



The Role of Osteotomy for the Treatment of PCL Injuries

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Abstract

Purpose of Review The purposes of this review are to (1) describe the anatomic and biomechanical rationale for high tibial osteotomy (HTO) in the setting of posterior cruciate ligament (PCL) deficiency, (2) review the indications for concomitant HTO and PCL reconstruction, (3) provide guidance for the clinical assessment of the patient with suspected PCL deficiency, and (4) summarize the key surgical steps necessary to attain the appropriate sagittal and coronal plane corrections.

Recent Findings The preponderance of available biomechanical data pertaining to the PCL-deficient knee suggests that an increased proximal tibial slope limits posterior tibial translation under axial compressive loads. Moreover, recent clinical data has demonstrated that decreased proximal tibial slope may exacerbate residual anterior-posterior laxity and jeopardize the durability of PCL reconstruction. Thus, in the setting of PCL deficiency, an HTO that increases the posterior tibial slope may be advisable.

Summary HTO may be an important treatment adjunct in the surgical management of PCL deficiency. In the setting of chronic injuries and varus malalignment, HTO should be considered in order to ensure a durable ligamentous reconstruction and forestall the progression of secondary osteoarthritis.

Keywords Posterior cruciate ligament (PCL) · High tibial osteotomy (HTO) · Tibial slope · Posterior tibial translation · Varus malalignment

Introduction

The posterior cruciate ligament (PCL) is a primary restraint to posterior tibial translation [1–7] and a secondary stabilizer to rotation, especially in higher flexion angles [8–10]. PCL injuries most commonly occur during sport activity or trauma, usually related to motor vehicles [11–13]. Moreover, males are the predominant patient population sustaining PCL injuries, with rates up to 75–93% being reported [11, 12, 14]. Isolated injuries of the PCL are relatively uncommon and have

historically been managed non-operatively with bracing and rehabilitation [15–18]. Conversely, PCL injuries occurring in conjunction with anterior cruciate ligament (ACL), medial collateral ligament (MCL), and/or posterolateral corner (PLC) injuries are commonly managed surgically as part of a multiligamentous reconstruction approach [11, 19–22]. However, in spite of the evolution anatomic PCL reconstruction (PCLR), residual anterior-posterior laxity has been observed in 33–56% of patients [23–31]. Although these results are assuredly multifactorial, an emerging body of biomechanical and clinical data suggests that the sagittal and coronal plane anatomy of the proximal tibia may play a key role in the success (or failure) of reconstructive procedures [32, 33, 34].

The role for high tibial osteotomy (HTO) in the management of coronal plane malalignment typically observed with chronic PLC/PCL injuries is well described [35–37]. Conversely, comparatively less has been written about the utility of HTO in addressing the sagittal plane anatomy of the proximal tibia. In fact, the reciprocal effect of increased tibial slope on diminishing the magnitude of posterior tibial translation under axial compressive loads may be of special relevance

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to the surgical treatment of the PCL-deficient knee. Therefore, the purposes of this review are to (1) describe the anatomic and biomechanical rationale for HTO in the setting of PCL deficiency, (2) review the indications for HTO and PCL reconstruction, and (3) provide guidance for the clinical assessment of the patient with suspected PCL deficiency, and (4) summarize the key surgical steps necessary to attain appropriate sagittal and coronal plane corrections. While varus malalignment may be corrected with either lateral or medial-based HTO, this review will focus on medial opening wedge HTO given the fact that the preponderance of available biomechanical and clinical data pertains medial opening wedge HTO.

Anatomy

The PCL is composed of two functional bundles, the anterolateral (AL) and the posteromedial (PM) bundles [3, 6, 7, 38–41]. Together, these bundles are able to bear maximum tensile loads of up to 1627 N [6, 42–44]. The PCL has a broad area of femoral insertion from the medial aspect (PM bundle) to the roof (AL bundle) of the intercondylar notch [40]. The femoral insertional areas of the AL and PM bundles range from 112 to 118 mm² and 60 to 90 mm², respectively [45, 46]. Tibial insertional areas have been reported to be a mean of 88 and 105 mm² for the AL and PM bundles respectively [45].

A thorough understanding of proximal tibial anatomy is critical for the surgeon contemplating HTO. The proximal lateral tibial cortex is nearly perpendicular to the posterior margin of the tibia. In the axial plane, the proximal anteromedial tibial cortex has an oblique or triangular shape, forming an angle of $45 \pm 6^\circ$ with the posterior margin of the tibia [47]. In the sagittal plane, the proximal tibia slopes posteriorly with subtle differences observed between the medial and lateral tibial plateaus (medial 9–11° v. lateral 6–11°). However, significant variation in the degree of proximal tibial slope has been reported in the literature, which underscores the importance of an individualized approach to the assessment of patients with suspected PCL deficiency [48–52].

Physical Examination

Given the fact that approximately 60% of PCL injuries are observed in conjunction with posterolateral corner (PLC) injuries, the examiner should maintain a high index of suspicion for combined injuries [11]. Both isolated PCL deficiency and combined PCL/PLC injuries each have implications on coronal and sagittal plane knee alignment, which can have several important clinical manifestations. The examiner should assess for knee hyperextension or

hyperextension with an associated varus thrust gait as both have been demonstrated to alter knee flexion angles throughout all phases of the gait cycle [53]. Additionally, varus malalignment may lead to overloading of the articular surfaces of the medial compartment, and the presence of joint line tenderness may alert the examiner to associated osteoarthritic changes. Similarly, posterior translation of the tibia increases contact pressures across the patellofemoral joint, which may accelerate osteoarthritic changes. Therefore, the patellofemoral joint should be assessed for tenderness, crepitus, and a painful arc of motion [54, 55].

PCL tears can be detected with a number of described physical examination maneuvers, which have all been shown to be both sensitive and specific for PCL injury [36, 56, 57]. A posterior sag sign is a static finding that is assessed with both hips flexed to 45°, the knees flexed to 90°, and the feet held on the examination table. A posterior sag sign is best appreciated by comparing the injured to the uninjured knee: the PCL-deficient knee may result in a proximal tibia “sagging” posteriorly relative to the anterior aspect of the femoral condyle.

The posterior drawer test is performed with affected extremity positioned in a way such that the hip is flexed to 45°, the knee flexed to 90°, and the foot held on the examination table. Once again, comparison to the contralateral knee is useful. The normal relationship between the tibial plateau and medial femoral condyle has the tibial plateau resting 1 cm anterior to the anterior aspect of the medial femoral condyle. This relationship, noted as normal posterior tibial translation, is graded based upon the station of the tibial plateau relative to the medial femoral condyle. The examiner’s hands are placed on the anterior aspect of the proximal tibia with the thumbs positioned over the joint line, and a posteriorly directed force is applied. The test is graded I–III based upon the amount of posterior tibial translation: grade I, 0–5 mm of posterior tibial translation; grade II, 5–10 mm of posterior tibial translation, resulting in the tibial plateau lying flush with the medial femoral condyle; and grade III, greater than 10 mm of posterior tibial translation, resulting in the tibial plateau translating posterior to the medial femoral condyle. It is important to maintain the leg in neutral rotation as it has been suggested that intact menisiofemoral ligaments tighten in internal rotation and may obscure the appreciation of a grade I injury [58].

The quadriceps active test is a dynamic assessment of posterior knee instability with the affected extremity held in the position identical to that of posterior drawer test. The quadriceps active test relies on quadriceps contraction, which reduces the posteriorly subluxated tibia anteriorly in the setting of PCL deficiency. A positive result is defined as any translation greater than 2 mm [57]. Finally, the status of the PLC and

the presence of posterolateral rotatory instability must be thoroughly scrutinized as the definitive surgical plan may require a combined PCL/PLC reconstruction.

Imaging

Plain radiographs and magnetic resonance imaging (MRI) are indispensable in the evaluation of patients with suspected PCL deficiency. Rosenberg posterior-anterior (PA) flexion weight-bearing radiographs of the affected knee are useful to assess for degenerative changes in the medial joint space. The Merchant's view allows for inspection of the patellofemoral joint and detection of the degenerative changes typical of the chronically PCL-deficient knee. A precise understanding of the patient's axial alignment and tibial slope informs the surgeon's decision to perform an osteotomy and dictates the orientation and magnitude of the required correction. In the setting of a varus knee deformity, single cassette, full-length anterior-posterior (AP) standing radiographs of bilateral lower extremities is mandatory (Fig. 1). Moreover, the utility of single cassette, full-length AP supine radiographs of bilateral lower extremities has also been advocated in order to eliminate the added, dynamic varus deformity that may be a consequence of deficient lateral and posterolateral structures, which may complicate a precise understanding of the patient's coronal plan alignment attributable solely to an underlying osseous anatomy [36, 59].

The utility of lateral radiographs of the knee cannot be overstated as well in order to both assess the patient's native tibial slope and plan an osteotomy that appropriately alters the native sagittal plane anatomy. Multiple methods for measuring the native slope of the tibia have been described and used reliably (Fig. 2), although it has been shown that the anterior tibial cortex (ATC) measurement method may overestimate tibial slope, while the posterior fibular anatomic axis (PFAA) method may underestimate tibial slope [61]. Still, there is no consensus about which method should be used; no method has been shown to be most accurate.

Stress radiographs of the knee are routinely used in order to more precisely quantify the degree of posterior tibial translation relative to the uninjured knee. Kneeling lateral radiographs are perhaps the most expedient technique for assessing posterior tibial translation, and it is generally accepted that partial PCL tears result in less than 8 mm of posterior tibial translation, complete PCL tears in 8–12 mm of posterior tibial translation, and combined PCL-PLC tears in greater than 12 mm of posterior tibial translation [62, 63].

The native PCL appears as a continuous, low signal intensity structure on fluid sensitive magnetic resonance imaging (MRI) sequences with a maximum anterior to posterior diameter of 6 mm, and diameters greater than 6 mm and/or increased intrasubstance signal intensity are

common features of a torn PCL [64]. However, the diagnosis of PCL insufficiency by only inspection of the ligament's appearance on MRI may be inadequate in the setting of chronic tears, as the sensitivity of MRI for detecting PCL in chronic cases has recently been shown to be as low as 60 versus 100% in cases of acute PCL rupture [65, 66]. This fact underscores the utility of stress radiographs in equivocal cases or suspected chronic tears in quantifying the precise amount of posterior tibial translation. Finally, MRI is of particular utility in diagnosing associated injuries to the main structures that comprise the PLC, the lateral collateral ligament (LCL), the popliteus tendon (PLT) and the popliteofibular ligament (PFL), which are all particularly well visualized with thin slice (2 mm), coronal oblique proton density sequences [67].

The Biomechanical Rationale for Osteotomy

A medial opening wedge HTO can accommodate both sagittal and coronal plane corrections that both negate the consequences of PCL deficiency and decrease the strains seen by the reconstructed PCL and PLC. The utility of medial opening wedge HTO for correction of coronal plane malalignment is well described in the setting of isolated medial compartment osteoarthritis. However, in cases of isolated PCL or combined PCL/PLC deficiency, medial opening wedge HTO may also be advisable in light of clinical results indicating increased rates of soft tissue reconstruction failure among patients with varus malalignment [29, 68, 69, 70, 71].

With respect to sagittal plane correction, biomechanical testing has demonstrated that medial opening wedge HTO increases the posterior slope of the tibial plateau from approximately 8° to 13°, resulting in anterior translation of the tibia relative to the femur up to 3.6 ± 1.4 mm in full extension. Furthermore, under similar testing conditions with the addition of axial compressive forces, medial opening HTO resulted an additional anterior tibial translation of 1.9 ± 2.5 mm (Fig. 3) [72]. In a separate study assessing the effect of a medial opening wedge HTO of comparable magnitude, an increase in anterior tibial translation was observed when the axial compressive load was increased from 134 to 200 N [73]. These biomechanical data are corroborated by recently published clinical results, which have observed significant correlations between decreased tibial slope and an increased risk of PCLR failure [34].

The dynamic effects of PCL deficiency also have a number of long-term effects on the contact forces applied to patellofemoral and medial knee compartments. Posterior subluxation of the medial tibial plateau with increasing degrees of knee flexion subjects the posterior horn of the medial meniscus to supraphysiologic loads, thereby increasing the contact pressures in the medial compartment by approximately 30%

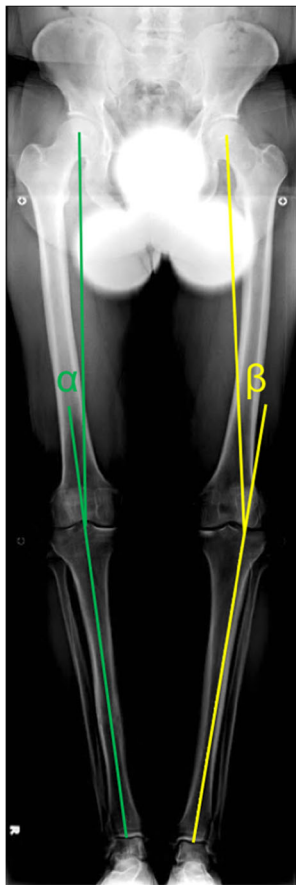


Fig. 1 Single cassette, full-length anterior posterior standing radiograph of bilateral lower extremities is used to calculate required correction of varus malalignment in the coronal plane. Right knee: When OA changes are not present in the medial compartment, the correction should target for the mechanical axis to cross the tibial plateau at 50% of total tibial plateau width. The angle α represents the required correction. Left knee: If OA in the medial compartment is present, the correction should target for the mechanical axis to cross the tibial plateau at 62% of total tibial plateau width, from medial to lateral. The angle β represents the required correction

[74–76]. Moreover, the coupled anterior-posterior and rotatory instability observed in PCL deficiency have been shown to expose the patellofemoral joint, specifically the lateral patellar facet and inferior pole of the patella, to abnormally high contact pressures [54]. These consequences assuredly contribute to the increased rates of osteoarthritic changes observed among these patients [53, 54, 77] and underscore the utility of medial opening wedge HTO in altering the natural history of the PCL-deficient knee.

Osteotomy Principles

The biomechanical rationale for HTO is based on the short- and long-term effects of PCL deficiency. A number of biomechanical analyses have demonstrated that an isolated PCL

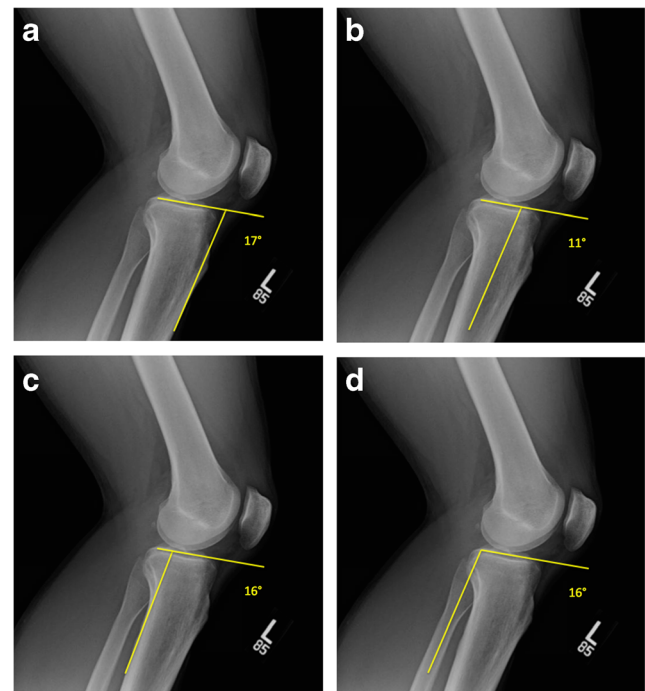


Fig. 2 Four methods for measuring the native tibial slope using lateral radiographs of the knee. **a** Anterior tibial cortex (ATC) [60]. **b** Proximal tibial anatomic axis (PTAA) [51]. **c** Posterior tibial cortex (PTC). **d** Proximal fibular anatomic axis (PFA) [48]

lesion results in external rotation and posterior translation of the proximal tibia relative to the femur, especially with flexion angles greater than 60° [8, 10, 73, 78]. The clinical implications of these effects are manifold, as anterior-posterior tibial translations have been observed to be significantly increased in activities such as walking and stair ascent [79]. Similarly, significantly increased hyperextension moments have been observed in PCL-deficient knees throughout all phases of the gait cycle [53]. These effects can be exacerbated by a concomitant PLC lesion, and in the setting of a chronic PCL/PLC injury, the so-called triple varus (tibiofemoral varus geometry, attenuation of the lateral soft tissues, and hyperextension secondary to an incompetent PLC) may also be observed [80].

Indications and Surgical Timing

In the setting of isolated PCL or combined PCL/PLC injuries, medial opening wedge HTO can be considered in cases of varus malalignment of 5° – 10° and/or a posterior tibial slope less than 5° . For the treatment of chronic injuries, these thresholds may be lowered at the discretion of the surgeon. Additionally, medial opening wedge HTO may be considered in the setting of isolated PCL or combined PCL/PLC injuries associated with radiographic evidence of low to intermediate grade medial compartment osteoarthritis. Symptomatic

patellofemoral compartment osteoarthritis should not necessarily be considered a contraindication to medial opening wedge HTO given the available evidence demonstrating its effect on diminishing patellofemoral compartment contact pressures.

HTO for the treatment of PCL or combined PCL/PLC injuries may be performed in isolation or in conjunction with ligamentous reconstruction. In fact, it has been shown that HTO alone can yield acceptable clinical outcomes [70, 81]. The authors most commonly perform a combined procedure with arthroscopic predrilling of tunnels and tibia osteotomy. The tunnels are re-drilled prior to final graft passage. In case of two staged surgery, the osteotomy is performed first including slope alteration. A time period of 3–6 months is observed to allow for healing of the osteotomy. A second stage ligament reconstruction can be performed if residual ligament instability persists.

Principles of Sagittal Plane Correction

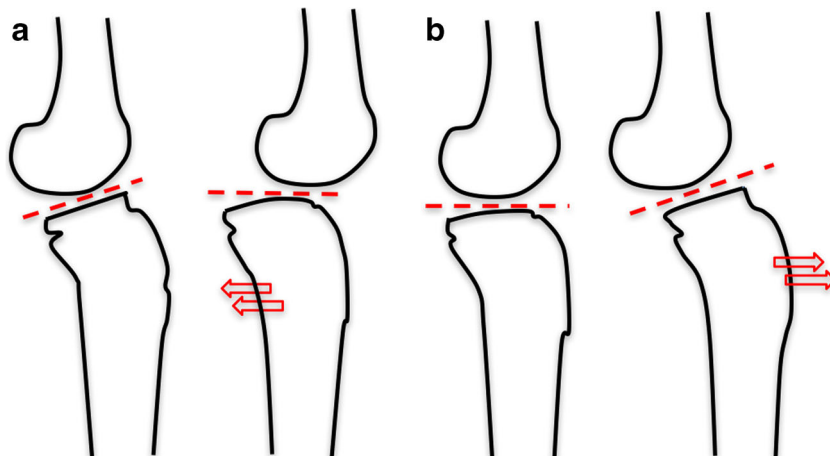
The anatomy of the proximal tibia governs the sagittal and coronal plane effects of medial opening wedge HTO. When viewed in cross section, the proximal anteromedial tibia is triangular in shape, forming a $45^\circ \pm 6^\circ$ relative to the posterior cortex. Conversely, the lateral tibial cortex forms a near 90° with respect to the posterior cortex, and there are several consequences of these relationships that predictably affect sagittal and coronal plane corrections. In order to maintain the native tibial slope, the height of the osteotomy posteriorly should be twice that of osteotomy anteriorly. Thus, an increase in the osteotomy's anterior height relative to the posterior height will increase the tibial slope (Fig. 4). In fact, it has been shown that every millimeter of anterior osteotomy height results in a 2° increase in tibial slope [47]. Alternatively, HTO may be completed without altering the anterior and posterior gap heights, and instead, the placement of a wedge of predetermined height

can be inserted anteriorly into the osteotomy site to increase the tibial slope.

Operative Technique

A 10-cm longitudinal incision is made over anteromedial proximal tibia adjacent to the patella tendon with the elevation of full thickness soft tissue flaps. The sartorial fascia is then incised in line with its fibers and subperiosteal elevation of the superficial MCL is performed. Under orthogonal fluoroscopic imaging, a 2.4-mm kirschner wire is then introduced in the anteromedial tibia, proximal to the tibial tubercle, and directed toward the proximal tibiofibular joint (Fig. 5a). A second 2.4-mm kirschner wire is introduced 1–2 cm posterior and parallel to the first kirschner wire, to serve as a guide for osteotomy and ensure that the planned osteotomy trajectory is parallel with the slope of the proximal tibial plateau. The osteotomy is performed with an oscillating blade beginning inferior to the guide kirschner wires and extending to a point that is approximately 10 mm from the lateral tibial cortex. The osteotomy is completed with a straight 1-in. osteotome. A laminar spreader is introduced anteriorly and the osteotomy site is distracted in order to achieve the desired coronal plane correction (Fig. 5b). A wedge of predetermined height is then inserted into the osteotomy site to provide provisional stabilization while the direction and magnitude of correction can be scrutinized. The aforementioned relationship between the anterior osteotomy height relative to the posterior osteotomy height should be considered as a wedge inserted anteriorly in the osteotomy site would be expected to increase the tibial slope and vice versa. The authors' preference is that for opening corrections of 8 mm or greater, a corticocancellous allograft wedge of bone is fashioned and inserted into the osteotomy site, the laminar spreader is removed, and a locking plate of the appropriate length is selected and fixed to the medial proximal tibia cortex (Fig. 5c, d).

Fig. 3 Changes in the tibial slope and consequences in the anteroposterior tibial translation. **a** A decrease in the tibial slope leads to a posterior translation of tibia, stabilizing knees with ACL deficiency. **b** An increase in the tibial slope promotes anterior translation of the tibia, improving stability of PCL-deficient knees



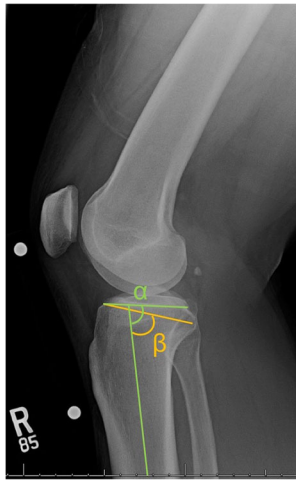


Fig. 4 Preoperative plan for sagittal correction in PCL deficiency. Green: lines for measurement of tibial slope using the proximal tibial anatomic axis (PTAA) method; α angle: decreased tibial slope angle in a PCL-deficient knee; β angle: desired increase in tibial slope angle

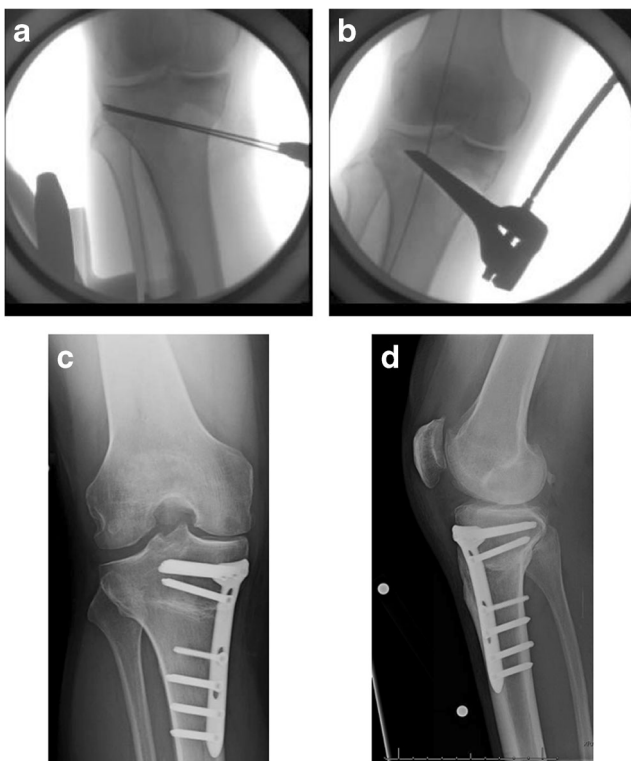


Fig. 5 Medial opening wedge HTO. **a** Introduction of two kirschner wires aimed toward the proximal tibiofibular joint (intraoperative fluoroscopic image). **b** Laminar spreader is introduced anteriorly and the desired opening from preoperative measurements is achieved to simultaneously correct varus and increase tibial slope if so desired (intraoperative fluoroscopic image). **c**, **d** Locking plate application to the medial proximal tibia cortex to maintain desired correction and stabilize the osteotomy (postoperative radiographs)

Postoperative Rehabilitation

Range of motion from full extension to 90° of flexion is encouraged beginning the day after surgery. Patients are restricted to non-weight-bearing activity for 4 weeks. The use of crutches is encouraged until 6–8 weeks postoperative. Quadriceps and hamstring strengthening exercises are encouraged during all rehabilitation phases, but closed kinetic chain exercises are only commenced at 6 weeks postoperative. Progressive return to full activities is considered at 3 months postoperative once sufficient quadriceps and hamstring strength has been regained and a non-antalgic gait is demonstrated.

Outcomes

In spite of the relative paucity of clinical studies pertaining to HTO performed either in isolation or in conjunction with PCL or combined PCL/PLC reconstructions, there is limited evidence to suggest HTO alone may be a reasonable approach to the management of PCL deficiency and an associated hyperextension-varus thrust gait. One study evaluating 14 patients with ligamentous instability (ACL, PCL, or PCL deficiency) and varus malalignment treated with HTO alone or in conjunction with ligament reconstruction observed significant improvements in the Cincinnati Knee Rating Scale in all cases. Of note, three of nine patients (33.3%) with combined PCL/PLC injuries were treated successfully with HTO alone [81]. Another case series of 21 patients with multiligamentous knee injuries and hyperextension and varus thrust gait reported a similar proportion of patients in which HTO alone was a viable management approach (two of six patients (33%) with combined PCL/PLC injuries were managed successfully with HTO alone) [82]. Even higher rates of acceptable clinical outcomes after HTO alone have been reported in a third, comparably sized cohort, as significant improvements in Tegner and Lysholm scores were observed among all patients. Moreover, 11 out of 16 patients (68.7%) did not require a subsequent ligamentous reconstruction [70]. While it is difficult to draw definitive conclusions based upon these relatively small groups of patients, the available clinical results coupled with a sound body of biomechanical data support the utility of HTO in the treatment of PCL deficiency.

Conclusions

Medial opening wedge HTO may be an important treatment adjunct in the surgical management of isolated PCL or combined PCL/PLC injuries. With a thorough understanding of the anatomy of the proximal tibia, the surgeon can effectively employ the HTO to correct coronal plane malalignment and

mitigate the biomechanical consequences of PCL deficiency. In the setting of chronic PCL injuries and varus malalignment, HTO should be considered in order to ensure a durable ligamentous reconstruction and prevent the progression of secondary osteoarthritis.

Compliance with Ethical Standards

Conflict of Interest All authors 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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