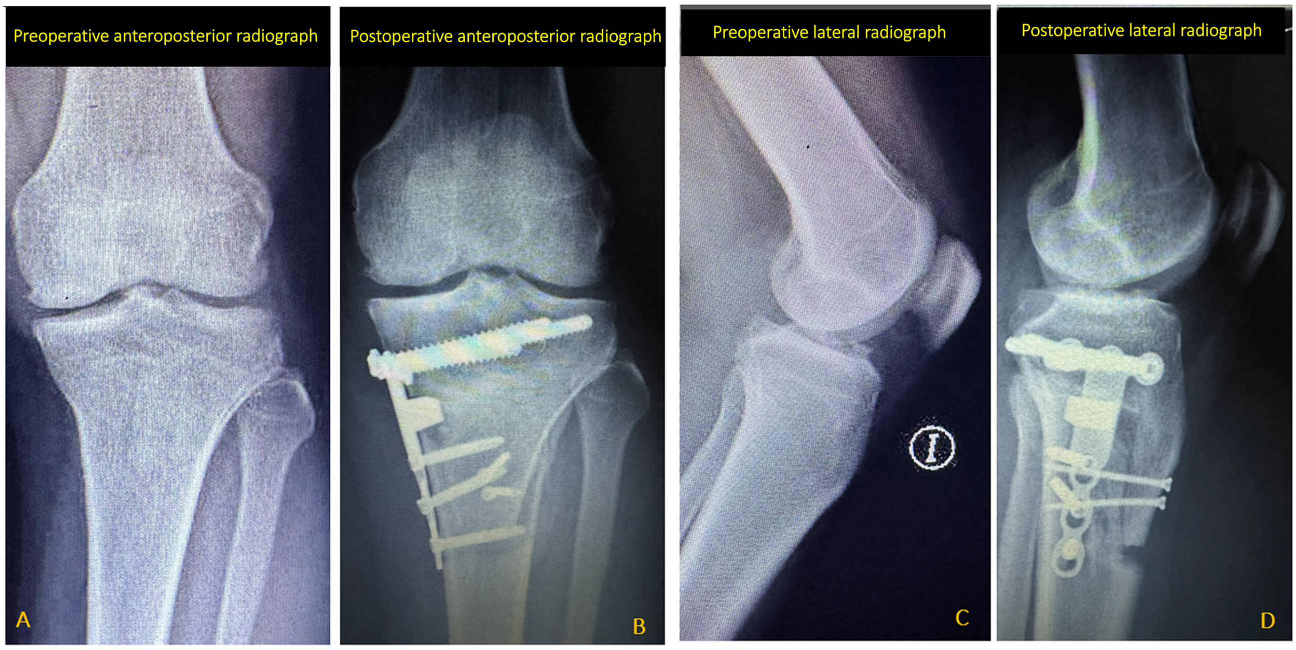

Fig. 3. Illustrative radiographic case before and after correction using oblique vertical component and dual anteroposterior fixation in sagittal "L"-shaped high tibial osteotomy. (A) Preoperative anteroposterior radiograph. (B) Post-correction coronal radiograph obtained after the procedure. (C) Preoperative lateral radiograph. (D) Postoperative lateral radiograph illustrating the final sagittal profile after correction.

ical report incorporated supplementary anteroposterior fixation as a stabilization strategy during application of the original "L"-shaped configuration [3]. The principal refinement described in the present technical note is the incorporation of a slight sagittal obliquity in the vertical osteotomy component. Unlike the previous clinical report [3], which focused on the application of the original "L"-shaped osteotomy configuration combined with osteochondral transplantation, the present manuscript specifically addresses a geometric modification of the vertical osteotomy component. This oblique sagittal orientation represents the principal technical contribution of the present report. Supplementary anteroposterior fixation is maintained as part of the stabilization strategy previously described, whereas the geometric modification of the vertical osteotomy component constitutes the principal novelty of the present manuscript.

Biomechanical studies support the concept that supplementary fixation may improve construct stability in proximal tibial osteotomies. Yang et al. [8] demonstrated that the addition of a supplemental screw significantly increased construct stiffness and reduced loss of correction during cyclic loading in medial opening-wedge high tibial osteotomy. Likewise, Chang et al. [9] reported that parallel dual-screw fixation configurations in tibial tubercle osteotomy produced lower fragment displacement, reduced gap opening, and more favorable load distribution compared with less stable fixation patterns. Although these studies evaluated different osteotomy models, their findings support the rationale for supplementary fixation strategies intended to improve stability and reduce micromotion of the osteotomized fragment. Dual anteroposterior fixation had already been incorporated into the surgical technique as a pragmatic stabilization strategy based on the original technical concept and previous clinical experience with this osteotomy configuration [3], before the screw deformation illustrated in Fig. 2D was observed. During clinical application of the technique, deformation of a single anteroposterior screw was incidentally observed in one illustrative fluoroscopic image included in the surgical sequence. Although this finding may reflect the mechanical demands generated during osteotomy opening, no biomechanical testing, quantitative analysis, or systematic clinical evaluation was performed to determine its mechanism or clinical relevance. Therefore, it should be regarded solely as an isolated descriptive observation and not as evidence of fixation failure or superiority of any fixation strategy.

Geometric studies support the concept that osteotomy configuration may influence the biological and mechanical environment of bone healing. Pape et al. [10] demonstrated that osteotomy configurations incorporating a longer and more oblique secondary plane generate significantly larger cancellous bone contact surfaces than alternative configurations. Although the oblique vertical component proposed in the present technique was not specifically evaluated, the modification was conceived according to the same geometric principle of increasing the available metaphyseal contact area. Similarly, finite element analyses have shown that osteotomy geometry may influence load transfer and stress distribution across the construct under specific experimental conditions [11]. Although no biomechanical investigation has specifically evaluated the modification proposed in the present technique, these studies provide indirect support for its geometric reasoning. Therefore, any potential biomechanical advantages should be considered theoretical. It may be hypothesized that increasing the metaphyseal cancellous contact area through a more oblique osteotomy plane may influence load transfer across the osteotomy interface; however, the actual biomechanical effect of this modification remains unknown and requires further investigation.

The proposed 10°–20° obliquity should be interpreted as a technical recommendation rather than a validated biomechanical parameter. This range was selected to potentially increase the metaphyseal cancellous contact surface without substantially altering the original geometry of the "L"-shaped osteotomy. Greater degrees of obliquity could theoretically compromise reproducibility and modify the relationship between the tibial tubercle fragment and the metaphyseal segment.

From a biomechanical standpoint, control of posterior tibial slope in the "L"-shaped configuration depends on a combination of osteotomy geometry, controlled opening of the posterior cortex, and stabilization of the tibial tubercle fragment, rather than on the opening pattern alone [1]. This configuration enables precise multiplanar correction while facilitating preservation of posterior tibial slope and patellar height. Incorporation of the tibial tubercle into the proximal fragment maintains the integrity of the extensor mechanism and prevents patellar distalization, which is especially advantageous in patients with associated patellofemoral pathology [1,2,3]. By contrast, conventional supratuberosity techniques may generate greater alterations in sagittal alignment parameters, particularly when larger angular corrections are required [1,2,3,4].

Furthermore, the possibility of combining this technique with additional reconstructive procedures, such as cartilage restoration techniques, may facilitate treatment of complex joint-preservation scenarios within a single operative setting, as previously reported [3].

Limitations

The main limitation of this study is that it represents a technical description without comparative analysis or long-term clinical outcome evaluation. In addition, the proposed biomechanical advantages of the oblique vertical component remain theoretical and require future experimental and clinical validation. No biomechanical testing or comparative fixation analysis was performed in the present study. The purpose of this manuscript is to provide technical considerations and biomechanical reasoning to facilitate reproducibility of the procedure.

Conclusions

The sagittal biplanar "L"-shaped osteotomy is a useful technical option for the treatment of symptomatic varus knee with low patellar height when preservation of extensor mechanism biomechanics is desired. The addition of a sagittal oblique vertical component combined with dual anteroposterior fixation may provide a theoretical biomechanical framework for increasing metaphyseal contact during correction maneuvers. This refinement was designed to increase the available metaphyseal contact surface and provide a technical framework for performing the procedure in complex correction scenarios.

Availability of Data and Materials

No datasets were generated or analyzed during the current study.

Author Contributions

EJF is the sole contributor to this manuscript. The author confirms sole responsibility for the conception and design of the study; the acquisition, review, and interpretation of clinical and imaging information; the preparation of the manuscript; and for being accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Ethical approval was not required for this study because this manuscript describes a technical modification and does not involve a prospective clinical study. Written informed consent for publication of the clinical images was obtained from the patient. The procedure and use of the clinical material were conducted in accordance with the principles of the Declaration of Helsinki.

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Conflict of Interest

The author declares no conflict of interest.

Declaration of Generative AI and AI-Assisted Technologies in Manuscript Preparation

Artificial intelligence software ChatGPT (GPT-5, OpenAI, San Francisco, CA, USA; https://openai.com) was used exclusively for language editing, grammar correction, and improvement of manuscript readability. The author takes full responsibility for the accuracy, integrity, and originality of the content.

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