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ORIGINAL

HIGH TIBIAL OSTEOTOMY WITH LATERAL EXTRA ARTICULAR AUGMENTATION FOR CHRONIC ACL DEFICIENT KNEE WITH VARUS OSTEOARTHRITIS AND HIGH PIVOTING: A PILOT STUDY

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ABSTRACT

Background: The management of chronic anterior cruciate ligament (ACL) deficient knees with concurrent varus osteoarthritis with high pivoting poses a significant challenge. This prospective pilot study investigates the clinical, functional, and radiographic outcomes of a one-stage surgical approach combining ACL reconstruction with open-wedge high tibial osteotomy (HTO). **Methods:** We enrolled 16 patients with chronic ACL-deficient knees and medial compartment osteoarthritis and high pivoting. All patients underwent open-wedge HTO with lateral extra-articular augmentation. We assessed clinical and functional outcomes using the Lysholm and International Knee Documentation Committee (IKDC) scores, as well as the Lachman, anterior drawer, and pivot-shift tests. Radiographic parameters, including the mechanical tibiofemoral angle (TFA), proximal medial tibial angle (PMTA), and posterior tibial slope (PTS), were measured preoperatively and at final follow-up. **Results:** The combined procedure yielded significant improvements in all measured outcomes. The mean Lysholm and IKDC scores increased from 47.25±3.23 and 41.5±3.25preoperatively to 66.0±5.32 and 67.5±7.03 postoperatively, respectively ($p<0.001$). All patients showed a reduction in pivot-shift grade, with a conversion of the mechanical axis from a median varus of −8◦ to a mild valgus of 3◦. The mean PMTA was successfully corrected from 78.88 to 88.85 ◦. Notably, the mean posterior tibial slope was reduced from 10.50◦ to 8.56◦. The complication rate was low, with no major complications such as nonunion or graft failure. **Conclusion:** The one-stage surgical procedure of open-wedge

HTO with lateral extraarticular augmentation in chronic ACL-deficient varus knees with early osteoarthritis provides significant improvements in function and stability while reliably correcting coronal and sagittal alignment. This approach offers a safe and effective strategy for joint preservation.

KEYWORDS: Anterior Cruciate Ligament, High Tibial Osteotomy, Varus Osteoarthritis, Lateral Extra-Articular Augmentation

1. INTRODUCTION

The anterior cruciate ligament (ACL) is an essential component of the knee joint. Its primary role is to serve as the main restraint against the anterior movement of the tibia in relation to the femur. Additionally, it contributes significantly to the knee's rotational stability (Cantivalli et al., 2019). The ACL deficiency negatively impacts the biomechanical environment, leading to alterations in gait biomechanics. This includes reduced knee flexion moments and increased external knee adduction moments, which may accelerate degenerative changes, especially in the medial compartment, leading to potential loss or injury of the meniscus or articular cartilage (Kanakamedala et al., 2022). Management of chronic ACL injuries has garnered increased attention in literature due to the rising functional demands of the aging population. However, little evidence exists regarding the outcomes of ACL reconstruction in a chronically ACL-deficient knee with medial compartment degenerative changes. Therefore, additional research is necessary to determine the potential effect of surgical management on these patients (Malahias et al., 2018). Literature indicates that patients with an ACL-deficient varus-angulated knee might need both a high tibial osteotomy (HTO) and an ACL reconstruction, either at the same time or in stages. Previously, ACL insufficiency was deemed a contraindication for HTO. However, it is now common to address painful varus osteoarthritis (OA) alongside ACL instability by performing HTO and ACL reconstruction simultaneously (Jin et al., 2018). HTO has been utilized for treating symptomatic uni compartmental arthrosis related to coronal plane malalignment in a stable knee since its popularization by Coventry in the 1960s. Recently, realignment surgery has been regarded as a crucial component in the treatment protocol for coronal malalignment and associated knee instabilities (Kawanishi et al., 2024). Additionally, there has been increased interest in the sagittal plane deformity of the proximal tibia. Specifically, the posterior tibial slope (PTS) has garnered attention for its significance in maintaining sagittal balance of the unstable knee. Various investigators have shown that, in the ACL-deficient knee, anterior tibial translation can be minimized by reducing the PTS to normal values (normal value in the medial plateau 9–11 degrees, in the lateral plateau 6–8 degrees) (COVENTRY, 1965). This clinical pilot study aims to evaluate the safety and preliminary clinical outcomes of a single-stage combined procedure of ACL reconstruction and HTO in patients with a chronic ACL-deficient knee and

coexisting varus osteoarthritis with high pivoting. We hypothesize that this combined surgical approach will not only restore knee stability but also improve functional outcomes and reduce pain by addressing both ligamentous instability and varus malalignment.

2. Methods

2.1 Study Design and Approval

This was a prospective pilot study conducted on 16 patients with chronic ACL-deficient knees and varus OA with high pivoting. The study was conducted at the Knee Surgery Unit, Mansoura University, between 2021 and 2024. The study protocol was approved by the Institutional Ethics Committee under reference number (MD.21.5.470), and all patients provided informed consent to participate.

2.2 Eligibility Criteria

Patients were selected based on specific inclusion and exclusion criteria. For inclusion, patients had to be 35 years or older with varus malalignment, an isolated anterior cruciate ligament injury, and isolated medial compartment osteoarthritis. Their pivot shift test result had to be +2 or +3, and they were required to have a full range of motion. Conversely, patients were excluded if they had tricompartmental osteoarthritis, severe articular damage of the medial compartment (Kellgren-Lawrence grade 3 or higher), a multi-ligament injury, or a BMI greater than 35. Other exclusion criteria included a decreased range of motion less than 120◦ or a flexion contracture greater than 10◦, the presence of inflammatory knee disease (e.g., Rheumatoid Arthritis), a history of previous knee surgery, associated knee injuries requiring repair (such as large osteochondral defects), or an unwillingness to undertake a postoperative rehabilitation program.

2.3 Patients' Evaluation

All patients underwent a thorough preoperative evaluation, including a detailed clinical examination by the same observer, as well as radiological and physical assessments. The physical examination included an inspection for any knee inflammation or previous scars, assessment of the knee's range of motion, and standard ligamentous stability tests, such as Lachman's test, anterior drawer test, pivot shift test, posterior drawer, McMurray's test, and varus and valgus stress tests. Prior to surgery, all patients underwent X-ray and MRI scans for comprehensive assessment, with radiographic measurements taken to determine the Hip-Knee-Ankle (HKA) angle, Lateral Distal Femoral Angle (LDFA), Medial Proximal Tibial Angle (MPTA), and patellar height using the Caton-Deschamps and Insall-Salvati methods. The PTS angle (defined as the angle between the line perpendicular to the tibial shaft axis and the posterior

inclination of the tibial plateau) was also measured on a lateral radiograph both preoperatively and at the final follow-up.

2.4 Operative Procedures

All surgeries were performed by a senior high-volume orthopedic` team with a satisfactory leading curve. The surgical plan was based on radiographic analysis, using the Dugdale method to calculate the required correction angle and medial opening to achieve a slight overcorrection of approximately 3◦. The surgical technique involved several steps: first, diagnostic arthroscopy was performed to treat any concurrent injuries. Next, under fluoroscopic guidance, two guidewires were positioned, and an open wedge HTO was performed with an oscillating saw, preserving the lateral cortical hinge. Osteotomy was gradually opened to the desired correction angle, with special consideration given to reducing the posterior tibial slope by closing the anterior aspect of the osteotomy. Fixation was achieved using a titanium T-locked plate after that, a slightly curved 10-cm-long incision was made along the lateral side of the knee, over the ITB, starting proximally at the Gerdy tubercle. Dissection down to the ITB was performed. A parallel-blade knife was used to score a 1-cm-wide mid-substance ITB tissue strip, aiming for about 8 cm in length. The dissection was completed with scissors, and the proximal end of the tissue strip was released, leaving the distal attachment to the Gerdy tubercle intact. A Vicryl suture was used to whipstitch the free end of the ITB strip. The location of the lateral collateral ligament (LCL) was identified, and its borders were outlined with a scalpel. A Kelly hemostat was placed beneath the LCL to create space for the ITB tissue strip underneath. The attachment site was just anterior and proximal to the lateral head of the gastrocnemius, on the lateral metaphyseal flare of the lateral femoral condyle, roughly 31.4 mm proximal to the lateral epicondyle. A guide pin was drilled into the femur, aiming anteriorly and proximally to avoid the trochlea. A 6-mm closed-socket tunnel was created to a 30-mm depth, then the graft was fixed with the knee at 60 of flexion and the foot in neutral rotation to prevent lateral compartment over constraint.

2.5 Study Outcomes and Follow-up

All patients were followed up at 2 weeks and at 3, 6, 12 and 24 months postoperatively. Clinical outcomes were assessed at the baseline preoperatively and at the final follow-up 24 months post-operatively. The study's primary outcomes included subjective scores using the Lysholm Knee Scoring Scale and the International Knee Documentation Committee (IKDC) score, as well as objective stability via physical examination using the pivot shift test, anterior drawer test, and Lachman test.

2.6 Statistical Analysis

Statistical analysis was performed to compare preoperative and

postoperative outcomes. Continuous variables will be presented as mean ± standard deviation, and categorical variables as frequencies and percentages. A paired t-test will be used to compare preoperative and postoperative scores. A p-value of less than 0.05 will be considered statistically significant.

2.7 Participants' Baseline Characteristics

The study included 16 male patients with an average age of years 40.12±3.14. The average BMI was30.44±1.57 Kg/m^2. The right knee was affected in 10 patients (62.5%), while the left knee was affected in 6 patients (37.5%). The majority of patients (81.2%) were non-smokers. Of the total patients, 13 (81.2.%) had no significant medical history, while three (18.8%) had hypertension. All patients had no history of previous knee surgery. Kellgren-Lawrence grade 1 osteoarthritis was present in 7 patients (43.8%), and grade 2 was present in 9 patients (56.2%). Preoperative clinical stability was assessed using the Lachman, anterior drawer, and pivot shift tests, with all patients demonstrating either grade 2 or grade 3 instability. Table 1 summarizes the baseline participants' characteristics.

Table 1: Baseline Demographic and Clinical Characteristics

VARIABLES		STUDY PARTICIPANTS (N=14)
AGE (YEARS)†		40.12±3.14
GENDER (MALE)		16 (100%)
SIDE (		Right 10(62.5) left 6(37.5)
BMI (KG/M^2) †		30.44±1.57
SMOKERS (YES)		1(6.2)
MEDICAL HISTORY	DM	3(18.8)
OA GRADE	Grade 1	7(43.8)
	Grade 2	9(56.2)
PREOPERATIVE LACHMAN	Grade 2	8(50)
	Grade 3	8(50)
PREOPERATIVE ANTERIOR DRAWER	Grade 2	9(56.2)
	Grade 3	7(43.8)
PREOPERATIVE PIVOT	Grade 2	11(68.8)
	Grade 3	5(31.2)

†Continuous variables reported in Mean ±SD, categorical variables reported in N (%).

*Statistically significant p-value <0.05.

2.8 Radiological Outcomes

Significant improvements were observed in several radiographic parameters. The mean posterior tibial slope (PTS) was significantly reduced from a preoperative value of10.50±1.59 ◦ to a postoperative value of 8.56±1.37 ◦ (p<0.001). The mean medial proximal tibial angle was corrected from a preoperative value of78.88±1.86 ◦ to a postoperative value of88.85±0.19◦ (p=0.001). The tibiofemoral angle also improved significantly, from a median of

−8◦ (range −12◦ to −5◦) preoperatively to 3◦ (range −1◦ to 3◦) postoperatively (p=0.001). Patellar height, as measured by the Caton-Dechamps Index, showed a statistically significant decrease from a preoperative mean of1.03±0.06 to a postoperative mean of0.887±0.22 (p=0.013). Similarly, the Insall-Salvati ratio decreased from a preoperative mean of 1.1056±0.09to a postoperative mean of1.05±0.09 (p=0.001). Table 2 summarizes the radiological outcomes of the study participants.

Table 2: Pre- and Postoperative Radiological Outcomes

VARIABLES	PREOPERATIVE MEAN ±SD	POSTOPERATIVE MEAN ±SD	P-VALUE
POSTERIOR TIBIAL SLOPE	10.50±1.59	8.56±1.37	<0.001*
TIBIOFEMORAL ANGLE†	-8 (-12: -5)	3 (-1:3)	<0.001*
MEDIAL PROXIMAL TIBIAL ANGLE	78.88±1.86	88.85±0.19	<0.001*
CATTON DECHAMP INDEX	1.03±0.06	0.887±0.22	0.013*
INSALL-SALVATI RATIO	1.1056±0.09	1.05±0.09	0.001*

†Continuous variables reported in Mean ±SD, categorical variables reported in N (%).

*Statistically significant p-value <0.05.

2.9 Lysholm and IKDC Scores

Patients showed significant improvement in subjective and objective clinical scores. The mean Lysholm score improved from a preoperative mean of 47.25±3.23to a postoperative mean of 66.0±5.32(p=0.001). The International Knee Documentation Committee (IKDC) score also significantly increased from a preoperative mean of41.5±3.25 to a postoperative mean of 67.5±7.03 (p=0.001).

2.10 Postoperative Stability Assessment

At the 24-month follow-up, all 16 patients showed improved pivot shift stability, with 4 patients (25%) having a grade 0, 8 patients (50%) having a grade 1 and 4 patients (25%) having a grade2 result. Postoperatively, patients showed significant improvement in both the Lachman and anterior drawer tests. For the Lachman test, 6 (37.5%) achieved a grade 0, 7 (43.8%) achieved a grade 1, and 3 (18.8%) achieved a grade 2. For the anterior drawer test,5 (31.3%) achieved a grade 0,8 (50.0%) achieved grade 1 and 3 (18.8%) achieved grade 2. All of these postoperative results were a substantial improvement over their preoperative scores. The mean postoperative range of motion was126.88. Union was achieved with a median duration of 25 weeks (ranging from 12: 34 weeks (Table 3).

Table 3: Pre- and Postoperative Clinical Outcomes

VARIABLES	PREOPERATIVE MEAN ±SD	POSTOPERATIVE MEAN ±SD	P-VALUE
LYSHOLM SCORE	47.25±3.23	66.0±5.32	0.001*
IKDC SCORE	41.5±3.25	67.5±7.03	0.001*

*Statistically significant p-value <0.05.

2.11 Operative and Postoperative Complications

Intraoperative complications included hinge fractures in 5 patients (31.3%), with 2 patients of type 1 and 2 patient with type 2 fractures. All of the intraoperative complications were managed intraoperatively. Postoperative complications were rare, with 2 patients (6.2%) experiencing knee instability after 1 year. There was one case of superficial wound infection which was managed with daily dressing and antibiotics (Table 4). Managing the chronically ACL-deficient, varus-aligned knee with medial compartment osteoarthritis (OA) and high pivoting demands is one of the most challenging issues in sports knee surgery.

Table 4: Postoperative Complications and Outcomes

VARIABLES	STUDY PARTICIPANTS (N=14)
INTRAOPERATIVE COMPLICATIONS	
NONE	11 (68.8%)
HINGE FRACTURE TYPE 1	3 (18.8%)
HINGE FRACTURE TYPE 2	2 (12.5%)
POSTOPERATIVE COMPLICATIONS	
NONE	13(81.2)
KNEE INSTABILITY	2(12.5)
SUPEREFICIAL WOUND INFECTION	1(6.2)
POSTOPERATIVE PIVOT SHIFT	
GRADE 0	4 (25%)
GRADE 1	8 (50%)
GRADE 2	4 (25%)
POSTOPERATIVE ROM (DEGREES)	126.88 7.61

†Continuous variables reported in Mean ±SD, categorical variables reported in N (%).

*Statistically significant p-value <0.05.

3. Discussion

3.1 Findings Summary

This study demonstrates that the simultaneous procedure reconstruction open-wedge high tibial osteotomy with lateral extra articular augmentation

results in substantial clinical and functional improvements for patients with chronic ACL-deficient knees and varus osteoarthritis. The significant increases in Lysholm and IKDC scores, from preoperative means of 47.25±3.23and 41.5±3.25 to postoperative means of 66.0±5.32 and 67.5±7.03 respectively, reflect a restoration of knee function and a marked reduction in symptoms. These findings are consistent with existing reports that show OWHTO can improve knee function in ACL deficient knee with varus OA. Mustamsir et al. concluded that isolated HTO alone improves symptoms in ACL-deficient knees, questioning the necessity of intra-articular grafting in lower-demand patients (Mustamsir et al., 2025). Monaco et al. demonstrated that LET reduces axial tibial rotation during pivot shift (Monaco et al., 2014). Perelli et al. reported stability and performance improvements with modified Lemaire LET, including as stand-alone in older ACL-deficient patients (Perelli et al., 2023; Perelli et al., 2022). Earlier extra-articular procedures (Andrews & Sanders, 1983; Arnold, 1985; MacIntosh, 1988; reviewed by Marston & Chen, 1993) controlled pivot shift but left residual anterior laxity and failed to prevent OA (Marston & Chen, 1993). Vail et al. similarly found subjective improvement but progression of degeneration (Vail et al., 1992). OWHTO with LEA provides meaningful rotational control but cannot replace ACLR in restoring anterior stability. It may be suitable for revision, salvage, or older patients where grafting is undesirable. The observed improvements in pivot-shift grades were also notable, with all patients achieving an improvement from a grade 2 or 3 to a grade 0, 1or 2, effectively eliminating high-grade instability. This highlights the combined procedure's ability to restore both anterior-posterior and rotational stability. Radiographic, clinical and biomechanical outcomes in the context of pervious literature. Successful radiographic correction was achieved in all patients. The mean proximal medial tibial angle was corrected from78.88±1.86◦ to 88.85±0.19◦, and the mechanical tibiofemoral angle was converted from a median varus of −8◦ to a mild valgus of 3◦. These corrections are crucial for offloading the medial compartment and preventing a shift in load to the lateral compartment, aligning with principles established in several previous reports (Dugdale et al., 1992; Robin & Neyret, 2016). Regarding the biomechanical perspectives, our results showed a successful reduction in the PTS from a preoperative mean of10.50±1.59 ◦ to a postoperative mean of 8.56±1.37◦. Increased PTS is strongly correlated with anterior tibial translation, which elevates in situ forces on the ACL graft and increases the risk of graft failure. By controlling and reducing the slope to a more physiological range. This change, although smaller than in some targeted slope-reducing series, is biomechanically meaningful, as experimental data indicate that reductions of just 2–3° can decrease anterior tibial translation (Imhoff et al., 2021). The biomechanical rationale for combining HTO with lateral extra-articular augmentation is based on the interplay between coronal and sagittal alignment and their effect on ACL function. Varus alignment increases the knee adduction moment, which places abnormal stress on the knee. Similarly, an excessive

PTS accentuates anterior tibial translation under axial load. The combined procedure, therefore, creates a synergistic environment: valgus realignment reduces varus, while slope correction mitigates anterior tibial translation (Giffin et al., 2004). An experimental study conducted by Imhoff et al. demonstrated that slope and varus correction through HTO reduced anterior tibial translation and ACL graft forces in cadaveric models (Imhoff et al., 2021). These data explain the durable improvements in stability and function observed clinically in our cohort.

3.2 Procedure Complications and Safety

We observed a low incidence of complications, with 5 patients (31.3.%) experiencing an intraoperative hinge fracture and 2 patients (12.5%) experiencing a postoperative knee stability. These complications were managed conservatively without impacting the final outcomes. Our complication rates are consistent with prior published data, which report similar rates for hinge fractures and hardware-related issues in HTO (Lee et al., 2019; Mehl et al., 2017). Kucirek and his colleagues reported a two-year complication rate of 31.7% after HTO (Kucirek et al., 2022). Notably, our series had no major complications such as nonunion, infection, which confirms the safety of combining HTO with lateral extra-articular augmentation.

3.3 Study Limitations

Despite these promising results, several limitations must be acknowledged. As this was a pilot study, the small cohort size limits the statistical power and the ability to detect rare complications; future large-scale studies are therefore needed. The relatively short follow-up period restricts conclusions regarding long-term graft survival, the progression of osteoarthritis. The absence of a comparative control group (ACL reconstruction with HTO) also limits the strength of our causal inferences.

4. Conclusion

This study reinforces the value of simultaneous ACL open wedge HTO with lateral extraarticular augmentation in chronic ACL-deficient varus knees with early OA. The combined procedure yields significant improvements in function and stability, reliably corrects coronal and sagittal alignment, and does so with a low complication rate. By addressing both the mechanical and biological challenges inherent in this patient population

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