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Sagittal Tibial Osteotomy

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Abstract

The anatomy of proximal tibia is such that the anterior part is higher than the posterior, both medially and laterally, which causes a natural posterior tibial slope (PTS). The 'normal range' of this slope is variable across geography, ethnicity and gender. The morphology of the slope has profound impact on knee biomechanics, especially with respect to the anterior and posterior cruciate ligaments. A high slope increases forces across the anterior cruciate ligament (ACL), while the posterior cruciate ligament (PCL) function is compromised when the slope is flat or reversed (sloping anteriorly). A flat or reversed slope also contributes to the 'bony' component of a genu recurvatum deformity, which can become symptomatic. A sagittal tibial osteotomy (STO) is one in which the PTS is altered without changing the coronal plane alignment. When the slope is reduced, it is known as an extension STO and when the slope is increased, it is known as a flexion STO. This review describes the biomechanics of the PTS; the planning, indications, technique and complications of a STO and discusses some case examples.

Keywords: Posterior tibial slope, Osteotomy, Sagittal plane deformity, Revision anterior cruciate ligament reconstruction, Genu recurvatum

Introduction

The geometry of the tibial plateau has a direct influence on the biomechanics of the tibiofemoral joint in terms of translation, the location of instantaneous centre of rotation, the screw-home mechanism, and the strain biomechanics of the knee ligaments such as the anterior and posterior cruciate ligaments [1]. An important characteristic of the tibial plateau is its posterior slope, with the anterior elevation being higher than the posterior elevation [2]. The posterior tibial slope (PTS) is defined as the angle between the perpendicular to the middle part of the diaphysis of the tibia and the line representing the posterior inclination of the tibial plateau [3].

There is a wide racial and gender variation in the values reported in healthy individuals [4-6]. One needs to be aware of the prevalent mean PTS values in his/her region of practice to better decide what constitutes an 'abnormal' slope. In Pangaud's cohort from Europe, the mean global, medial and lateral PTS were reported as 6.3°, 6.2° ad 5.3° respectively, based on CT measurements. The PTS of Asians was mean 1.9° greater than whites, while females had a lower global and lateral PTS [4]. In a study of osteology specimens from United States of America, Weinberg reported significantly greater medial (mean 8.7° vs 5.8°) and lateral (mean 5.9° vs 3.8°) PTS in blacks than whites, and females having significantly steeper medial and lateral slopes than males [5]. Aljuhani et al have reported a mean medial PTS of 5.8±3.0° and 6.61±3.3°, and the lateral PTS of 4.4±3.3° and 4.6±2.8° in men and women, implying no gender dimorphism in the Saudi population [6]. A CT based study from China reported that females had higher PTS than males (mean medial PTS 9.5° vs 8.8° and mean lateral PTS of 8.5° vs 8.4°) [7]. In a MRI study from Japan, reported the mean PTS in the medial plateau as 10.7° (range 5 - 15.5°) and in the lateral plateau as 7.2° (range 0 - 14.5°) [8].

Changes in tibial slope have a strong effect on cartilage pressure and kinematics of the knee [9]. In this review article, we shall discuss the biomechanics of the tibial slope vis-à-vis the anterior and posterior cruciate ligaments, methods of measuring the slope and the types and techniques of performing a sagittal tibial osteotomy (STO) for various indications.

Biomechanics of tibial slope

Tibial shear force determines the force transmitted to the cruciate ligaments of the knee. This force derives from three main sources: an external load arising from the presence of the ground reaction force; knee muscle activity; and the contact force acting between the femur and tibia. Due to posterior slope of tibial plateau the tibiofemoral contact forces induces an anteriorly directed shear force (Figure 1). During walking this shear force is more than the ground reaction force. This causes relative anterior translation of the tibia with respect to femur and stretches the anterior cruciate ligament [10, 11]. Agneskirschner et al provided one of the earliest evidence of the effects of a high tibial flexion osteotomy of the tibia in a cadaveric model [9]. They found that the flexion osteotomy to increase the PTS caused the contact area and pressure to shift anteriorly on the tibial plateau. Further, the posterior tibial sag caused by resecting the

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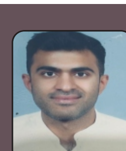

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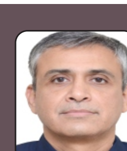

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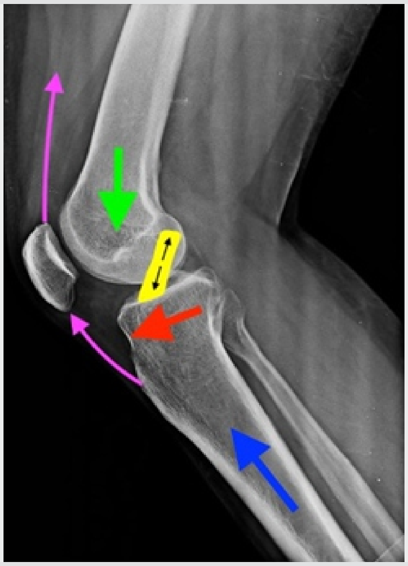

Figure 1: Biomechanical forces in play in the knee are the joint loading directed distally (green arrow), ground reaction force directed proximally (blue arrow), superior pull of the extensor apparatus (pink arrows) and the anterior translatory force (red arrow) which is resisted by the tension of the intact Anterior Cruciate Ligament (yellow band).

Figure 2: The centres of circles touching the anterior and posterior tibial cortices at 5 cm. (red dot) and 15 cm. (blue dot) distal to the joint line are marked and joined to obtain the anatomic axis of the tibia (yellow line), which is then extended proximally to the joint level. A second line is drawn perpendicular to this line centring on the tibial articular surface (green line) and a third line is drawn along the joint line of the tibia (orange line). The angle subtended between the second and third lines is the posterior tibial slope, 8.1 deg. in this case.

posterior cruciate ligament (PCL) was neutralized by the anterior and superior shift of the tibial head. Moreover, the increased slope resulted in higher quadriceps strength [9]. Giffin demonstrated that increasing the tibial slope by 5 mm anterior opening wedge osteotomy resulted in an anterior shift of the resting position of the tibia in relation to the femur by a mean of 3.6 ± 1.4 mm. Further, this affect was accentuated by axial loading of the knee. They postulated that increasing the slope would be beneficial in PCL deficient knees while reducing the slope would similarly lead to a posterior translational effect on the tibia and benefit anterior cruciate ligament (ACL) deficient knees [12, 13].

The effect of the PTS on ACL biomechanics has been studied extensively in cadaveric models in recent times. A cadaveric experiment by Bernhardson et al found a highly positive linear relationship between PTS and ACL graft force when the knee is axially loaded. The graft force was significantly higher at 0° of knee flexion [14]. Mclean et al studied a simulated jump landing task on cadaveric lower limbs to understand the relationship between PTS and ACL strain and anterior tibial translation on impact loading. There was significant co-relation between PTS with peak anterior tibial translation (r= 0.75) and peak anteromedial bundle ACL strain (r= 0.76) [15]. Thus, the posterior tibial slope has a bearing on the ACL, both in the static position and the loaded knee. Yamaguchi et al found that a 10° anterior closing osteotomy reduced ACL force and anterior tibial translation (ATT) on application of tibiofemoral compression in human cadaveric knees using a robotic set-up [16]. Imhoff also reported a reduction of ATT on axial loading after a 10° extension osteotomy. The ACL graft force reduced by mean 17% on application of 200 N axial load and by mean 33.1% on application of 400 N axial load [17]. These in-vivo experiments provide rationale for the protective effect of an extension STO on the ACL graft.

Genu recurvatum could be due to soft-tissue and bony factors. Reversal or a flat tibial slope is the most important bony abnormality which causes the knee to go in to hyperextension. A recurvatum knee is inherently unstable as active locking of the joint is not possible. The patellofemoral lever arm is abolished and quadriceps function is impaired. The quadriceps contraction tends to exacerbate the recurvatum and it becomes painful due to patella cartilage erosion. A recurvatum may also cause instability of the patellofemoral joint by producing a pseudo-patella-alta pattern [18]. A flexion osteotomy to increase the PTS reduces the knee hyperextension and improves quadriceps function [19].

Measurement of posterior tibial slope

The posterior tibial slope can be measured on a short lateral radiograph of knee joint, a full-length lateral radiograph of the tibia and knee, Magnetic resonance imaging (MRI) scan or a 3-dimensional Computed Tomography (CT) scan. The commonest methods used for calculation of the PTS are the short lateral radiograph and MRI Scan and are described here.

1. Short Lateral Radiograph: A true lateral view of the knee joint with both femoral condyles overlapping and about 20 cm. of the tibia exposed in necessary to measure the slope accurately. Several techniques have been described but the one by Utzschneider is easily reproducible [20]. Two circles are drawn touching the anterior and posterior tibial cortices at 5 cm and 15 cm distal to the joint line. The centers of these circles are joined to obtain the anatomic axis of the tibia which is extended to the joint level. A second line is drawn tangential to the tibial plateau and third line is drawn perpendicular to the first line centring on the tibial articular surface. The angle subtended between the second and third lines is the posterior tibial slope (Figure 2).

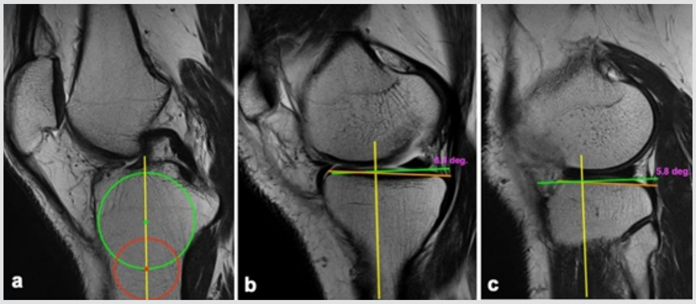

Figure 3: (a) The central sagittal slice of the MRI is chosen which shows the tibial PCL attachment and the intercondylar eminence. Two circles were drawn- one cranial (green) touching the anterior and posterior cortices and the joint surface and one caudal (red) touching the anterior and posterior cortices. The centers of these circles are joined and extended proximally to obtain the longitudinal axis (LA). (b) The medial posterior tibial slope (PTS) is calculated in the central mediolateral section of the medial plateau. The LA is projected as previously determined (yellow line). A line perpendicular to the LA is drawn (green line), a tangent is drawn along the articular surface of the cartilage (orange line) and the angle between these two lines is the medial PTS. (c) The lateral PTS is calculated in the central mediolateral section of the lateral plateau. The LA is projected as previously determined (yellow line). A line perpendicular to the LA is drawn (green line), a tangent is drawn along the articular surface of the cartilage (orange line) and the angle between these two lines is the lateral PTS.

2. MRI Scan: The technique described by Hudek et al can be performed without restriction of length of tibia exposed on the scan [21]. Sagittal T2-weighted sections are selected at the level of tibial PCL attachment for drawing the longitudinal axis of the tibia and at the mid-plateau levels for measuring the medial and lateral PTS separately. The central sagittal image is chosen which contains the tibial attachment of the PCL, the intercondylar eminence and the anterior and posterior tibial cortices appear. A cranial circle is drawn which should touch the anterior, posterior, and cranial tibial cortices bone and a caudal circle which touches the anterior and posterior cortices. The MRI longitudinal axis is defined by a line that connects the centers of these two circles. All measurements are positioned as an overlay and remain in a fixed position on the complete image series. A tangent to the medial plateau is drawn by connecting the uppermost superior-anterior and posterior cortex edges on the MRI section showing the mediolateral center of the medial plateau. The medial PTS is defined by the angle between a line orthogonal to the MRI longitudinal axis and the tangent to the medial plateau. The lateral PTS is similarly measured on the MRI section showing the mediolateral center of the lateral plateau (Figure 3).

Indications for a sagittal tibial osteotomy

The understanding and impact that an abnormal PTS can have, is still evolving. As such, there is no consensus as to when a sagittal plane slope changing osteotomy must be performed. Small changes of the PTS can be done while performing a coronal plane altering osteotomy and a STO must be contemplated only when the major deformity lies in the sagittal plane. Generally, there are two types of STO which can be performed: (a) Flexion osteotomy to increase the PTS and (b) an Extension osteotomy to decrease the PTS. The clinical indications where this surgery can be beneficial are [22]:

1. Repeated ACL reconstruction failure(s) with a high PTS (>12°)- Extension Osteotomy [23-26]

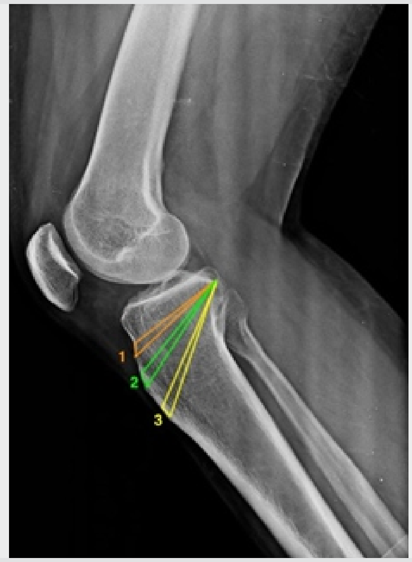

Figure 4: A schematic representation of the levels of sagittal tibial osteotomy to reduce or increase the slope i.e., supra-tuberosity (1- orange); at the level of tuberosity (2- green) and infra-tuberosity (3- yellow).

2. Chronic/neglected PCL instability with a flat or reversed slope - Flexion Osteotomy
3. Symptomatic Genu recurvatum of >20° due to a flat or reversed tibial slope - Flexion Osteotomy

Technique of osteotomy

A sagittal plane osteotomy of the tibia can be performed at three levels: (a) supra-tuberosity; (b) at the level of tuberosity; (c) infra-tuberosity (Figure 4). Each technique has its advantages and disadvantages. We prefer the osteotomy at the level of tibial tuberosity via a tibial tubercle osteotomy (TTO) approach. This technique allows good exposure and can be tailored to perform both a flexion and extension osteotomy.

1. Planning: A 'rule of thumb' was proposed by Friedmann et al stating that a 1 mm wedge of removal or addition of bone causes the posterior slope to change by 1.5-2° [27]. However, a more accurate method would be to plan the osteotomy on calibrated radiographs and to plot the length of wedge on the anterior tibial cortex to be removed or added, depending on the indication.

2. Surgical Approach: A para-median incision just medial to the tibial tuberosity (TT) about 8-10 cm. in length is made. Full-thickness fascio-cutaneous soft-tissue flaps are raised medially and laterally. Medially, the anterior portion of the superficial medial collateral ligament is released, preserving its distal attachment and the pes tendons. The anterolateral surface of tibia is exposed by releasing the tibialis anterior muscle for a distance of 5-6 cm. A Hohmann's retractor is placed on the medial and lateral side to expose the tibia from the front (Figure 5). A tibial tubercle osteotomy is performed to achieve a tongue of bone that is about 6 cm long and 5 mm thick. The anterior cortex can be pre-drilled with a 3.5 mm drill bit to facilitate fixation later. A thin saw blade must be used perform this osteotomy in the medial-lateral direction and then the distal cut made. A broad osteotome must be used complete the osteotomy gently, to avoid

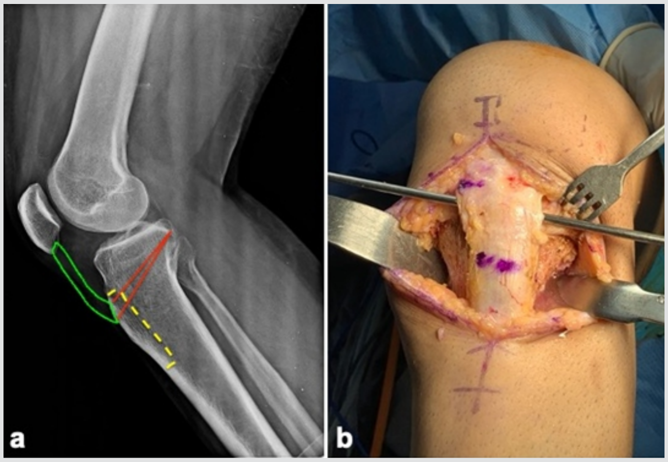

Figure 5: (a) Schematic representation of the patella tendon (green area), tibial tubercle osteotomy (TTO) (yellow rectangle) and sagittal tibial osteotomy (red triangle). (b) Intra-operative photograph of the surgical exposure of left knee showing the retractors placed medially and laterally and a Wissinger rod behind the insertion of the patella tendon at the tibial tuberosity.

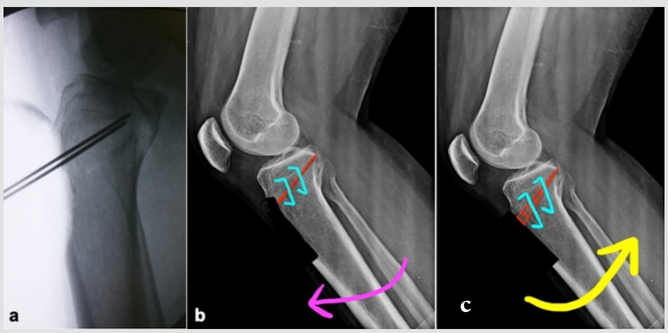

Figure 6: (a) Intra-operative image intensifier image showing the trajectory of the K wire inserted form anteromedial and anterolateral tibia towards the hinge point posteriorly. (b) Schematic representation of closure of the extension osteotomy (red line) by extending the distal tibia (pink arrow) and fixation of the osteotomy with staples (blue lines). The completion of the surgery after closure of the tibial tubercle osteotomy and its fixation with screws (blue). Schematic representation of opening of the flexion osteotomy and bone graft (red shaded area) by flexing the distal tibia (yellow arrow) and fixation of the osteotomy with staples (blue lines).

fracturing the bone tongue. The patella retinaculum needs to be released for 2-3 cm medially and laterally to allow the osteotomized bone to be lifted proximally. The anterior tibial surface is now clearly visible to perform the osteotomy and fixation. The next step differs in whether the wedge needs to be opened (flexion) or closed (extension).

3a. Extension Osteotomy: This is performed when the PTS needs to be reduced and is accomplished by closing a wedge of bone anteriorly. Starting at the level of tibial tuberosity, 2 mm K wires are drilled from the anterior surface, starting both medially and laterally, and directed to the PCL insertion site of the tibia. This is performed under fluoroscopy guidance in the flexed knee and the wires must be parallel to each other (Figure 6a). The width of wedge to be resected is measured and marked on tibia, distal to the K wires. Two 2 mm K wires are then drilled from the marked points to converge with the first two wires at the hinge point. A thin saw blade is used to perform

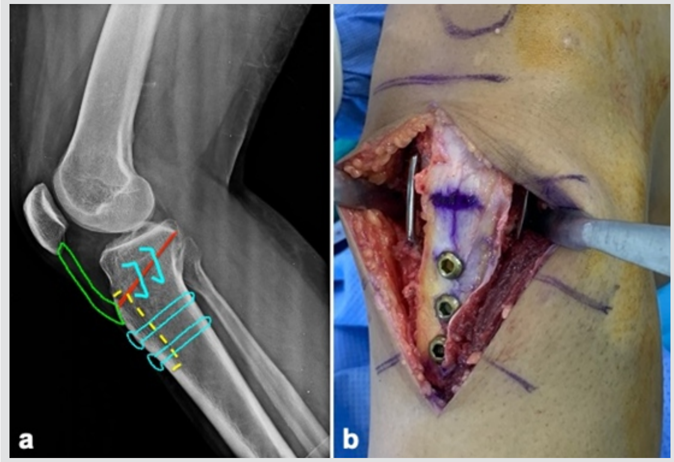

Figure 7: (a) Schematic diagram of the completion of the osteotomy after closure of the tibial tubercle osteotomy (TTO) and its fixation with screws (blue). (b) Intra-operative image of the sagittal tibial osteotomy fixed with bone staples medially and laterally and the TTO fixed with three cortical screws.

the bone cuts and resect the wedge of bone. Osteotomes are used to complete the osteotomy and remove the wedge of bone under fluoroscopy. A curette can be used to remove residual bone posteriorly, taking care to preserve the cortex. The wedge is closed by gradually bringing the knee into extension, while applying anterior pressure at the osteotomy site to shorted the lever arm of applied force (Figure 6b). This step is performed very gradually over several minutes and under fluoroscopy control. Once the wedge is fully closed, wires used to mark the osteotomy are removed and provisional fixation performed using two cross K wires.

3b. Flexion Osteotomy: This is performed when the PTS needs to be increased and is accomplished by opening a wedge of bone anteriorly. The 2 mm K wires are drilled from anterior to posterior aiming for the hinge point in the same manner as for the extension osteotomy. The wires and then cut short. A thin oscillating saw blade is used to perform the osteotomy just distal to the K wires. The osteotomy is stopped about 15 mm short of the posterior cortex to avoid a hinge fracture. A 1.8 mm K wire is used to drill the posterior cortex in the flexed knee under fluoroscopy guidance to weaken the cortex while protecting popliteal neurovascular structures. All K wires are removed. Two lamina spreaders are placed medially and laterally and the osteotomy is gradually opened to the planned width. This is measured and a tricortical bone graft of the same width is harvested from the ipsilateral iliac crest. The harvested graft is inserted into the opened wedge of the osteotomy (Figure 6c). Alternatively, a bone substitute wedge maybe used.

4. Fixation: The tibial osteotomy is stabilized using 1-2 bone staples each on the anteromedial and anterolateral cortex. These staples act as a tension-band in the presence of an intact posterior hinge. More rigid fixation with plates and screws are generally not required but can be performed. The tibial tubercle bone tongue is brought down to its native location and the patellar height is measured on fluoroscopy to decide whether to perform a distalization or proximalization of the osteotomy. The posterior cortices through the previously drilled anterior holes with a 2.7 mm drill bit after determining the site of

TTO fixation which also acts like a biological plate. Two or three 3.5 mm cortex screws provide adequate stability of this osteotomy (Figure 7). The stability of both osteotomies is assessed by taking the knee through a full range of motion as this determines progression of rehabilitation.

Rehabilitation: Bracing in full extension is done for 4 weeks to allow the TTO to heal. Early passive range of motion from 0-90° can be allowed if the osteotomy fixation is stable. Immediate toe-touch weight-bearing with crutches can be allowed unless specifically contra-indicated by the soft-tissue (ligament/meniscus/cartilage) repair or reconstruction. Multimodality interventions are necessary to control pain and to reduce edema. Full weight bearing is usually allowed after 4-6 weeks if the osteotomies show radiological signs of consolidation.

Complications

STO is a technically demanding surgery. There are certain complications that are specific to this procedure. A hinge fracture is a devastating complication which renders the entire osteotomy and fixation unstable. The hinge lies posteriorly in the area of the tibial PCL insertion and occurs when osteotomy violates the posterior cortex. This usually happens if the osteotomy wedge is opened or closed rapidly without allowing for plastic deformation of the bone. The hinge fracture can cause the tibial head to tilt or rotate in any direction. Direct stabilization of this fracture is not possible due to its location. In this scenario, the osteotomy must be fixed with an angle-stable plate anteromedially and staples laterally for extra stability. Rehabilitation is slowed and weight bearing must be deferred till the osteotomy shows signs of healing. Patella alta is possible when a supra-tuberosity osteotomy is performed due to infra-patellar shortening of the patellofemoral complex. This has not been found to occur when the osteotomy is performed at the level of the tuberosity [22]. Hardware related complications are due to irritation from the staples or screws used for STO fixation, especially medially. It might necessitate hardware removal upon healing of the osteotomy. Injury to popliteal vessels or tibial nerve due to penetration of K wires or saw or osteotome is also possible. This disastrous complication can be prevented by careful surgical technique, performing each step under fluoroscopic guidance and keeping the knee flexed during the entire procedure. Knee hyperextension can occur after a flexion STO. Keeping a close watch on knee extension when closing the wedge and stopping short of the desired correction if >10° hyperextension occurs can prevent disability and symptoms.

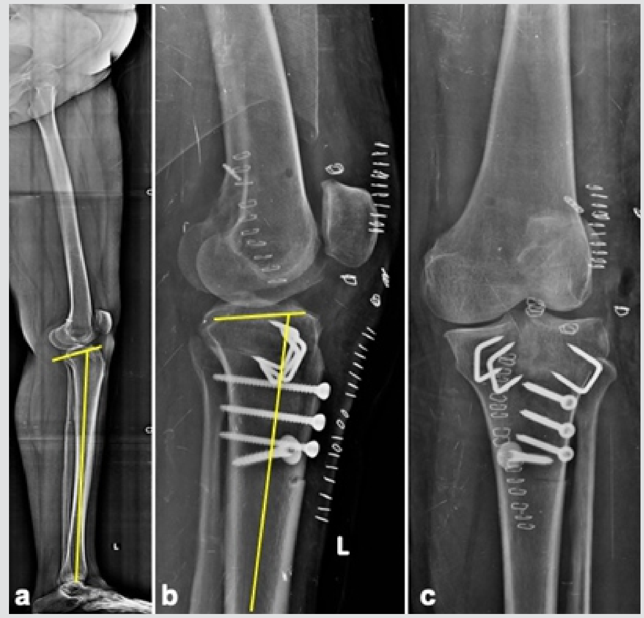

Figure 8: (a) Lateral view single-stance weight bearing radiograph showing the posterior tibial slope to be 17° in the patient with two prior anterior cruciate ligament failures. (b) Post-operative lateral radiograph showing the slope reduced to 5° (c) Post-operative radiograph anterior view showing the fixation of the sagittal tibial osteotomy with staples and the tibial tubercle osteotomy with cortical with screws.

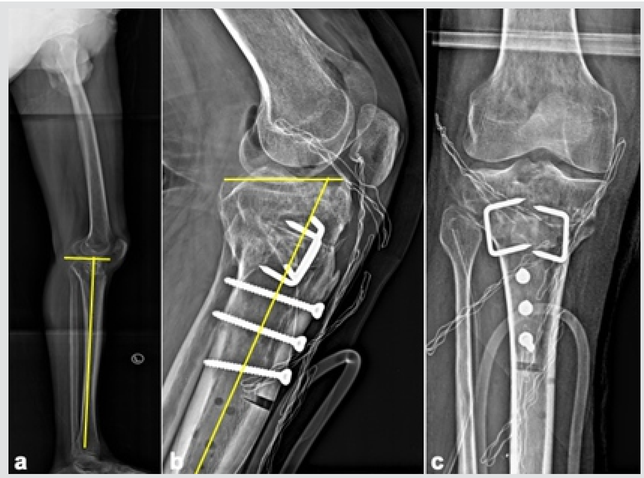

Figure 9: (a) Lateral view single-stance weight bearing radiograph showing the posterior tibial slope to be -2° in the patient with malunited proximal tibia fracture and posterior cruciate ligament instability. (b) Post-operative lateral radiograph showing the slope changed to 7° (c) Post-operative radiograph anterior view showing the fixation of the sagittal tibial osteotomy with staples and the tibial tubercle osteotomy with cortical with screws.

Case Examples: We present below examples of a STO performed for three typical scenarios.

1. Extension osteotomy with Revision ACL Reconstruction: A 37-year-old amateur football player had failure of left knee ACL reconstructions twice. The first was 3 years prior when the reconstruction was performed using his ipsilateral hamstrings graft. That failed after a year following non-contact trauma and revision reconstruction was performed using the contralateral hamstrings graft. The revision graft also ruptured after almost 2 years. Further investigation of his bone anatomy revealed a PTS of 17°. He underwent an extension STO along with a re-revision ACL reconstruction using his ipsilateral quadriceps tendon graft and a lateral extra-articular tenodesis to control the high-grade pivot instability. The post-op PTS was reduced to 5° (Figure 8).

2. Flexion osteotomy for Chronic PCL instability: A 45-year-old male had sustained a right-side proximal tibia fracture 4 years prior for which surgery (open reduction and internal fixation) was performed. The implants were removed after about two years of surgery but the patient complained of persistent knee pain and occasional instability. He was found to have grade 3 PCL instability and a PTS of -2°. He underwent a flexion STO to correct his slope to 7° and a PCL reconstruction could be avoided (Figure 9).

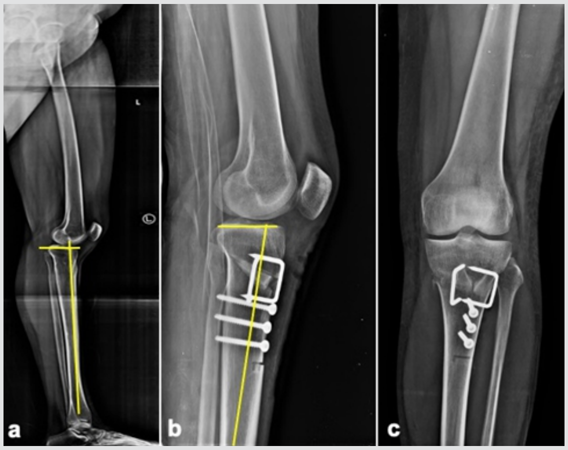

Figure 10: Lateral view single-stance weight bearing radiograph showing the posterior tibial slope to be -3° in the patient with symptomatic genu recurvatum of 20°. (b) Post-operative lateral radiograph showing the slope changed to 7° (c) Post-operative radiograph anterior view showing the fixation of the sagittal tibial osteotomy with staples and the tibial tubercle osteotomy with cortical with screws.

3. Flexion osteotomy for symptomatic Genu Recurvatum: A 19-year-old girl presented with complaint of anterior knee pain on the left side. She was found to have a knee hyperextension deformity of 20° with a PTS of -3° and generalized ligament laxity with a Beighton score of 7/9. Her right knee had a hyperextension of about 10°. She underwent a flexion STO to change the PTS to 7° (Figure 10). This surgery brought down her recurvatum to about 5° and resolved the knee pain.

Conclusion

Sagittal tibial osteotomy is a very powerful tool to alter the posterior tibial slope. It can be used to reduce the slope in cases of repeated failures of the ACL reconstruction when the PTS is more than 12°. In cases of chronic PCL instability or genu recurvatum due to a flat or reversed slope, a STO can increase the slope by flexing the proximal tibial.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

Conflict of Interest: NIL; **Source of Support:** NIL

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