

INTERACTION BETWEEN ANTERIOR CRUCIATE LIGAMENT AND TIBIAL SLOPE: WHAT IS THE ROLE FOR TIBIAL DEFLEXION OSTEOTOMY

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SUMMARY

Background: Anterior cruciate ligament (ACL) reconstruction failure remains a clinical challenge, with graft rupture rates reaching 25% in revision settings. While technical errors such as tunnel malposition were historically primary causes of failure, recent evidence identifies excessive posterior tibial slope (PTS) as a critical anatomical risk factor. Increased PTS correlates linearly with elevated graft tension and static anterior tibial translation (SATT), potentially leading to fatigue failure and residual laxity.

Objective: This article evaluates the biomechanical influence of PTS on ACL graft stability and details the radiographic assessment and surgical management of sagittal tibial malalignment through tibial deflexion osteotomy (TDO).

Key Points: Biomechanical data indicate that each degree of medial PTS increases anterior translation by 0.46 mm. Radiographic assessment requires true lateral views in single-leg weight-bearing to measure PTS and SATT. Surgical intervention via supra-tubercular, trans-tubercle, or infra-tubercle TDO is indicated for revision cases with $PTS \geq 12^\circ$ and $SATT \geq 5$ mm. The supra-tubercular technique involves a biplanar anterior closing wedge osteotomy to achieve a target PTS of $4-6^\circ$. Clinical outcomes demonstrate graft rupture rates as low as 2% following TDO, though risks include iatrogenic genu recurvatum and minor increases in patellar height.

Conclusion: Addressing sagittal plane tibial morphology is essential in managing recurrent ACL deficiency. Tibial deflexion osteotomy effectively reduces graft strain by correcting excessive PTS and SATT, providing a stable environment for ligament reconstruction and improving long-term functional outcomes in high-risk patients.

KEYWORDS

Anterior Cruciate Ligament Reconstruction; Osteotomy; Tibia; Joint Instability; Reoperation

INTRODUCTION

Anterior cruciate ligament (ACL) tear is an extremely common pathology that mainly affects people who frequently practise pivot-torsion sports. In most cases, ligament reconstruction is indicated. In France in 2019, 50,000 of these kinds of interventions were performed [1]. This surgery offers excellent long-term functional outcomes. However, in the event of repeat tears, further surgery is more complex, and the course of specific rehabilitation may need to be longer, with lower rates of resuming sport and poorer functional outcomes than the patient has been hoping for [2]. Moreover, when a graft has torn once, the rate of further ruptures may be as high as 25% [3]. This means that it is crucial to analyse and isolate the factors that could lead to these failures, and to treat them when the graft is first fixed. Some anatomical, or sometimes congenital or hormonal, factors are intrinsic and specific to the patient. Other factors are external, such as the type of sport practised, the conditions in which sport is played, and the physical preparation [4].

Poorly positioned tunnels, especially the femoral tunnel, have been described as being the main cause of repeat tear [5]. However, improvements to surgical techniques and instrumentation developments mean that the impact of this factor has been reduced.

The current trend is for an augmentation consisting of a modified Lemaire extra-articular tenodesis or ALL reconstruction, which the latest published series have found to decrease the number of repeat tears. This may be leading to this strategy becoming routine, although it is still not without risk [1].

For this reason, it is essential to look closely at other factors. In the field of veterinary medicine, where the rate of fatigue tears of the ACL in “large dogs” is high, it has been clearly shown that an excessive posterior tibial slope is the cause [6]. Although this may have often been neglected in studies looking at repeat tears, posterior tibial slope has become an anatomical factor of major interest, and particularly since it has been associated with static anterior tibial translation (SATT) in single-leg stance [7],[8]. Patients who have an excessive posterior tibial slope are at a significantly greater risk of tear or repeat tear of an ACL graft [9].

It is therefore important to explore methods to quantify and then treat this intrinsic anatomical risk factor to reduce the rate of repeat tears.

The objective of this article is to set out the importance of posterior tibial slope, and how to assess and manage it in ACL tears.

BIOMECHANICS

The ACL is made up of two bands of connective tissue named for their tibial attachment sites: the anteromedial bundle and the posterolateral bundle. The anteromedial bundle mainly acts on anterior translation, while the posterolateral bundle has an action that controls internal rotation. When the ACL tears, the loss of its function results in increased anterior tibial translation in weight-bearing but also instability in internal rotation, which is worsened if the anterolateral bundle is affected.

We will take a separate look at the compartments of the knee and their tibial slopes:

1. Medial :

When there is a greater medial tibial slope, there will be increased anterior tibial translation during weight-bearing. For each degree of slope, translation shifts by 0.46mm [7]. The medial meniscus is the main secondary stabiliser of anterior translation, and it is essential to take it into account when assessing tibial slope. A medial meniscectomy will increase the functional slope and accentuate this tibial translation in single-leg stance by a mean of 0.5 to 1.5 mm [10].

2. Lateral :

An elevated lateral tibial slope in the context of an ACL tear will mean increased rotatory instability and pivot shift grade [11]. The lateral meniscus is also an important secondary stabiliser of the lateral compartment [12]. This can be demonstrated by the improved rotatory stability achieved through lateral meniscal root repair [13].

Simply put, the medial compartment mainly impacts anteroposterior translation while the lateral compartment acts on rotational control [12].

IMAGING ASSESSMENT

Method

There are several methods for measuring tibial slope, which means that the method used must be stated as they have different threshold values.

We use a simple and reliable method to measure tibial slope and SATT.

Radiology images should be obtained to include true lateral views showing 15 cm of proximal tibia with 20° of flexion in single-leg weight-bearing. The condyles will be aligned under fluoroscopy before the conventional radiography is performed. Any deviation from lateral will lead to distortions and the measurements will not be possible to interpret [14] (Figure 1). Next, the technique for measuring the tibial slope must be chosen so that it is reproducible and can be compared from one study to another. It is crucial to choose one method and stick to it. The technique that uses the proximal anatomical tibial axis has a normal value of 9° of slope and the method is described in Figure 2 [15]. The normal value for SATT is 1.31 mm [16]. If translation is posterior, the measurement will have a negative value. The measurement method is described in Figure 3.

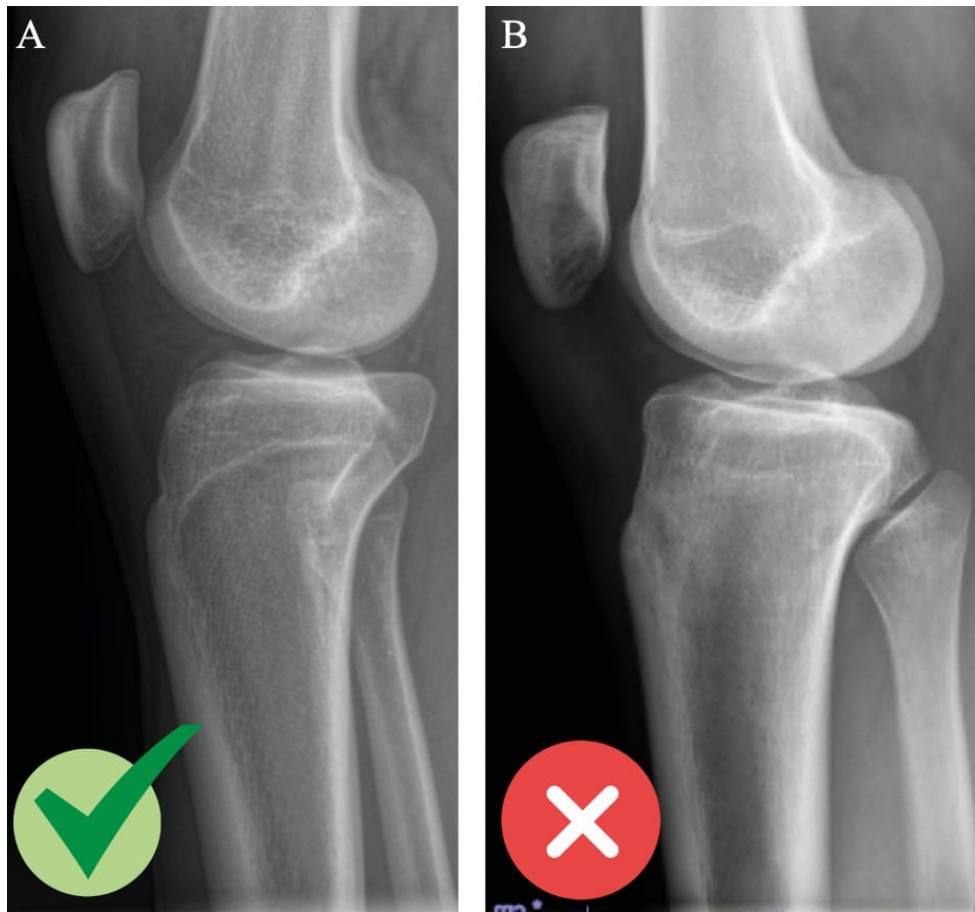


Figure 1. Example of a correctly performed radiograph (A) and one that cannot be interpreted because there is hyperextension and the condyles are not superimposed (B)

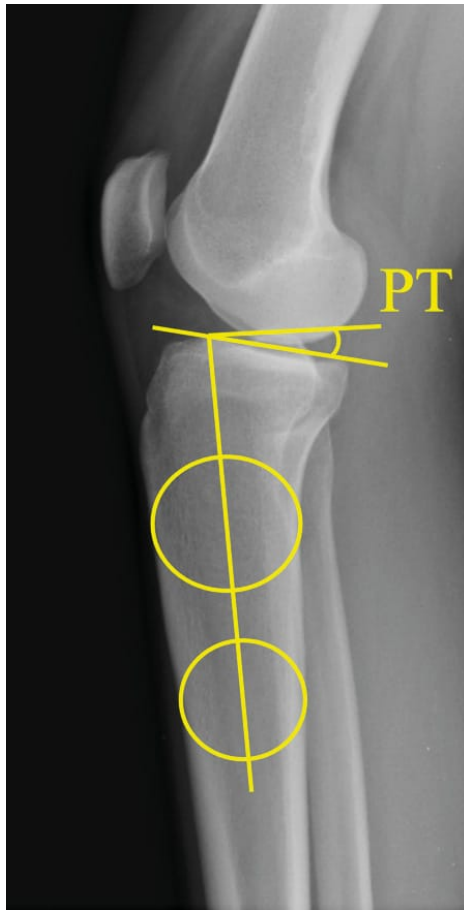


Figure 2. Lateral radiograph of the right knee in single-leg stance illustrating the method for measuring posterior tibial slope (PTS). PTS is the angle formed by the line perpendicular to the diaphyseal axis of the tibia and the tangent of the medial tibial plateau.

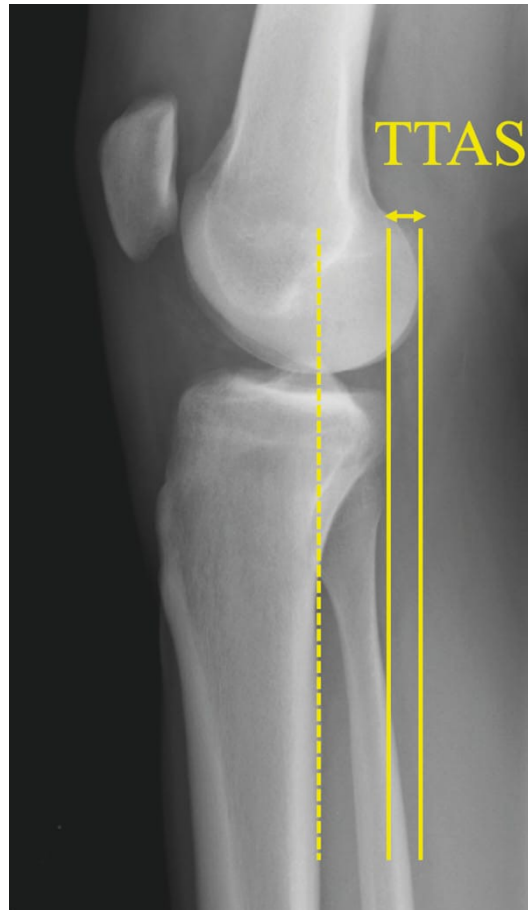


Figure 3. Lateral radiograph of the right knee in single-leg weight-bearing illustrating the method for measuring static anterior tibial translation (SATT). Two lines are traced parallel to the posterior tibial cortex. The first is a tangent to the posterior part of the medial tibial plateau. The second is a tangent to the medial femoral condyle. The SATT is the distance between these two lines.

Treatment

How do these measurements influence the treatment strategy?

Post-operative weight-bearing protocol:

Firstly, they may have an impact on the post-operative weight-bearing protocol. For example, patients with a tibial slope greater than 12° and/or a SATT greater than 5mm prior to surgery will begin with a non-weight-bearing phase lasting 21 days in order to decrease the stresses of excessive translation on the graft to protect it [17].

Surgical :

The intervention that directly addresses tibial slope is the tibial deflexion osteotomy (TDO) [18]. This intervention was notably described by Dejour et al. in 1998, although it has been discussed at the Lyon Knee Surgery Congress since the early 1990s [19],[20]. It is a sagittal realignment osteotomy. The technique described here is a supra-tubercular osteotomy (Figure 4). However, trans-tubercle and infra-tubercle strategies are also possible (Figure 5). This intervention is performed at the same time as the ACL reconstruction.

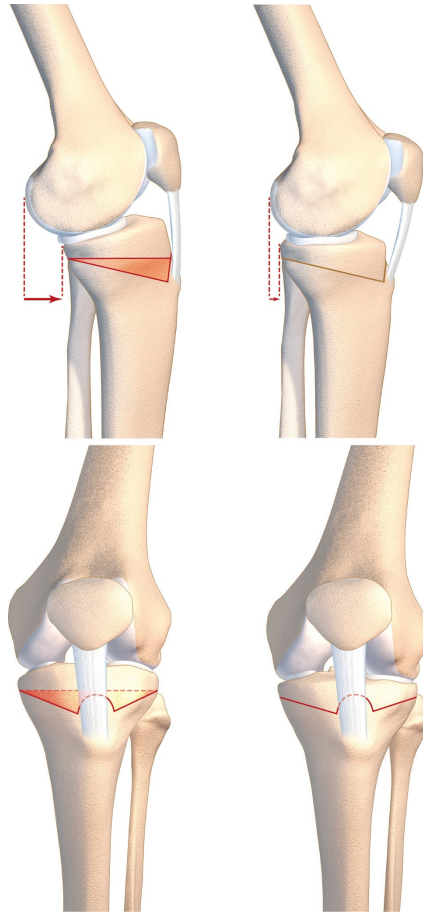


Figure 4. Deflexion osteotomy. This is a biplanar and supra-tubercular osteotomy.

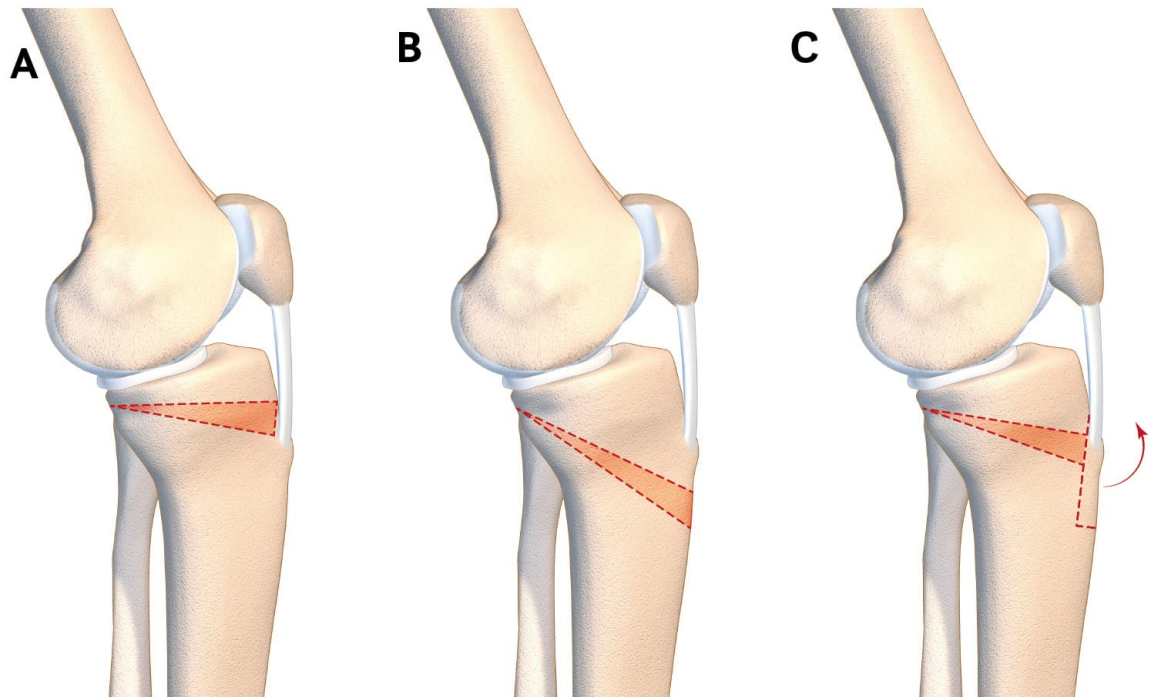


Figure 5. Different forms of deflexion osteotomy. A) supra-tubercular, B) infra-tubercle, C) trans-tubercle.

SURGICAL TECHNIQUE

Indication: Repeat rupture and tibial slope $\geq 12^\circ$ and a SATT $\geq 5\text{mm}$. The number of surgical revisions and meniscal condition may lower these thresholds.

Contraindication: Genu recurvatum $\geq 10^\circ$, early stage or established femorotibial osteoarthritis, skeletal immaturity.

Patient preparation

The patient is positioned in dorsal decubitus, with a lateral thigh post and a support holding the knee in 90° of flexion. The intervention is performed with a tourniquet positioned at the proximal end of the limb, and the whole procedure is under general or regional anaesthesia.

Incision

A longitudinal incision is made, medial to the anterior tibial tubercle (ATT). It starts 4 cm below the joint line and extends for around 6 cm. The hamstring tendon graft can be removed using this same incision. If the patellar tendon is being used as a graft, the cut extends further proximally as far as the corner of the patella; if the quadriceps tendon is to be used, a separate incision is made.

Osteotomy

The first key step is to identify the insertion of the patellar tendon over the ATT. Then, the fascia lata and tibialis anterior muscle are released following the Kewish lateral approach. The deep medial collateral ligament is released medially. It is then possible to position double-curved retractors on both sides of the tibial metaphysis. Two proximal K-wires (diameter 2.5mm) are inserted at the patellar tendon insertion, positioned 1 cm away on both sides. Next, the two distal K-wires are inserted as planned pre-operatively, with the goal being to achieve a final tibial slope of $4\text{-}6^\circ$ [7]. The wires must converge at the posterior cortex, 1 cm below the tibial plateau (Figure 6). The osteotomy is performed using an oscillating saw, using the proximal wires as guides inferiorly and the distal wires superiorly. In order to weaken the hinge without entirely breaking it apart, it is best to gently butt up against the posterior cortex, as if “knocking on the door”. The biplanar osteotomy is then performed just behind the patellar tendon. The bone wedge can be removed. The hinge is tested by lowering the proximal part over the distal part. Reduction is applied by gently extending the lower limb. A staple 2 cm lateral to the patellar tendon is used for temporary fixation, and the slope is checked using fluoroscopy. If the result is satisfactory, it is also fixed medially with a staple. Once the osteotomy is reduced, the tibial tunnel will be slightly angulated and it will need to be drilled again. This is done by pushing the drill bit by hand to avoid applying excessive stress on the osteotomy line. The graft can then be passed through and fixed in place. Fixation is performed in 70° of flexion to avoid any genu recurvatum.

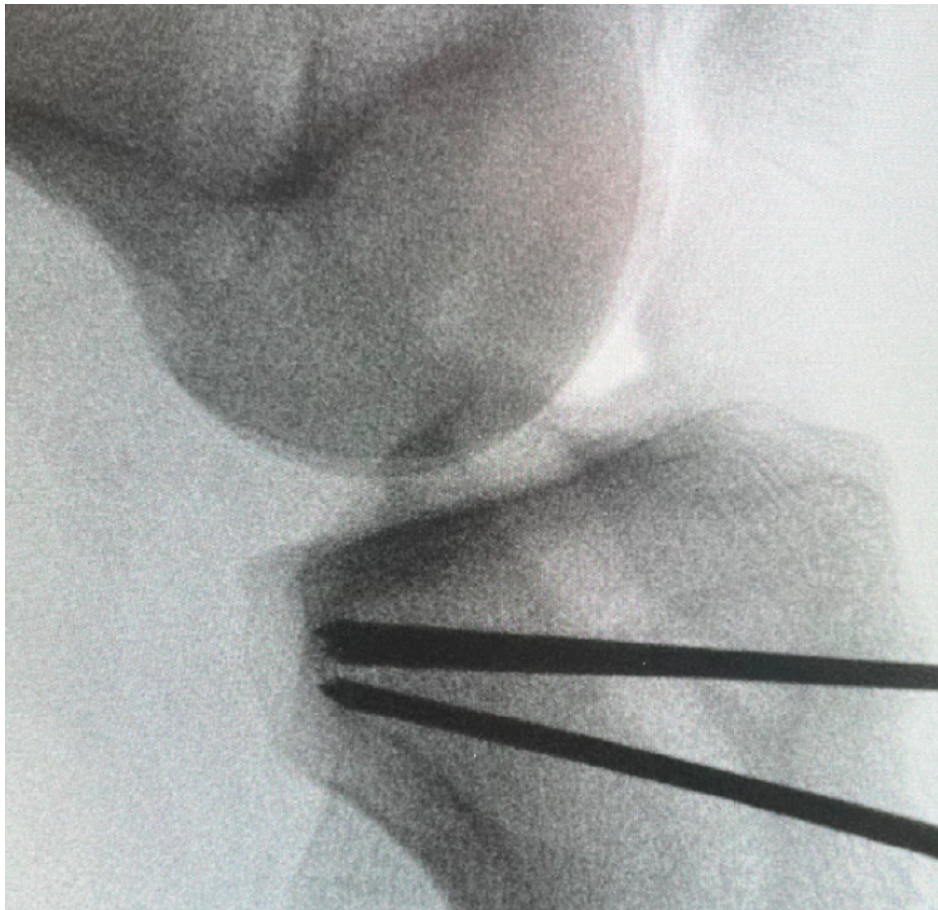


Figure 6. Peri-operative placement of K-wires marking the boundaries of the osteotomy. They converge posteriorly 1 cm below the tibial plateau.

Closure

The fascia lata and the medial collateral ligament are closed. A line of straight sutures at the proximal aponeurosis of tibialis anterior helps to prevent pressure increasing in the anterior compartment of the leg. The subcutaneous and cutaneous planes are then closed. There is no drain left in place.

Summary of the surgical steps:

Note: If performing transosseous meniscal repair, the suture threads are passed through the meniscus in step 2 and the bone tunnel is made after the osteotomy.

Post-operative protocol

The leg is immobilised in an extension brace for 6 weeks post-surgery to prevent any genu recurvatum. However, the brace is removed for physiotherapy sessions, which are started immediately after surgery. Partial weight-bearing resumes after 3 weeks and full weight-bearing is achieved at 6 weeks. From this point, a standard post-ACL reconstruction rehabilitation protocol can be followed. In short, the programme is delayed by 6 weeks compared to in a standard ligament reconstruction.

Advantages of the surgical technique:

- No bulky hardware that can impinge on the tunnels.
- The extensor mechanism remains untouched.
- There is minimal invasion at the metaphysis (optimum consolidation).

- Low cost.

Risques spécifiques :

- Posterior hinge fracture (theoretical)
- Iatrogenic genu recurvatum
- Tibial varus increased by 1° [21]
- Patellar height raised by 0.08 on Caton-Deschamps index [21]

These last two risks could be considered to be negligible, but it is still important to consider them during surgery to avoid perpetuating this tendency.

DISCUSSION

With the improvements in surgical techniques and the reduction in the rates of repeat tear due to issues of technique, other risk factors have come into the foreground. It is not only in humans that tibial slope is relevant, as this assessment is also used in the veterinary field. In fact, medium to large dogs can tear the cranial cruciate ligament (CCL), which is equivalent to the ACL in humans. These animals have a tibial slope of between 20 and 30°. The treatment offered for CCL tear is bone surgery rather than ligament surgery, consisting of a deflexion osteotomy [6]. The link between tibial slope and CCL tear is clear in dogs and carrying out a single bone procedure delivers stability and decisive functional outcomes.

It was in 1991, that the deflexion osteotomy in humans (then called the extension osteotomy) was presented to the Lyon Knee Surgery Congress [20]. It has been known for many years that there is a link between tibial slope, SATT and ruptured ACL graft [22]. There is a linear relationship between increasing the tibial slope and the force that the ACL needs to bear [23]. After 20 years of follow-up, adolescents with a tibial slope $\geq 12^\circ$ had a repeat tear rate of up to 78% when a hamstring had been used for the graft [24]. The short term risk of repeat tear is doubled when the patellar tendon is used [25]. By contrast, a less steep tibial slope ($<6^\circ$) drastically reduces the risk of repeat tear [26]. SATT, which is itself related to tibial slope, is an indicator of the load that the graft will have to support in weight-bearing. Excessive stress will result in gradual elongation of the graft, meaning there will be residual laxity and, ultimately, an increased risk of fatigue tear (Figure 7) [25],[27].

Although lateral extra-articular procedures have reduced the rate of repeat tear, they do not mean that every rupture can be avoided [1]. ACL tear involves excessive anteroposterior translation but also instability in rotation. A modified Lemaire tenodesis has no effect on SATT [28]. It may well be indicated in patients with rotatory instability or in revision surgery, but it will not correct excessive anterior translation [28].

The procedure to choose to directly address posterior tibial slope is tibial deflexion osteotomy. It is possible to perform a supra-tubercular, trans-tubercle or infra-tubercle deflexion osteotomy, as described above (Figure 7). The most important factor in choosing a technique is that the surgeon feels at ease using it, since there is currently no technique emerging as superior to any other and each one has its own advantages and drawbacks [29]. We have set out the technique for the supra-tubercular osteotomy because this technique means that the resection can be made at the site of the deformity, in the metaphysis, in an area that is favourable to bone healing [30]. It has been clearly demonstrated that this osteotomy technique preserves sufficient metaphyseal bone for fixation [31]. The goal of this surgery is to obtain a tibial slope of between 4 and 6°, which means that SATT will be kept between 0 and 5mm without increasing the stresses on the posterior cruciate ligament (Figure 8).

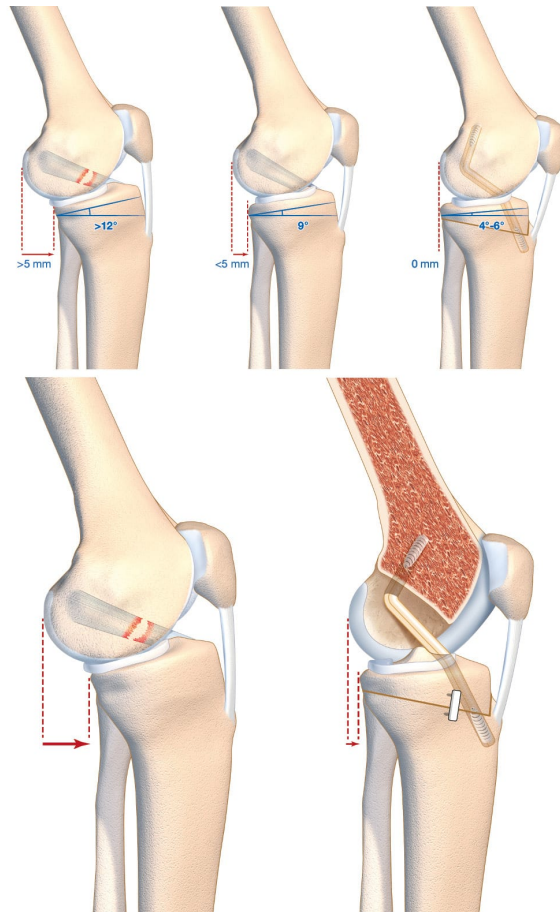


Figure 7. Impact of the posterior tibial slope (PTS) and static anterior tibial translation in single-leg stance (SSAT) on the load that the anterior cruciate ligament must support.

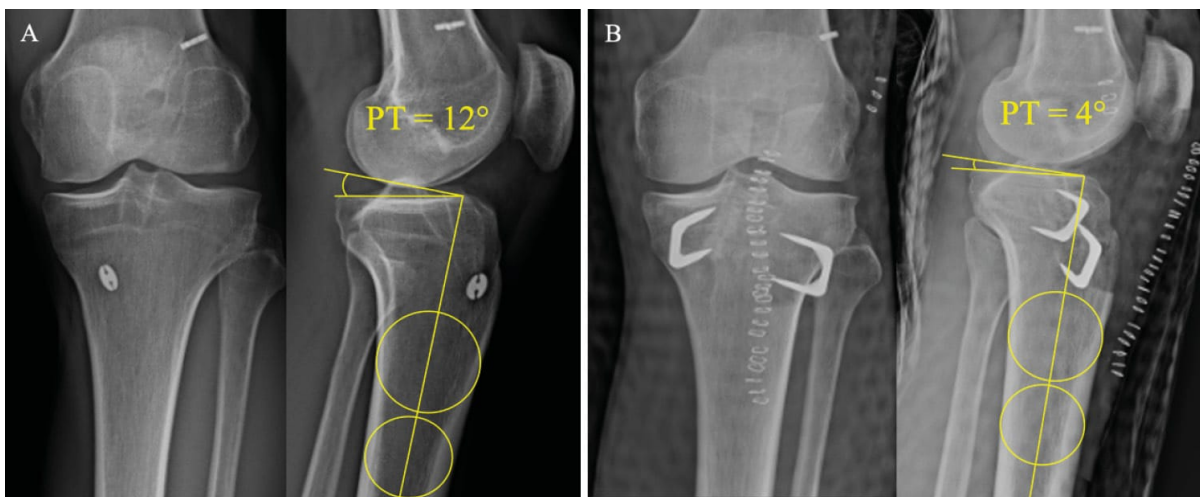


Figure 8. Assessment of the posterior tibial slope (PTS) before (A) and after (B) deflexion osteotomy for a first revision.

While deflexion osteotomy was initially indicated in secondary revisions only, primary revision was subsequently added to its indications and later, some cases of primary tear [32],[33],[34]. TDO produces excellent functional outcomes over observation periods exceeding 5 years with a graft rupture rate of around 2% after over 3 years of follow-up [9],[32]. Some studies have reported a 100% rate of resuming sport at the same level without repeat tear when TDO has been performed at primary revision [9]. This procedure is an effective way to decrease posterior tibial slope, reduce SATT and increase joint stability with the goal of protecting the graft. In terms of rotatory

instability, we do not recommend using a lateral extra-articular procedure as an adjunct. Reducing the lateral slope will increase stability in rotation [35].

What are the consequences of TDO?

Supra-tubercular TDO theoretically increases the Caton-Deschamps index by 0.02 for each degree by which the slope is reduced [36]. However, these results were obtained through radiological simulation and one clinical study found a mean 0.08 increase on the Caton-Deschamps index for a 9° decrease in posterior tibial slope [21]. This shows that TDO has a not-insignificant effect on patellar height.

In the frontal plane, TDO does tend to produce a varus deformity of one degree [21]. The explanation for this could be that the medial side is slightly easier to expose, which probably means that a slightly thicker resection is made. It is important to remain aware of this factor in the frontal plane during this surgery.

The patient must be warned that they will have a larger permanent scar than with a standard ligament reconstruction. This can sometimes be the aspect that is most difficult for the patient to accept, especially when TDO is being offered as a first line surgery.

PERSPECTIVE FOR THE FUTURE

Assessment of the posterior tibial slope and SATT does, however, present some issues. For example, it is not always straightforward obtaining true lateral view radiographs and consequently to be able to correctly interpret these images. The same can be said of the requirement for 20° of flexion. The measurement methods do not take extra-articular bone deformities into account if they are located outside the imaged area. A 2D assessment of a 3D structure can also lead to issues. In future it is likely that there will be a move to using CT or 3D radiography in weight-bearing in order to reduce bias and increase reproducibility of the examinations. EOSTM is a modality initially used for imaging spinal deformities, but it is now finding an increasing number of lower limb indications [37]. Cone Beam is used in maxillofacial surgery, but it can also be used for taking single-leg stance imaging. This promising technology could be used to obtain a more precise assessment of posterior tibial slope and SATT.

A question that can legitimately be asked is whether TDO should be offered as an adjunct to ACL graft as a first line intervention when the posterior tibial slope and SATT are elevated. The thresholds for these indications are still to be determined, and while these interventions add additional complexity to the primary indication they may prevent repeated operations down the line.

CONCLUSION

ACL reconstruction is an extremely common intervention that is known to produce excellent results. In this context it is crucial to analyse and address the risk factors for repeat tear. The posterior tibial slope and its impact on anterior tibial translation in static single-leg stance have become key factors to consider in ACL tears. These are measurements that should be taken as part of the initial assessment. Tibial deflexion osteotomy as an adjunct to ACL graft repair is a treatment strategy that offers good results in specific indications.

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