

THE ROLE OF TIBIAL SLOPE IN ACL RERUPTURE: WHEN AND HOW TO CORRECT IT

<https://doi.org/10.71165/p8kt-2u70>

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SUMMARY

Background: Anterior cruciate ligament (ACL) reconstruction failure remains a clinical challenge, with annual surgical volumes increasing significantly. While extrinsic factors such as surgical technique and rehabilitation are well-documented, intrinsic anatomical risk factors, specifically an increased posterior tibial slope (PTS), are increasingly recognized as primary drivers of graft failure and persistent sagittal instability.

Objective: This article evaluates the biomechanical influence of PTS on knee stability, details standardized radiographic measurement methodologies, and describes the surgical technique and clinical outcomes of tibial deflexion osteotomy (TDO) in the management of ACL insufficiency.

Key Points: An increased PTS correlates with elevated static anterior tibial translation and increased sagittal forces on the ACL, often leading to fatigue-related graft failure. Measurement reliability is highest using the Tibial Proximal Anatomical Axis (TPAA) on true lateral radiographs. Surgical correction via a one-stage anterior closing wedge TDO, often performed during revision ACL reconstruction, aims to reduce the PTS to a target value of 2° to 5°. Clinical data indicate that TDO combined with ACL revision significantly improves functional scores, such as the IKDC and Lysholm scales, while effectively preventing subsequent graft rupture. Furthermore, maintaining medial meniscal integrity is critical, as meniscal loss exacerbates the destabilizing effects of a steep PTS.

Conclusion: Tibial deflexion osteotomy is an effective procedure for addressing pathological posterior tibial slope in patients with recurrent ACL instability. The technique provides durable graft protection and favorable functional outcomes, particularly when the PTS exceeds 12° or is associated with significant static anterior tibial subluxation.

KEYWORDS

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

INTRODUCTION

Anterior cruciate ligament (ACL) tears are common acute knee injuries frequently resulting in ACL reconstruction (ALCR). The number of ACL surgeries performed in USA yearly has increased significantly from 2008. In 2018 about 100 000 ACLR have been performed in USA. Between 2.8 and 4.5 % despite improvements in surgical techniques and anatomic knowledge. Two types of risk factors have been associated with ACL rupture and failure: extrinsic and intrinsic.

EXTRINSIC RISK FACTORS

The type of sport practiced modifies the risk of ACL rerupture. Contact or pivoting sports are more prone to ACL injury than others. Furthermore, also the level of sport competition, the sport equipment and the playing surface have an influence. Early return to sport, not properly attended rehabilitation program and lack of physical preparation are associated with an increased risk of ACL re-rupture .

Surgery has an important role within this field. Femoral and or tibial tunnel position, type of graft or fixation used might increase the risk of an early failure. Finally associated lesions should diagnosed and properly treated: meniscal tears (especially lateral root lesions) and capsulo-ligament tears (antero-lateral or medial collateral ligament). All those factors increasing the risk of re-rupture have been studied during the last four decades.

INTRINSIC RISK FACTORS

The influence of hormonal cycle, genetic factors, neuromuscular control and hyperlaxity on ACL graft might not always be corrected. However, anatomic factors are validated risk factor and deserve all our attention. Femorotibial congruency and notch narrowing are known to increase the risk of ACL rupture as well as a high posterior tibial slope.

The goal of this article is to understand the association between high posterior tibial slope and ACL injury and iterative lesions. We'll see how to analyze and measure posterior tibial slope and defined when and how to correct it with our surgical technique.

INFLUENCE OF THE TIBIAL SLOPE ON KNEE STABILITY

The first association was made between high posterior tibial slope and ACL congenital absence [1]. A series of 8 ACL congenital deficient knees showed a mean posterior tibial slope of 20,6° [2]. It was then showed that when the PTS is increased, anterior tibial translation is increased in ACL deficient knees [3] (Figure 1A & B).

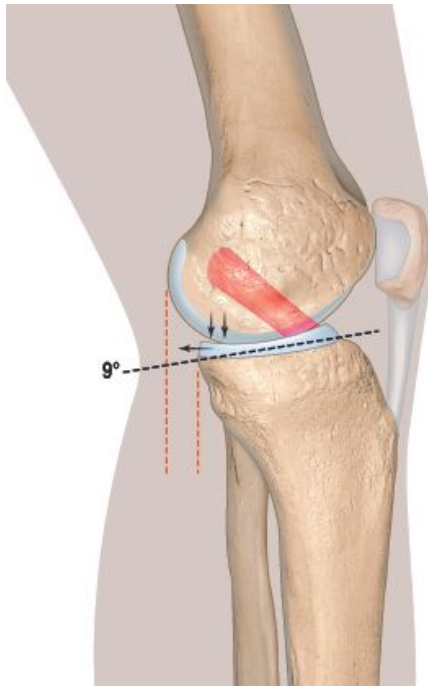


Figure 1: Influence of the Posterior tibial slope on ACL constraint and Static Anterior Tibial Translation on monopodal stance

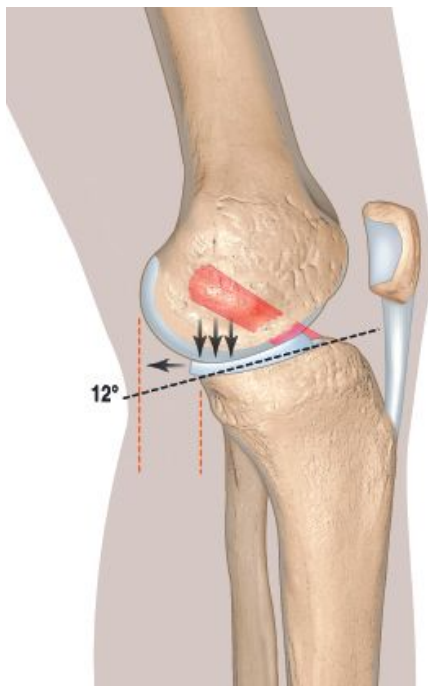


Figure 1: Influence of the Posterior tibial slope on ACL constraint and Static Anterior Tibial Translation on monopodal stance

This statement is also valid with dog ACL tear. Slocum and Slocum published their results in 1993 [4] and it has become a standard procedure in veterinary surgery since then. The influence of the tibial slope in knee biomechanics has been well investigated so far. In 2014, Marouane et al. showed that an increased posterior tibial slope caused a substantial increase in anterior tibial translation and the sagittal forces on the ACL [5]. This effect is reversed if the posterior tibial slope is decreased. It has been shown that anterior tibial translation and forces acting on the ACL were higher in activity involving compression forces especially standing and walking [6].

Those conclusions might explain that ACL injuries secondary to high posterior tibial slope are usually “fatigue” injuries since the ACL is under higher pressures (Figure 2). It is not automatically associated with a new traumatic

event on the knee. High posterior tibial slope in ACL deficient knee also showed a higher rate of high-grade pivot shift [7].

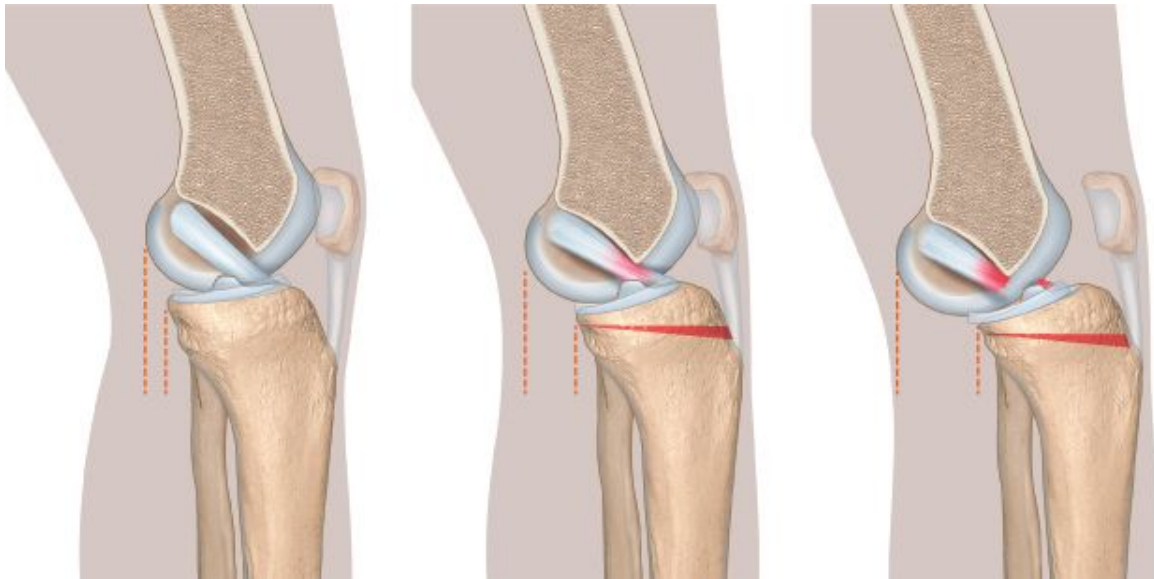


Figure 2: The increased Tibial Posterior Tibial Slope leads to fatigue rupture of ACL and meniscus

The consequences of high posterior tibial slope might be accentuated by associated meniscal lesion. An MRI measuring study has shown that menisci generate a more horizontal tibial slope especially in the lateral compartment [8]. If injured, the menisci lose their protective effect, essential in high posterior tibial slope knees. This was confirmed with measurements of static and dynamic anterior tibial translation before [9] and after [10] ACL repair surgery. It showed that only high posterior tibial slope had an influence on static anterior tibial translation (sATT) while dynamic anterior tibial translation was affected by both high posterior tibial slope and medial meniscal tear in ACL deficient knees. After ACL repair, both static and dynamic anterior tibial translation increased with tibial slope and partial medial meniscectomy. These results suggest that rehabilitation program should be adapted for high posterior tibial slope patient with delayed weightbearing and encourage conservation of medial meniscus. Multiple studies confirmed that patient with an ACL injury, and even more patient with repeat ACL injury, had a higher posterior tibial slope than general population. A study with 20 years of follow-up showed that high posterior tibial slope was the strongest predictor of repeat ACL injury [11]. Managing this intrinsic risk factor could be a solution to improve ACLR results as the graft alone cannot address the consequences of high posterior tibial slope.

METHODS FOR POSTERIOR TIBIAL SLOPE MEASUREMENT ---

A true lateral radiographic view of the knee is necessary for posterior tibial slope measurement. It can be obtained using fluoroscopy, by placing the patient in a monopodal weight bearing position with the knee flexed by 20 degrees, superimposing the posterior femoral condyles. It's a simple exam available anywhere. There are six different methods for radiological PTS measurement [12] (Figure 3A&B).

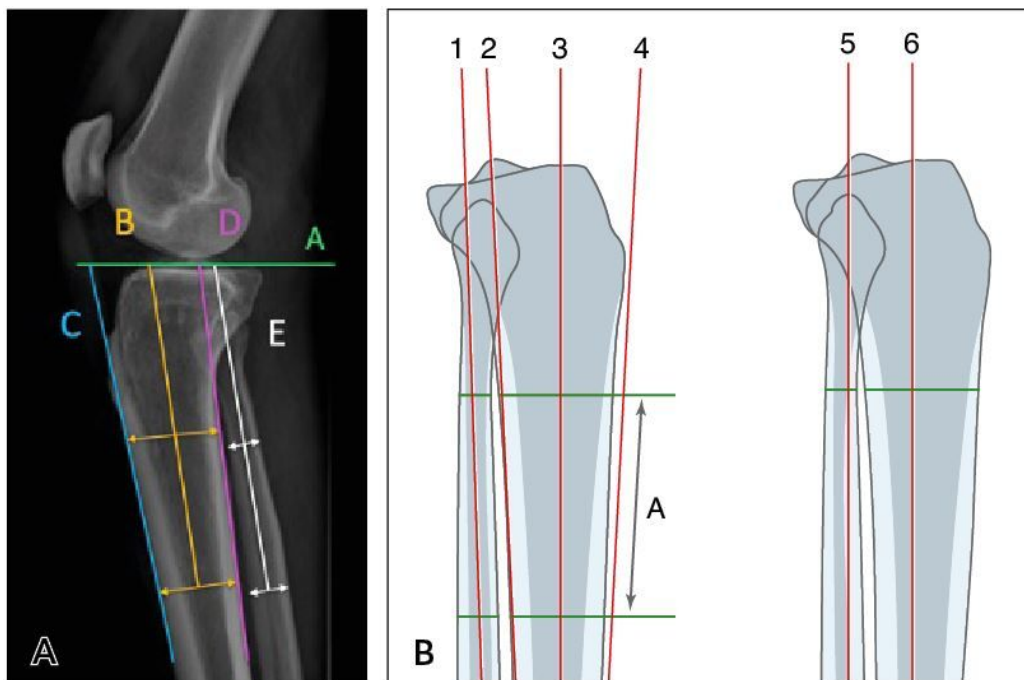


Figure 3 A: method for measuring the posterior tibial slope, need for a true lateral view on monopodal stance B: The 6 method for measuring the posterior tibial slope

The posterior tibial slope is the angle between the line perpendicular to the longitudinal axis and the line tangent to the most superior points at the anterior and posterior edges of the medial tibial plateau. Each methods use a different longitudinal axis line. All those axes are not parallel, therefore posterior tibial slope value varies a lot between each method. It is important to describe the chosen method of measurement when talking about posterior tibial slope. The two last way of measuring radiographic posterior tibial slope requires the full tibial length on the true lateral radiographic view of the knee.

1. **Tibial Proximal Anatomical Axis (TPAA)** : The longitudinal axis used is the line joining the center of 2 width of the proximal tibia located under the anterior tibial tuberosity and 10cm apart. Its physiological value is 9° and has a high reliability.
2. **Fibular Proximal Anatomical Axis (FPAA)**: The longitudinal axis used is the line joining the center of 2 width of the proximal fibula located under the neck of the fibula and 10cm apart. Its physiological value is $9,5^{\circ}$.
3. **Anterior Tibial Cortex (ATC)**: The longitudinal axis used is the line tangent to the anterior tibial cortex. Its physiological value is 11° . It's the method who gives higher values.
4. **Posterior Tibial Cortex (PTC)**: The longitudinal axis used is the line tangent to the posterior tibial cortex. Its physiological value is 7° . It's the method giving lower values. Like the TPAA, PTC also gives high reliability.
5. **Tibial Shaft Anatomical Axis (TSAA)**: The longitudinal axis used is the line joining the center of 2 width of the diaphyseal tibia. Its physiological value is 10° .
6. **Fibular Shaft Axis (FSA)**: This method uses the line joining the center of 2 width of the diaphyseal fibula as longitudinal axis. Its physiological value is 8° .

Method	Tibial Slope value
Anterior Tibial cortical	11.44 ± 3.61
Proximal Anatomical Axis (Dejour)	9.16 ± 3.71
Long Anatomical Axis	10.39 ± 3.72
Post cortical	6.96 ± 3.28
Fibula Short	9.54 ± 3.62
Fibula Long	8.23 ± 3.51

Table 1 : Values of each Tibial Slope measurement method

Posterior tibial slope can also be analyzed on knee MRIs. It allows to measure the bony and meniscal posterior tibial slope of each plateau. The first line is the anatomical proximal tibial axis. It is drawn using a sagittal view located at the center of the knee on an axial view. It's the line joining the center of two transversal section of the proximal diaphysis. This line will then be transposed to other sagittal views centered on the lateral or medial plateau depending of the posterior tibial slope measured. For the bony posterior tibial slope, a tangent to the tibial plateau is drawn. For the meniscal posterior tibial slope, a line joining the two summit of anterior and posterior meniscal horn is drawn. The posterior tibial slope is the angle between adequate plateau line and the perpendicular to the proximal anatomical tibial axis. Bony posterior tibial slope average values are closed to 5°. Meniscal posterior tibial slope reduced the tibial slope towards 0° and tend to be more horizontal on the lateral side of the knee [8]. In cases of meniscal lesion or meniscectomy, posterior tibial slope can be aggravated as well as the knee stability. This notion is important to keep in mind when addressing ACL deficient knees with meniscal lesions. Unfortunately, MRI measuring has its limitation. The MRI acquisition is often not long enough on the tibial side, key point are difficult to identify and reproducibility of MRI measurements isn't that good. For all those reasons it's not used in every day practice.

The most used method in every day practice and publication is the TPAA [3]. It has the highest reliability and the most practical to realize on routine x-rays (Figure 4).

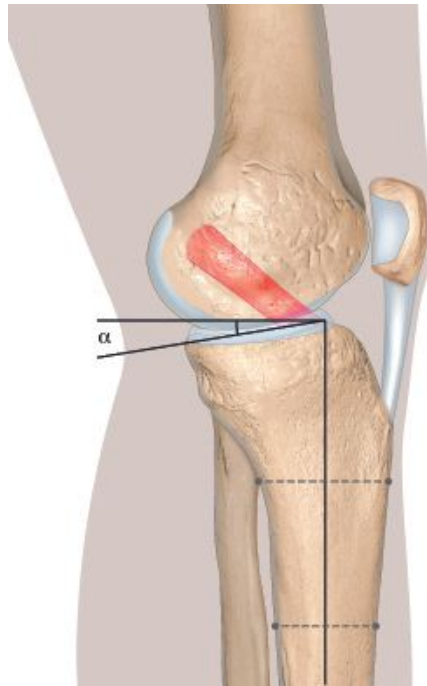


Figure 4: The proximal tibial shaft method to measure the PTS (Dejour) is the most reliable and simple method, it allows to evaluate the static anterior tibial translation

TIBIAL SLOPE CORRECTION

When a correction of a high PTS is indicated, the surgical correction is a tibial deflexion osteotomy (TDO). Several techniques have been described. We will get into the details of the original Dejour's technique. It was first published in 1991 by Pr Henri Dejour for the "Journées lyonnaises de chirurgie du genou". It was again reported in 1998 [13] and more recently in two articles with results at short [14] and long term [15]. The osteotomy is performed in a 1 stage procedure with ACL reconstruction reconstruction.

An anterior longitudinal incision is performed medial to the tibial tuberosity, after harvesting the graft, an arthroscopic evaluation of the cartilage, meniscii and position of the previous femoral and tibial tunnel is done. Hardwares are removed if necessary.

Femoral tunnel preparation is performed using an outside-in guide for femoral tunnel placement. It allows to correct any misplacement of the tunnel and mostly prevent from any bone grafting. For the tibial tunnel, a standard 60° angulation guide is used. Both tunnels are drilled at the needed diameter depending on the harvested graft.

Meniscal repair procedures are performed, if necessary, especially lateral root lesion and medial posterior horn lesion repairs. A notchplasty can be performed at this point in case of a narrow notch.

The patellar tendon insertion is exposed as a landmark of the osteotomy (Figure 5). The deep MCL is released to the far posterior side of the tibia. The fascia lata and tibialis anterior muscle are detached up to the posterior part of the tibia like a keblisch approach. The level of the osteotomy always starts from the superior margin of the patellar tendon insertion and continue inferiorly.

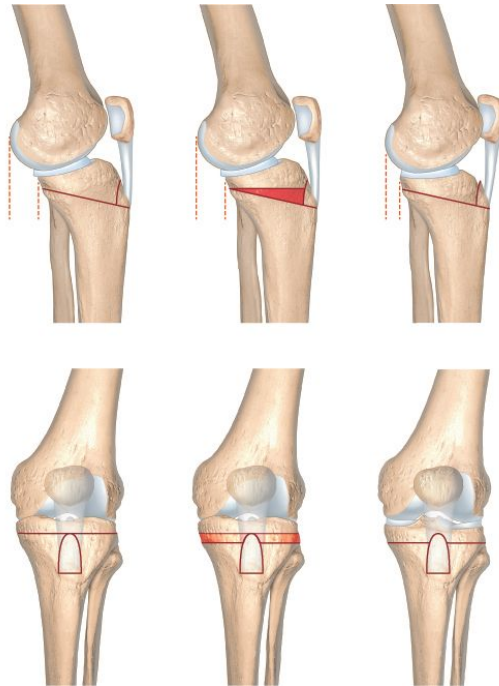


Figure 5: Principal steps for the Tibial Deflexion osteotomy

Two parallel K-wires are inserted under fluoroscopic control on both sides of the patellar tendon until the posterior tibial cortex is reached 1 cm below the joint line. Two other K-wires are positioned for the second cut. The thickness is defined by the amount of slope correction wanted. A 1 mm correction approximately equals to a 1 ° decrease of the posterior tibial slope. The targeted value for posterior tibial slope is between 2 and 5°. The patellar tendon is protected from the oscillating saw using spreaders. The proximal cut of the osteotomy is performed first under the upper pins, keeping the posterior cortex intact. The distal cut is then performed over the lower pins. The upper cut is then completed, and an anterior wedge is resected. The anterior closed wedge osteotomy is compressed simply by extending the knee, thereby exerting pressure by the femoral condyles onto the anterior tibial plateau. Corrected slope is confirmed by fluoroscopy after measurement, and final fixation is performed. Two staples are inserted for fixation, one on either side of the patellar tendon (Figure 6).

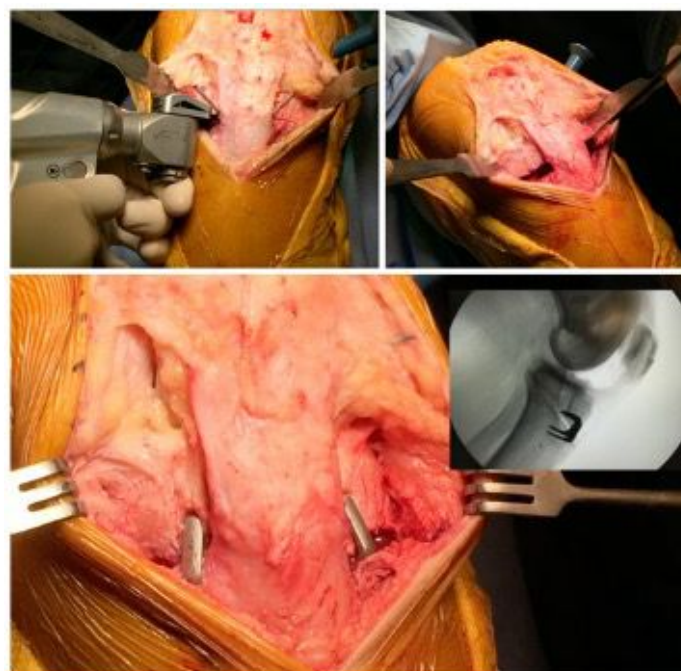


Figure 6: Operating view, patellar tendon landmark, Positioning the K-Wires under fluoroscopy, fixation with two staples

On the tibia, a manual re-drill is performed to debride the tibial tunnel from bone fragments. The graft used is then passed from proximal to distal and is fixed within the femoral tunnel at 20° of flexion by press fit for BTB or Quadriceps tendon and with an interference screw for hamstring, and at the tibial tunnel using an interference screw and extracortical fixation on the staples.

POSTOPERATIVE CARE

For the first 3 weeks, no weight bearing is allowed, the patient keeps his extension brace placed continuously to prevent from hyperextension. The physiotherapy is done three times a week plus personal training. The main objectives are reduction in knee swelling, quadriceps control, and recovery of range of motion. Weight bearing is gradually authorized from day 21 until day 45 with the extension brace. Afterwards, it's the standard ACL protocol with the phase 2 from day 45 to 90 where the patient is allowed to swim and cycle and then the phase 3 after 3–4 months, with the return to sports rehabilitation. Patients are allowed full sport activities if their isokinetic test show good quadriceps/ hamstrings ratio and a good a side-to-side muscle recovery after 9 months.

This technique gives a high stability for the osteotomy, the fixation is very light, does not need any plates, and the early weight bearing with the extension brace has a favorable effect on the bone healing.

RESULTS

Even if the surgical technique has been known for a long time, it is still not used worldwide. Several papers pointed out the association between high posterior tibial slope and ACLR failure [11,16]. Also, the retear rate reported for revision ACLR without tibial deflexion osteotomy is significant, ranging between 13 and 42% in the literature [17–19]. Yet there are still few literature papers available on tibial deflexion osteotomy associated with ACLR. Correction of high posterior tibial slope cannot be overlooked, mainly for patient with repeated ACL tears. Since 2014, results of small cohort of patient were published. The results of one stage tibial deflexion osteotomy performed revision ACLR with a minimum of 2 years follow-up were published. Two studies [14,20], including one from our surgical team, reported good functional outcome with similar IKDC subjective (71.6 and 79.1) and Lysholm scores (73.8 and 87.8) (Figure 7 A&B).

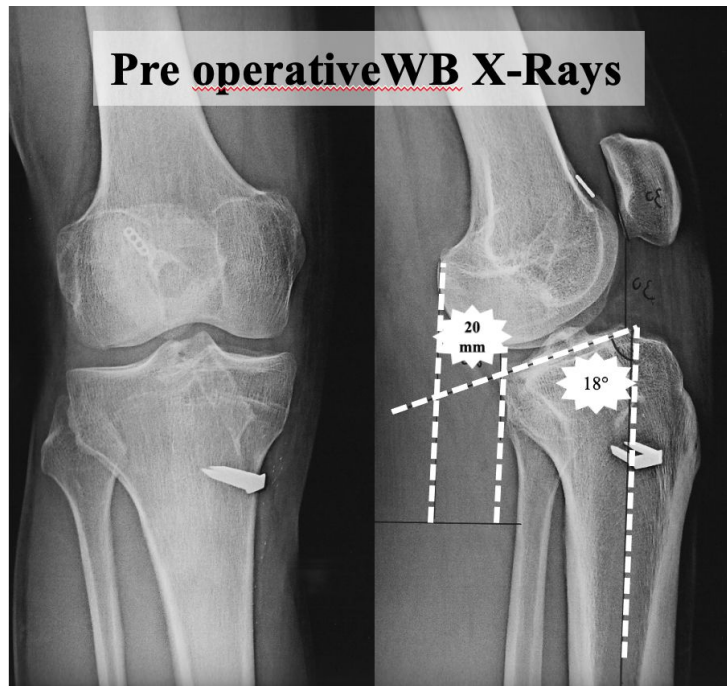


Figure 7: A. preoperative Monopodal stance x-rays of a third ACL rupture B. Postoperative Monopodal X-rays showing the correction of the tibial slope and the static anterior tibial translation.

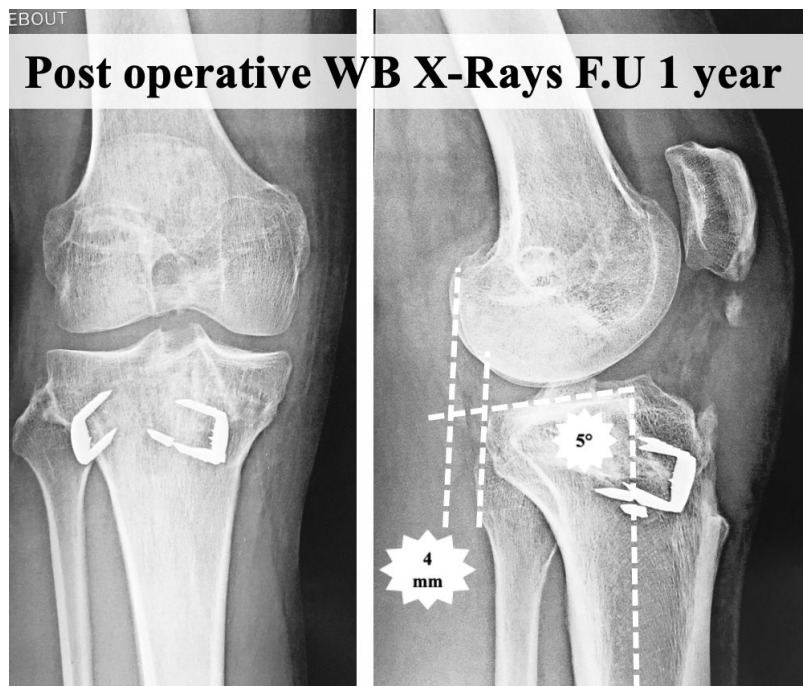


Figure 7: A. preoperative Monopodal stance x-rays of a third ACL rupture B. Postoperative Monopodal X-rays showing the correction of the tibial slope and the static anterior tibial translation.

There were no ACL retear reported. Those functional results are similar to those reported for ACLR revision without tibial deflexion osteotomy [17,18]. A follow-up study was published recently showing results at a minimum of 7 years follow-up [15]. There were still no retears reported and functional outcomes were maintained (mean IKDC subjective score 82.9 and mean Lysholm score 84.5). It is interesting to note that even if 8 of the 9 knees had meniscectomies or meniscal sutures before or during tibial deflexion osteotomy, osteoarthritis progressed in only 2 of the 6 knees that had signs of arthritis at the first follow-up and knees without osteoarthritis at the first follow-up didn't show any sign of arthritis. Looking at those good outcomes, indications of posterior tibial slope correction with ACL reconstruction could be interesting for first revision and even primary reconstruction. In 2020, a study about two stage tibial deflexion osteotomy with first and second ACLR revision and adjuvant lateral

extra articular tenodesis [21] reported similar outcomes at a minimum of 2 years follow-up and no ACL retears. Only one study reports results about one stage tibial deflexion osteotomy and primary ACL reconstruction in 18 patients with high posterior tibial slope, excessive anterior tibial translation and chronic meniscal posterior horn tears at a minimum of 2 years follow-up [22]. There were no ACL retears reported. Functional outcomes were good with a mean postoperative Lysholm score of 89, 5 comparable to all the previous studies.

CONCLUSION

The correction of high posterior tibial slope associated with ACL reconstruction in ACL revision surgery prevents ACL re-tear and presents good functional outcomes while preventing onset of osteoarthritis. The use of tibial deflexion osteotomy can be advised for first ACLR revision for patient with high posterior tibial slope over 12° or even with meniscal lesions associated with a pathological value of the Static ATT.

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