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ACL: RISK FACTORS, OUTCOMES, PREVENTIONS (R GALLO, SECTION EDITOR)

The Role of High Tibial Osteotomy in ACL Reconstruction in Knees with Coronal and Sagittal Plane Deformity

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Abstract

Purpose of Review Coronal and sagittal malalignment in the setting of anterior cruciate ligament (ACL) deficiency alters knee biomechanics and is shown to increase stress and strain on the native ACL and on the ACL graft during reconstruction. The purpose of this review was to determine the role and indications of high tibial osteotomy to correct coronal and/or sagittal plane malalignment with ACL reconstruction.

Recent Findings Recent literature illustrates that an increase in varus malalignment and increased posterior tibial slope increases the biomechanical stress that is seen in a native or reconstructed ACL graft. It has been proposed to correct the sagittal and coronal malalignment by employing a high tibial osteotomy either prior to or at the time of ACL reconstruction to correct these deformities and to decrease the stress placed on the reconstructed ACL graft.

Summary The use of high tibial osteotomy for deformity correction creates a more stable knee for ACL reconstruction and has been shown to have good outcomes with regard to post-operative pain, stability, satisfaction scores, and function.

Keywords High tibial osteotomy · ACL reconstruction · ACL · Varus alignment · Posterior tibial slope · Malalignment

Introduction

Coronal and sagittal malalignment in the setting of ACL insufficiency provides a difficult challenge to the treating surgeon as pre-existing deformity can contribute to post-operative instability. Increased varus alignment and increased posterior slope not only contribute to instability in an ACL deficient knee but also has been shown to increase the amount of stress experienced by the reconstructed ACL graft and leads to increased rates of graft failure [1, 2••, 3].

ACL reconstruction failure is due to several factors including surgical technique, surgical timing, graft material and incorporation, the integrity of secondary restraints, new trauma, and infection [4–6]. Crawford performed a systematic review of nearly 14 studies and found that after 10 year follow-up, approximately 6.2% of reconstructed ACL's re-ruptured and a total of 11.9% of ACL reconstructions were deemed a failure. Up to 50% of ACL failures are attributed to technical problems including tunnel malpositioning, anterior femoral tunnel, and failure of fixation [6]. Aside from technical errors, Lahav found that 1–8% of ACL reconstructions have recurrent instability post-operatively. It is difficult to ascertain exactly what percentage of instability after reconstruction is due to technical error or secondary to pre-existing instability from malalignment. Recent data has shown that deformity correction with high tibial osteotomy as a combined or staged procedure with ACL reconstruction have provided patients with good outcomes with regard to pain, function, stability, and satisfaction scores [7]. The aim of this review to evaluate the role of coronal and sagittal imbalance of the native knee on instability and to examine the pre-operative evaluation and indications of high tibial osteotomy to correct the varus alignment and posterior tibial slope as a staged or combined procedure with ACL reconstruction.

This article is part of the Topical Collection on *ACL: Risk Factors, Outcomes, Preventions*

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Coronal Alignment

The role of coronal plane malalignment in individuals with ACL insufficiency presents a challenge to the surgeon of how to address and correct the deformity with a concomitant ACL tear. ACL deficiency is associated with knee instability and can lead to the development and/or progression of medial compartment osteoarthritis and further malalignment and deformity [8]. Furthermore, medial compartment degenerative joint disease (DJD) is commonly seen in the population at large; addressing concomitant ACL insufficiency in the setting of medial compartment DJD can be a challenge [9]. Varus alignment alters the mechanical axis of the lower extremity and increases the load that is transmitted through the medial compartment during weight bearing [1, 2••, 10]. This load shift increases the stress that is placed on native, and reconstructed ACLs and can contribute to degeneration of the medial compartment and potential graft failure [1, 10]. Hinckel and associates illustrated the effect of the mechanical varus on the ACL in different knee positions in a finite element model. A finite element model was utilized to simulate knees in 0, 30, and 60 degrees of flexion and 0, 5, and 10 degrees of varus. These authors found that the mechanical varus increased the stress through the ACL in both the extended and 30 degrees of flexion. This increased stress on the ACL was found at 5 and 10 degrees of varus [1].

Varus deformity can progress in a stepwise fashion and make a subsequent ACL reconstruction more difficult. Noyes classically described the primary, double, and triple varus knee and advocated for correction of the varus deformity before ACL reconstruction [11]. Primary varus knee was described by these authors as a result of the loss of the medial meniscus and medial-sided articular cartilage in the tibiofemoral joint and the resultant change in osseous alignment of the knee. A double varus knee accounts for the tibiofemoral osseous malalignment but also includes the separation of the lateral tibiofemoral joint space due to deficiency and laxity in the lateral soft tissues. A triple varus knee is where the varus alignment occurs because of the tibiofemoral osseous degeneration, separation of the lateral tibiofemoral compartment and hyperextension, and increased external tibial rotation with a varus recurvatum position [11]. Due to this increased load and stress applied to the ACL in varus alignment, Noyes proposed that for a certain subset of patients, a staged procedure to first correct the varus deformity followed by ligament reconstruction should be employed. This included younger patients who had had previous operations and had concomitant ACL deficiency, varus angulation, loss of medial meniscus, and complete posterolateral ligament insufficiency. In Noyes' series, he found statistically significant improvements in pain, swelling, and giving way in patients who had undergone a staged procedure to first correct the varus alignment and subsequently reconstructed the ACL and posterolateral ligaments [11].

High tibial osteotomy in combination with ACL reconstruction has been demonstrated to improve the alignment, restore anterior knee instability, and help to slow the advancement of arthritis [12••]. Stride and associates found that combined ACL reconstruction and high tibial osteotomy surgery results in improvements in post-operative functional outcomes. Overall, he found that patients who underwent the combined procedure to have low complications rates, re-ruptures their knees and need revisions [13••]. Li and colleagues performed a systematic review examining simultaneous valgus high tibial osteotomy and ACL reconstruction. They examined 11 studies totaling 218 knees and demonstrated satisfactory restoration of anterior knee stability, prevention of the advancement of medial compartment osteoarthritis, improvement of post-operative subjective outcomes, and a predictable return to recreational activities. They concluded that the combination ACLR and HTO was a good salvage procedure for physically young patients who failed conservative treatment with previous ligament reconstruction [14•]. Although the outcomes of a combined procedure are positive at this point in time, it is unclear whether the favorable outcomes are due in part to restoration of the alignment of the knee joint in conjunction with the ligament reconstruction or solely due to the ACL reconstruction alone. Currently, there are no studies which directly compared an ACLR to a combined procedure.

Sagittal Alignment

There are well understood effects of sagittal knee alignment on both native and reconstructed ACL grafts. Biomechanical studies have shown that increased posterior tibial slope (PTS) increases weight-bearing anterior translation of the tibia and resultantly increases the amount of stress placed on the ACL and increases the risk of native or graft ACL rupture [2••]. By reconciling posterior tibial slope, biomechanical studies have demonstrated decreased anterior tibial translation [2••].

Clinical studies have confirmed the deleterious effects of increased tibial slope on risk of ACL re-tear after reconstruction. Webb and colleagues performed a prospective longitudinal study over 15 years in 200 patients undergoing primary ACL reconstructions. The PTS was measured from radiographs in patients who had ACL failure to the surgical knee post-reconstruction or the contralateral knee. These authors found that patients who had injury to their reconstructed or contralateral ACL had a mean PTS of 9.9° as compared with 8.5° in those who had no further injury; patients who had rupture of their ACL grafts or contralateral ACL had an increased PTS of 12.9°. Webb and colleagues concluded that those undergoing an ACL reconstruction and having a PTS of greater than 12° had five times higher odds of recurrent ACL injury or tear and 59% incidence of graft re-tear or re-injury [15]. Lee and colleagues found similar results in a

match cohort study of 64 patients who ruptured their ACL grafts and those who did not suffer re-rupture. The authors found that the mean PTS for those who suffered a graft re-tear (mean PTS = 13.2°) was significantly higher than a matched control group who did not have re-rupture (PTS = 10.9°) [3].

Sagittal alignment, with or without varus alignment and medial compartment osteoarthritis, contributes to ACL failure and may be corrected with a high tibial osteotomy performed in combination with an ACL reconstruction or revision [16]. Dejour and colleagues retrospectively looked at a series of patients that underwent revision ACL reconstruction with a tibial de-flexion osteotomy for excessive tibial slope. These authors examined 9 patients and found that at an average of 3 years of follow-up, all the patients had well healed osteotomies, stable knees and there were no intra-operative or post-operative complications. These authors also found that the mean posterior tibial slope had declined from 13.2 to 4.4° [2••]. These results were confirmed in another retrospective study performed by Schuster et al. who evaluated 50 patients who underwent combine HTO and ACL reconstruction with at least 2 year follow-up [17]. These authors found that at the time of follow-up, no patient had required conversion to arthroplasty, and the IKDC scores were a mean of 70 with a 94% satisfaction rate [17].

Pre-operative Evaluation

When evaluating a patient with an acute ACL tear or rupture of an ACL graft, it is imperative to evaluate if malalignment to determine if coronal or sagittal plane may contribute to increased risk of re-tear. Complete radiographs including full limb length AP and lateral weight-bearing views are required to determine mechanical axis and to measure posterior tibial slope [18]. In addition to radiographs, magnetic resonance should be obtained to identify meniscal pathology (including root and ramp lesions), osteonecrosis, osteochondral defects, concomitant ligamentous injury, subchondral edema, or medial compartment cartilage degeneration [18]. A detailed physical examination can assist in determining the degree of instability, joint line tenderness, assess for concomitant ligamentous laxity, recurvatum instance, and to assess any limits to range of motion such as contractures. Instability tests such as the Lachman, pivot shift, prone external rotation tests at both 30 and 90°, and anterior/posterior drawer texts should be performed to understand the extent of knee instability. Lower limb alignment in all 3 planes can assess for alignment and evaluation of gait can reveal any abnormalities such as a varus thrust [12••]. This information, along with history and imaging, can help determine the need for a single or staged osteotomy for coronal and/or sagittal plane correction.

Indications for a High Tibial Osteotomy

When considering a patient for an alignment correction in the setting of an ACL tear, choice of surgery and timing of surgery is highly dependent on the current deformity, soft tissue stabilizers, activity/occupational demands, and patients rehab potential. A high tibial osteotomy in isolation can re-distribute mechanical forces across the knee joint and thereby proving useful in situations that include knee instability, varus alignment with early medial compartment degeneration, medical compartment overload following meniscectomy, and osteochondral defects requiring resurfacing (Fig. 1). In addition to these indications, it can also be employed to correct posterior tibial slope in the sagittal plane [18]. A high tibial osteotomy with a staged ACL reconstruction or revision is indicated in chronic ACL deficiency with double or triple varus knee and alignment and/or medial compartment

Fig. 1. Varus thrust is a dynamic process that occurs with medial compartment narrowing and insufficiency of the lateral and posterolateral stabilizing structures. Example of a varus aligned knee with medial compartment narrowing and widening of the lateral compartment

osteoarthritis [18]. A ligament reconstruction may be avoided if the posterolateral structures are not completely disrupted in a double or triple varus knee because a high tibial osteotomy can potentially stabilize the knee and provide pain control [13]. Relative contraindications to high tibial osteotomy include patellofemoral arthrosis, severe articular damage of the medial compartment, tricompartmental arthritis, severely decreases range of motion of the knee including a flexion contracture greater than 5° or less than an arc of motion of 120°, age greater than 50, obesity, and nicotine use. [12••].

The senior author prefers an opening wedge biplanar (coronal and sagittal plane correction) high tibial osteotomy with the use of the Synthes Locking Tomofix plate and a tricortical allograft wedge. We typically perform this in staged fashion prior to ligament reconstruction and have found that the patient will rarely need the second-stage soft tissue ACL reconstruction because the sagittal slope correction alone will reconcile much of the patient's symptomatic instability. If the patient still is engaged in cutting, pivoting, or jumping sports, a single-stage concomitant ACL reconstruction with opening wedge biplanar high tibial osteotomy is performed. If required, the second stage should be performed no sooner than 6 months after the initial surgery and can often be performed while removing only one or two of the proximal rafter screws [19••].

Post-operative Outcomes

Outcomes of high tibial osteotomy with an ACL reconstruction have demonstrated significant improvement in patient reported outcomes, decreased pain, and improved stability and function.

Conclusion

Current evidence has shown that a high tibial osteotomy combined with a primary or revision ACL reconstruction have led to positive outcomes in patients with ACL deficiency and concomitant coronal and sagittal imbalance. Correcting the deformity of the knee in multiple planes with a high tibial osteotomy results in increased stability and less stress/strain on the reconstructed ACL. Unfortunately, there is no study that we are aware of that directly compares patients who undergo combined HTO and ACLR with a matched cohort who undergo only an ACLR. Based on basic science biomechanical work and limited comparison data, we believe that high tibial osteotomy may have an important role in reducing risk of ACL graft rupture, especially in revision cases, and should be considered in patients that require ACL reconstruction and have significant coronal and/or sagittal plane deformity.

Compliance with Ethical Standards

Conflict of Interest Michal Klek and Aman Dhawan declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

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2.•• Hinckel BB, Demange MK, Gobbi RG, Pecora JR, Camanho GL. The effect of mechanical varus on anterior cruciate ligament and lateral collateral ligament stress: finite element analyses. Orthopedics. 2016;39(4):729–36. https://doi.org/10.3928/01477447-20160421-02 **The current study analyzed changes in anterior cruciate ligament (ACL) and lateral collateral ligament stress as a result of mechanical varus. In an exploratory pilot study, progressive mechanical varus was introduced to a male finite element model of the lower limb at different knee flexion angles. Nine situations were analyzed (combinations of 0°, 30°, and 60° knee flexion and 0°, 5°, and 10° varus). The ACL stress was measured via changes in section force, von Mises stress, and fiber stress. Lateral collateral ligament stress was measured via changes in section force. For all 3 measures of the ACL, maximum stress values were found in extension, stress decreased with flexion, and the effect of varus introduction was most significant at 30° flexion. With 60° flexion, varus introduction produced a decrease in section force and von Mises stress and a small increase in fiber stress. In all situations and stress measures except fiber stress at 60° flexion, stress was concentrated at the posterolateral bundle. For the lateral collateral ligament, the introduction of 5° and 10° varus caused an increase in section force at all degrees of flexion. Stress in the ligament decreased with flexion. Mechanical varus of less than 10° was responsible for increased ACL stress, particularly at 0° and 30° knee flexion, and for increased lateral collateral ligament stress at all degrees of flexion. Stress was mostly concentrated on the posterolateral bundle of the ACL.**
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12.•• Cantivalli A, Rosso F, Bonasia DE, Rossi R. High tibial osteotomy and anterior ligament reconstruction/revision. Clin Sports Med. 2019;38(3):417–33. https://doi.org/10.1016/j.csm.2019.02.008 **High tibial osteotomy (HTO) is a procedure commonly used to treat medial early osteoarthritis (OA) in young and active patients. Combined HTO and anterior cruciate ligament reconstruction (ACL-R) is indicated in patients with medial OA and varus alignment (primary, double, or triple varus) associated with ACL tear with symptomatic anteroposterior instability, failed ACL-R, or increased posterior tibial slope (PTS). A PTS greater than 12 is a risk factor for ACL-R failure and should be modified. There are different surgical techniques to perform a concomitant HTO and ACL-R. Opening wedge and closing wedge HTO are the most commonly performed, but there is no evidence supporting the superiority of one procedure over the others. For ACL-R, soft tissue autograft or allograft is commonly used in association with anatomic reconstruction. There are few studies on combined HTO and ACL-R with short follow-up and few patients. However, most of these studies reported good outcomes, with complication rates similar to isolated or staged ACL-R.**
13.•• Crawford M, Lee DH, Amendola A. Surgical management and treatment of the anterior cruciate ligament deficient knee with malalignment. Clin Sports Med. 2017;36(1):119–33. https://doi.org/10.1016/j.csm.2016.08.006 **Malalignment can increase stress on anterior cruciate ligament (ACL) reconstruction, contributing to recurrent instability. Varus malalignment can lead to overload of the medial compartment and symptomatic arthritis. Realignment osteotomy can reduce symptoms of ACL instability and unload or reduce mechanical wear of the medial compartment. Correction of varus malalignment can improve outcomes of revision ACL reconstruction. Changes of tibial slope can affect symptomatic ACL laxity.**
14.• Schuster P, Geßlein M, Schlumberger M, Mayer P, Richter J. The influence of tibial slope on the graft in combined high tibial osteotomy and anterior cruciate ligament reconstruction. Knee. 2018;25(4):682–91. https://doi.org/10.1016/j.knee.2018.04.007 **Background: Young patients with severe medial osteoarthritis, varus malalignment and insufficiency of the anterior cruciate ligament (ACL) are difficult to treat. The tibial slope has gained attention with regard to osteotomies and ligamentous instability. The purpose was to evaluate the outcome of combined high tibial osteotomy (HTO), ACL reconstruction and chondral resurfacing (CR, abrasion plus microfracture), and to analyze graft failure rates with regard to the tibial slope. Methods: Fifty cases (48.9 ± 5.4 years) of combined HTO, ACLR and CR were retrospectively analyzed with regard to survival, functional outcome (subjective International Knee Documentation Committee (IKDC) examination form) and subjective satisfaction. The tibial slope was determined on lateral radiographs and analyzed with regard to its influence on graft functionality at the time of hardware removal. Results: Follow-up rate was 100% after 5.6 ± 1.6 years. No arthroplasties were performed. Subjective IKDC score was 70 ± 18, and 94% were satisfied with the result. The graft was intact in 39 cases (78%), and non-functional in 11 cases (22%). No significant changes were present in pre- and postoperative tibial slope ($P = 0.811$). Graft insufficiency was strongly dependent on tibial slope, with a failure rate of 7% in cases of postoperative tibial slope b 7.5°, 24% in cases of 7.5–12.5°, and 36% in cases of N 12.5°.Conclusion: Combined HTO, ACLR, and CR is an effective treatment in these cases. The graft failure rate increases with an increase in tibial slope, in particular when exceeding 12.5°.Level of evidence: Case series, Level 4.**
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19.•• Stride D, Wang J, Horner NS, et al. Indications and outcomes of simultaneous high tibial osteotomy and ACL reconstruction. Knee Surg Sports Traumatol Arthrosc. 2019;27(4):1320–31. https://doi.org/10.1007/s00167-019-05379-5 **Purpose: the purpose of this study was to systematically review the existing literature reporting surgical outcomes of simultaneous high tibial osteotomy (HTO) and anterior cruciate ligament reconstruction (ACLR) in anterior cruciate ligament deficient (ACLD) knees. Methods: This study was conducted per the methods of the Cochrane Handbook for Systematic Reviews of Intervention, with findings reported per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The electronic databases MEDLINE, EMBASE, and PubMed were searched for relevant studies and pertinent data was extracted. Studies reporting post-operative outcomes following simultaneous HTO and ACLR in ACLD knees were included. Results: The search identified 515 studies, of which 18 ($n = 516$) were included. The mean MINORS scores for non-comparative and comparative studies were 11.6 ± 1.34 and 17.3 ± 1.9, respectively. Simultaneous HTO and ACLR resulted in improved functional subjective patient outcomes across a variety of scales. Simultaneous HTO and ACLR was effective in correcting varus angulation, with the post-operative mechanical angle ranging from 0.3 to 7.7° valgus. The reported complication rate ranged from 0 to 23.5%. Across six studies, a total of 13 (6.5%) patients required revision HTO; while across four studies, 20 (17.5%) patients had failure of the ACL graft, with one receiving revision ACLR.**

Conclusions: Combined HTO and ACLR may be indicated in patients with ACLD knees with varus angulation. This systematic review found that the combined surgery resulted in significant improvement in post-operative functional subjective outcomes. However, it remains unclear if HTO with ACLR is superior to ALCR or HTO alone due to the lack of comparative studies. Overall, HTO with ACLR was found to have low rates of complications, re-ruptures, and need for revision surgery. This review found that patients continued to have progression of OA despite combined HTO with ACLR. Future research is required to better understand the effects of combined HTO and ACLR compared to ACLR or HTO alone and to evaluate the long-term post-operative progression of medial compartment OA following combined HTO and ACLR. Level of evidence IV.