Original article

Anterior cruciate ligament reconstruction: the role of lateral posterior tibial slope as a potential risk factor for failure

Paolo Di Benedetto[1, 2], *Michele Mario Buttironi*[1], *Francesco Mancuso*[1], *A. Beltrame*[1], *R. Gisonni*[1], *Araldo Causero*[1, 2]

[1]Clinic of Orthopedics, Academic Hospital of Udine, Udine, Italy; [2] DAME - University of Udine

Summary. *Background and aim of the work:* Anterior cruciate ligament (ACL) reconstructions is an extremely frequent surgery. The analysis of anatomical factors is becoming increasingly important and the study of clinical, arthroscopic and radiological methods to evaluate and understand them aims to positively affect the patient's outcome. This work aims to analytically analyze the anatomical factors that can influence the failure of an ACL reconstruction, to evaluate the data collected on a sample of patients undergoing ACL revision and compare them with those is present in the literature. *Materials and Methods:* At the Clinic of Orthopedic of Udine, between November 2018 and August 2020 were performed 47 revisions of the ACL. We analyzed MRI scans about Lateral Posterior Tibial Slope (LPTS). Patient surveys were analyzed by a single senior orthopedic surgeon who was blinded to patient history, age and gender. *Results*: Comparing with a value considered in the norm (LPTS estimated 6.5°) we see how the difference between the average LPTS values in the sample is significantly higher than the normal values (P <.0001). Dividing the simple according to sex, we notice that the LPTS in female patients is 11.8 while in male patients it is 8.7° (P <.005). *Conclusion*: The data collected show how an increased posterior lateral tibial slope can be correlated with a higher risk of ACL failure. The results are in line with what is present in the literature. Our analysis is absolutely preliminary, but it is intended to be the starting point of a path that allows us to think of the reconstruction of the ACL as an intervention to be planned more carefully based on the individual characteristics of the patient. (www.actabiomedica.it)

Key words. Anterior cruciate reconstruction; ACL; ACL failure; Anatomic; Posterior tibial slope; PTS; ACL failure predictors.

Introduction

Anterior cruciate ligament (ACL) reconstructions is an extremely frequent surgery. The annual incidence of ACL reconstructions is around 200,000 in the United States (1, 2). The annual incidence of revision of a previous ACL reconstruction is growing: indeed, the percentage of cases revised in the United States currently stands between 1% and 13% (2, 3). While ACL reconstructions is a reliable surgery, indeed more than 90% of patients record an improvement in functional outcomes after surgery (4, 5), it is not the same for revision surgery: the literature shows how functional outcomes are less favorable and how returning to sport is more difficult (6, 7). In addition, there is a higher percentage of subsequent surgical revisions (8). The literature is full of articles that analyze the factors that can contribute to the failure of primary ACL reconstruction: the choice of graft, the surgical technique, any errors such as positioning of the tunnels or the tension of the graft in addition to the intrinsic factors related to the patient such as anatomical factors (9-12). The analysis of anatomical factors is becoming increasingly important and the study of clinical, arthroscopic and radiological methods to evaluate and understand them aims to positively affect the patient's outcome. This work aims to analyze the role of Lateral Posterior Tibial Slope (LPTS) as a potential risk factor for ACL reconstruction failure, comparing a sample of patients undergoing ACL revision to literature data.

Causes of failure

There is no a single definition of failure of ACL reconstruction. The causes that can be at the root are many and can even be combined with each other and contribute to determining the failure (11). Attempts to frame the problem within rigid schemes can find a role, above all to settle the cases who need surgery compared to those who can be treated conservatively. However, it is right to remember that each patient has his/her own personal history, expectations and ambitions: these factors are not easily "pigeonholed" and therefore the orthopedic surgeon must be able to personalize and adapt the treatment.

Surely ACL reconstruction revision is a huge problem for the orthopedic surgeon: classically the literature has shown that the failures of ACL reconstruction are mainly caused by technical errors (estimated around 70%), chronic or acute trauma and biological causes.

The Multicenter ACL Revision Study Group (MARS) (13) developed a system to determine outcome predictors in the ACL review. The cohort analyzed was 460 patients and showed that the failure mode was due to traumatic cause for 32%, technical in 24%, biological in 7%, and a combination in 37%, while caused by infection in less than 1% of cases.

If we wanted to etiologically classify the failure of an ACL reconstruction we should first consider the patient's symptoms and in particular instability, stiffness and pain (14).

Anatomical parameters

Posterior tibial slope

Christensen at al compared the magnetic resonance imaging of 35 patients with early ACL failure and 35 of patients with unsuccessful reconstruction, measuring in particular the slope on the sagittal scans of the medial and lateral tibial plateau (15). He found a greater lateral tibial slope in patients who had graft failure (8.4° versus 6.5°). He estimated an increased relative risk for graft failure of 1.6 with a 2° slope increase, 2.4 with a 4° increase, and 3.8 with a 6° slope increase. These results were more evident in female patients. A similar conclusion was presented by Webb et al in their work, using lateral view of radiographs (16). It found an incidence close to 60% for graft rupture or contralateral ACL injury in patients with a tibial slope greater than 12°. Is the posterior tibial slope - especially the lateral one - to be considered a risk factor for non-traumatic ACL tears? (17)

In the literature there is great debate regarding the subject, since some studies describe the increase in the slope of the medial tibial plateau as the most important risk factor for ACL injury. Others believe that the meniscal slope is a more accurate measure than the bony slope of the tibial plateau. Furthermore, complicating the matter is the inhomogeneity of the measurement methods taken such as knee radiography or full-length lower limb radiographs, the use of magnetic resonance imaging, which increase the variability of the measurements made in the various studies and make it difficult to fully agree on this problem. However, it is accepted that increasing the overall posterior slope increases the risk of ACL injury or graft failure.

Intercondylar notch shape

A narrow shape of the notch is also considered a risk factor for atraumatic ACL injury. This particular shape was measured in patients with ACL injury and the ligament it appeared smaller and weaker compared to healthy patients with a wider notch. Furthermore, in the context of ACL reconstruction, Fujii et al found a smaller notch cross sectional area (251.7 mm^2) in patients who developed "cyclops syndrome" compared to patients without complications (335.6 mm^2) (18).

Anterior tibial translation

Tanaka et al reported an abnormal position of the femoro-tibial joint on magnetic resonance imaging in patients with failed ACL reconstruction (19). On average, there was an anterior tibial subluxation within the lateral compartment of 5.7 mm, with a value greater than 15 mm in 12.5% of cases. The extent of anterior subluxation was 3.9 mm and 3.1 mm greater than the values for normal knees and acute ACL injury knees. This association between anterior translation and failure of ACL reconstruction may provide a mechanical explanation for suboptimal clinical outcomes even in reviews of previous ACL reconstructions.

Geometry of the tibial plateau and femoral condyles

In the condition of non-traumatic ACL injury, Musahl et al noted a narrower lateral tibial plateau in patients with grade II pivot shift test compared to patients with grade I pivot shift test, (35.5 mm vs 30.3 mm) (20). It should be emphasized that this result was significant only in female patients and no other anatomical parameters seemed to influence preoperative laxity.

It can therefore be concluded that bone anatomy contributes to the extent of knee laxity in ACL-deficient knee; therefore, it could be argued that patients with specific anatomical features may represent patients with a higher risk of suboptimal outcomes after ACL reconstruction. In these cases of greater preoperative laxity, the association of adaptation of the technique or the addition of associated surgical gestures may be indicated, such as a lateral extra-articular plastic surgery (21).

Biomechanical effects of PTS

Anterior tibial translation

The association between posterior tibial slope (PTS) and ACL injury has been known in the veterinary field since the 1980s, particularly in dogs. The tibial plateau deflection osteotomy procedure in dogs is used to treat ACL lesions at the femur in dogs with good results (22). Although it is clear that canine anatomy and biomechanics are completely different from that of humans, the procedure may play a role in multiple ACL lesions (23). In the human knee, when subjected to a force on the vertical femoro-tibial axis or under the action of the quadriceps muscle, produces a shear force with an anterior direction which determines an anterior translation of the tibia on the femur (ATT) and that si influenced by PTS. In a clinical study of 281 patients with unilateral ACL tears, Dejour and Bonnin observed the effect of PTS measured using two radiographic tests (24): in the single leg station, a 10° increase in PTS resulted in an increase of 6 mm of ATT in both normal and ACL-deficient knees. They also noted that, during Lachman's radiological test, for every 10 degree increase in PTS, there was a 3.5mm increase in ATT. Several biomechanical studies report that increased PTS exacerbates ATT, which alters knee kinematics and, in turn, may change the distribution of contact pressures. Agneskirchner et al observed a significant increase in ATT after increasing the PTS by anterior opening wedge osteotomy, in 5° increments, up to a maximum change of 20° (23). The maximum ATT of 7.2 mm was observed when the STP was increased by 20° and with the knee flexed by 30°. Furthermore, the increase in STP caused a translation of the tibial plateau superior to the femoral condyles, with a maximum of 4.1 mm noted in full extension. Giffin et al observed a relative anterior displacement of the tibia in the resting position after a 5 mm opening wedge osteotomy, which was accentuated under axial loads

(200N) (25). Furthermore, the computerized musculoskeletal model by Shelburne et al revealed that ATT changes were linearly related to STP changes in standing, squatting and walking. In this work, a 5° increase in STP resulted in a 2 mm increase in ATT.

In the literature there are also works that are in disagreement with the above: Fenning et al states that ATT is not significantly correlated with the increase in PTS, but is correlated with load (26). This suggests that a proximal tibial osteotomy (HTO) cannot cause knee instability. In addition, Voos et al noted that the decrease in PTS does not affect the Lachman's clinical test but does have an effect on the Pivot Shift test (27).

A position of the tibia more anterior than the femur should determine an increase in the tension applied to the ACL: some authors have questioned this but have not found a correlation in an increase in the forces on the ACL and an HTO but affirm that the tension of the ACL is inversely proportional to the degree of anterior opening and directly proportional to the load in anterior-posterior (26). Therefore it is assumed that the tibial insertion of the ACL is not modified or that, where present, it does not cause significant increases in ligament tension.

McLean et al analyzed the forces of individual ACL beams in a cadaveric study and recorded a tension spike in the antero-medial (AM) bundle correlated with an anterior acceleration peak of the tibia, both dependent on an increase in PTS: for each degree of increase in PTS, the anterior acceleration of the tibia increases by 1.11 m/s^2 and the voltage in the AM beam increases by 0.6% (28). On the contrary Nelitz et al did not observe a statistically significant alteration of the ACL tension when with increasing PTS: the force recorded at the ACL decreased significantly when PTS increased and an external rotation moment (1 Nm) was applied (29).

Rotational stability

Most previous studies have looked at femorotibial stability in the sagittal plane; however, the role of the PTS on rotational stability plays an important role. Agneskirchner et al found no correlation between PTS and internal/external rotation of the tibia (23). Fening et al found that axial rotation (positive values represent the external rotation of the tibia) was significantly influenced by the size of the opening wedge during osteotomy (p = 0.011). The rotation increased from 1.0 degrees in the native knee to 3.8 and 4.1 degrees after using a plate with a wedge of 5 and 10 mm respectively, respectively (26). Martineau et al also found that an increase in external tibial rotation in the osteotomized knee was significantly correlated with the size of the anterior wedge (from 1.0 degrees in the native knee to 0.5 degrees after 5 mm opening osteotomy and 2.5 degrees degrees after osteotomy with 10 mm opening) (30). Interestingly, Voos in the previously cited work noted that a 5° increase in PTS results in a significant increase in ATT relative to the native knee, while a 5° decrease in PTS reduces ATT to a level similar to that of the native knee during the mechanized pivot shift test (27). Petrigliano et al observed that a 5° increase in tibial slope had little effect on external rotational laxity measured by dial test applying a force of 5 Nm at 30° or 90° of flexion (31). The increase in the PTS had no significant effects on the extent of the reverse pivot shift; on the contrary, a decrease in the PTS led to a significant increase in the size of the RPS. According to Nelitz et al, PTS influences knee kinematics by reducing internal/external tibial rotation (29).

Clinical study

Materials and Methods

At the Orthopedic Clinic of Udine in the period between November 2018 and August 2020, 47 revisions of failed ACL reconstructions were performed. The study excluded those cases that had undergone further knee surgeries in addition to the first ACL reconstruction such as osteotomies, meniscal transplants, combined multi-ligament reconstruction and allograft reconstruction.

MRI scans (minimum 1.5 Tesla) subsequent to the first reconstruction and preceding the surgical revision were analyzed. Patient surveys were analyzed by a single orthopedic surgeon who was blinded to patient history, age and gender. Measurements were performed with Horos for Mac software (Horos Project) for DICOM files reading.

We decided to analyze only the parameter of the lateral posterior tibial slope; it was measured on the sagittal scans of the T1-MRI scans. In particular, we decided to use the measurement technique described by Hudek et al (32) which identified the central sagittal image in which the tibial insertion of the posterior cruciate ligament (PCL) and the intercondylar eminence are seen. Next, two circles are placed in the proximal tibial metaphysis. A more proximal circle that touches the anterior, posterior cortex and the tibial plateau and a second more distal circle that touches the anterior and posterior cortex; care must be taken that the center of the distal circle is positioned on the circumference of the proximal circle. Hence the line connecting the centers of both circles is defined as the longitudinal tibial axis in MRI. This axis is propagated through the sagittal series scans.

On the contrary, the anatomical center of the lateral tibial plateau is identified on the axial scans always in T1-MRI images. Passed again on the corresponding sagittal scan, a tangent is drawn to the lateral plateau which connects the highest and most uniform part between the superior-anterior cortex and the posterior one. The angle between the line orthogonal to the longitudinal tibial axis of the MRI and the tangent to the lateral plate just drawn is defined as the lateral posterior tibial slope. (Fig.1)

Statistic analysis

Statistical analysis was carried out using Prism 8 for Mac software (ver. 8.2.1; GraphPad Prism Software). The means between the different sexes were compared by applying the Whelch's corrected T test. The data mean was compared with the hypothetical mean considered as normal value, drawing from the literature and in particular from the work of Christiensen et al (15), applying the Wilcoxon's statistical test to the sample parameters.

Results

Patients who have undergone ACL revision there were 27 female and 20 male, were aged between 17 and 42 years. The patients who met these criteria were 43 but those who gave consent for the analysis of magnetic resonance images were 36, of which 26 were female and 10 were male with age between 17 and 36 years. Magnetic resonance measurement of the posterior tibial slope of the lateral tibial plateau (LPTS) yielded results on average above the anatomical pa-

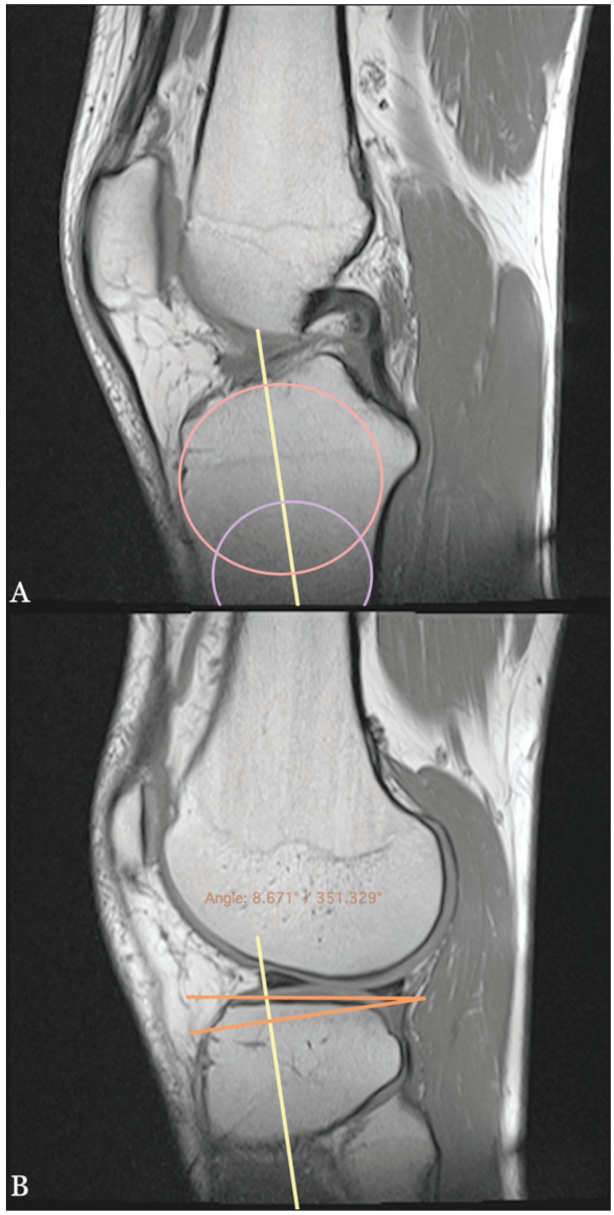

Figure 1. Posterior Tibial Slope measurement method: A) central sagittal image in which the tibial insertion of the posterior cruciate ligament (PCL) and the intercondylar eminence are seen for identify the longitudinal tibial axis; B) the angle between the line orthogonal to the longitudinal tibial axis of the MRI and the tangent to the lateral plate just drawn is defined as the lateral posterior tibial slope.

rameters considered normal. In particular, an LPTS of 10.9° on average was measured in the sample under analysis. (Fig.2-3) Comparing with a value considered in the norm (LPTS estimated 6.5°) we see how the difference between the average LPTS values in the sample is significantly higher than the normal values (P <.0001). (Tab.1)

If we analyze the sample by dividing it according to sex, we notice that the LPTS in female patients is 11.8 while in male patients it is 8.7°. Again, the difference between the means was analyzed with the specific statistical test and was statistically significant (P <.005). (Tab.2)

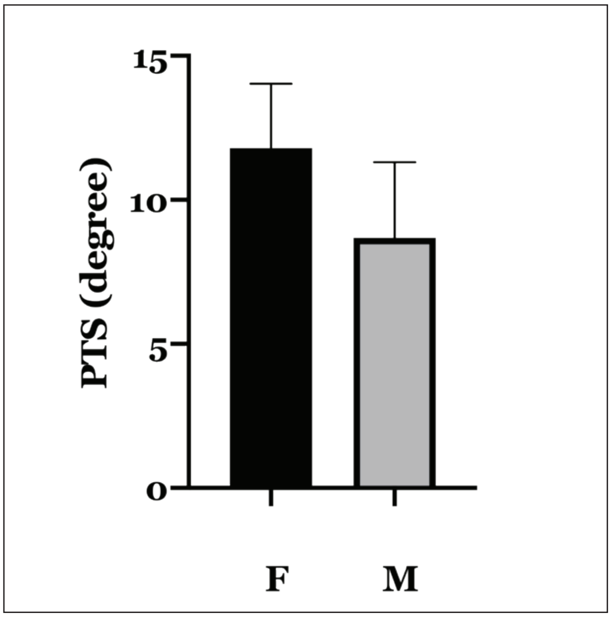

Figure 2. Posterior Tibial Slope, Female vs Male

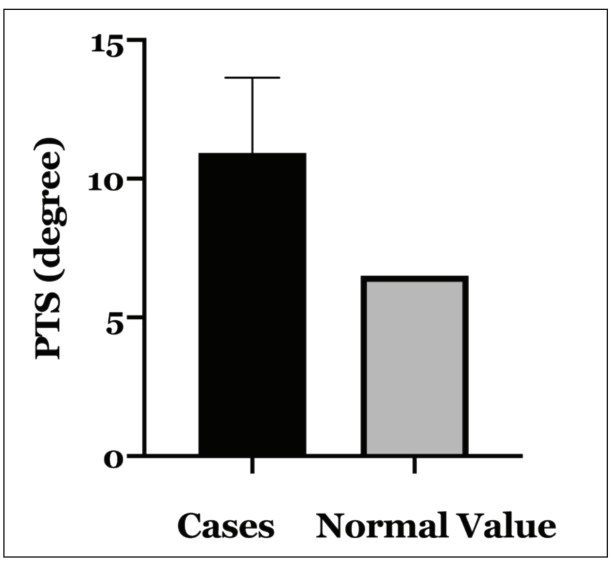

Figure 3. Posterior Tibial Slope, Cases vs Normal Value

Discussion

In general, patients undergoing ACL revision surgery usually have lower results when undergoing functional subjective scores then patients undergoing primary ACL reconstruction. It is well known that revision surgery is extremely complex for the orthopedic surgeon to deal with; perhaps we need to set not only the goal of improving results but also preventing ACL reconstruction failures. Prevention involves various areas: surely we must try to avoid technical errors such as malpositioning of the tunnels and the consequent impingement or residual instability, but also in the rehabilitation field there is a need to carefully follow the patient providing detailed information and seeking direct feedback and possibly collaborating with rehabilitation specialists.

As we have widely seen, anterior cruciate ligament reconstruction surgery is extremely frequent.

Tabable 1. Posterior Tibial Slope, Cases *vs* Normal Value (Wilcoxon test)

One sample t and Wilcoxon test	
Theoretical median	6.500
Actual median	10.85
Number ofvalues	36
Wilcoxon Signed Rank Test	
Sum of signed ranks (W)	648.0
Sum of positive ranks	657.0
Sum of negative ranks	-9.000
P value (two tailed)	<0.0001
Exact or estimate?	Exact
P value summary	****
Significant (alpha=0.05)?	Yes
How big is the discrepancy?	
Discrepancy	4.350
95% confidence interval	3.600 to 5.900
Actual confidence level	97.12

Perhaps for this reason, it can sometimes be underestimated. To better plan the surgery, the patient must be fully assessed: the medical history, for example, in addition to collecting data on the trauma, must also investigate what the patient's activity levels are. The physical examination must aim to exclude any unrecognized associated injury. The study of radiological investigations, in addition to highlighting the lesion, must be able to provide data on lesions that are difficult to assess clinically or on pre-existing risk factors for failure. The surgery must be planned so that all the instruments are available, ensuring the possibility of making changes during the work and that it is possible to remedy any unforeseen circumstances. The rehabilitation phase must also be designed and tailored as much as possible to the patient. Of course, all this is not easy to implement, but the path of collaboration between multiple professionals makes it possible.

The surgeon, for his part, has the onerous task of giving the precise surgical indication. For this reason, it is absolutely imperative that you know the factors that can lead to one type of intervention over another.

Obviously, the anatomical parameters should be among these, given that the literature is now full of works that highlight their importance. The methods for measuring the posterior tibial slope are many and within everyone's reach: any DICOM reader allows it. The female sex, as already mentioned, sometimes shows a greater correlation with an increased slope or with a narrow intercondylar notch. Stress radiographs should also become commonly used: for example, they are very useful for grading instability in a specific direction and therefore could determine one type of intervention over another or the need for an associated gesture or not. The surgeon's ability to evaluate associated injuries or constitutional risk factors must necessarily be reflected in the ability to dominate the surgical gestures (including reconstructive) of those peripheral structures that have proved so important.

There are specific populations that show an increased risk of persistent rotational instability or increased risk of subsequent ipsilateral ACL injury: improved rotational stability control is imperative for these patients. It is important to pay attention, for example, to female pediatric patients, to active patients who return to their level of activity antecedent to the trauma, to elite athletes who show a high rate of contralateral re-ruptures and ruptures. Returning to some specific activities, including those that require knee twisting (such as ski and volleyball) or contact sports (such as football or rugby) are also known to be a risk factor for ACL rupture ipsilateral and contralateral (2).

It is therefore important that the objectives of an ACL reconstruction associated with an accessory surgical gesture are to reduce the risk of rupture of the neo-ACL graft and to improve the control of rotational stability of the knee.

Recalling that any surgical indication is based on a favorable risk-benefit ratio, we can affirm that the reconstruction of the antero-lateral ligament (ALL) or make extra-articular reconstructions find an important role in this type of surgery.

Table 2. Posterior Tibial Slope, Female vs Male (Whelch's test)

Welch's test	
Table Analyzed	LPTS (Me F)
ColumnB	Data Set-B
vs.	vs.
ColumnA	Data Set-A
Unpaired t test with Welch's correction	
Pvalue	0.0050
P value summary	**
Significantly different (P < o.o5)?	Yes
One- or two-tailed P value?	Two-tailed
Welch-corrected t, df	t=3·315, df=14.30
How big is the difference?	
Mean of column A	11.80
Mean of column B	8.680
Difference between means (B -A) ± SEM	-3.116 ± 0.9399
95% confidence interval	-5.128 to -1.104
R squared (eta squared)	04346
F test to compare variances	
F, DFn, Dfd	1.384, 9, 25
Pvalue	04949
P value summary	ns
Significantly different (P < o.o5)?	No
Data analyzed	
Sample size, column A	26
Sample size, column B	10

More invasive extra-articular reconstructions have proven to be useful and quick to make, with good subjective and objective results for the patient, although associated to higher complications rate (33). Modern ALL reconstruction techniques differ significantly from these extra-articular procedures: the growing knowledge of anatomy and ALL function has allowed us to define the basis of this reconstruction, with isometric positioning of the tunnels and a specific area for the fixation position of the graft. Even the reconstructions, although technically more demanding, have proven their effectiveness. In fact, in a recent study that evaluated combined ACL and ALL reconstructions, it demonstrated good subjective and objective short-term results without specific complications (34).

To address the problem in a systematic way, it would be desirable to follow a decision-making algorithm that takes into account primary and secondary factors that can lead to gestures on the periphery: in the literature there are numerous examples, but of course they must be adapted to the patient (35). Each ACL revision is different from the others according to the characteristics of the patient and according to the cause, technical or not, that determined the failure.

Conclusions

This work mainly highlights how careful patient evaluation allows for better results in ACL reconstruction. Magnetic resonance investigations are essential in planning the surgery; the analysis of the patient's anatomical conformation guides us in the surgical indication itself and allows us to adapt it to the specific case. Of course, only the knowledge and in-depth study of each individual case allow the recognition of these anatomical variants.

The data collected show how an increased posterior lateral tibial slope can be correlated with a higher risk of ACL failure. The results are in line with what is present in the literature. Our analysis is absolutely preliminary, but it is intended to be the starting point of a path that allows us to think of the reconstruction of the ACL as an intervention to be planned more carefully based on the individual characteristics of each patient.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

References

1. Gottlob, C.A., et al., Cost effectiveness of anterior cruciate ligament reconstruction in young adults. Clin Orthop Relat Res, 1999(367): p. 272-82.
2. Andernord, D., et al., Patient predictors of early revision surgery after anterior cruciate ligament reconstruction: a cohort study of 16,930 patients with 2-year follow-up. Am J Sports Med, 2015. 43(1): p. 121-7.
3. Maletis, G.B., et al., Comparison of community-based ACL reconstruction registries in the U.S. and Norway. J Bone Joint Surg Am, 2011. 93 Suppl 3: p. 31-6.
4. Freedman, K.B., et al., Arthroscopic anterior cruciate ligament reconstruction: a metaanalysis comparing patellar tendon and hamstring tendon autografts. Am J Sports Med, 2003. 31(1): p. 2-11.
5. Ardern, C.L., et al., Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. Br J Sports Med, 2014. 48(21): p. 1543-52.
6. Lind, M., F. Menhert, and A.B. Pedersen, Incidence and outcome after revision anterior cruciate ligament reconstruction: results from the Danish registry for knee ligament reconstructions. Am J Sports Med, 2012. 40(7): p. 1551-7.
7. Gifstad, T., et al., Inferior results after revision ACL reconstructions: a comparison with primary ACL reconstructions. Knee Surg Sports Traumatol Arthrosc, 2013. 21(9): p. 2011-8.
8. Wright, R.W., et al., Outcome of revision anterior cruciate ligament reconstruction: a systematic review. J Bone Joint Surg Am, 2012. 94(6): p. 531-6.
9. George, M.S., W.R. Dunn, and K.P. Spindler, Current concepts review: revision anterior cruciate ligament reconstruction. Am J Sports Med, 2006. 34(12): p. 2026-37.
10. Samitier, G., et al., Failure of Anterior Cruciate Ligament Reconstruction. Arch Bone Jt Surg, 2015. 3(4): p. 220-40.
11. Di Benedetto, P., et al., Causes of Failure of Anterior Cruciate Ligament Reconstruction and Revision Surgical Strategies. Knee Surg Relat Res, 2016. 28(4): p. 319-324.
12. Wylie, J.D., L.S. Marchand, and R.T. Burks, Etiologic Factors That Lead to Failure After Primary Anterior Cruciate Ligament Surgery. Clin Sports Med, 2017. 36(1): p. 155-172.
13. Group, M., et al., Descriptive epidemiology of the Multicenter ACL Revision Study (MARS) cohort. Am J Sports Med, 2010. 38(10): p. 1979-86.
14. Johnson, D.L., Anterior cruciate ligament injury: what does it really mean? Orthopedics, 2007. 30(7): p. 515.
15. Christensen, J.J., et al., Lateral Tibial Posterior Slope Is Increased in Patients With Early Graft Failure After Ante-

rior Cruciate Ligament Reconstruction. Am J Sports Med, 2015. 43(10): p. 2510-4.
16. Webb, J.M., et al., Posterior tibial slope and further anterior cruciate ligament injuries in the anterior cruciate ligament-reconstructed patient. Am J Sports Med, 2013. 41(12): p. 2800-4.
17. Bisson, L.J. and J. Gurske-DePerio, Axial and sagittal knee geometry as a risk factor for noncontact anterior cruciate ligament tear: a case-control study. Arthroscopy, 2010. 26(7): p. 901-6.
18. Fujii, M., et al., Intercondylar notch size influences cyclops formation after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc, 2015. 23(4): p. 1092-9.
19. Tanaka, M.J., et al., Passive anterior tibial subluxation in anterior cruciate ligament-deficient knees. Am J Sports Med, 2013. 41(10): p. 2347-52.
20. Musahl, V., et al., The influence of bony morphology on the magnitude of the pivot shift. Knee Surg Sports Traumatol Arthrosc, 2010. 18(9): p. 1232-8.
21. Marcacci, M., et al., Arthroscopic intra- and extra-articular anterior cruciate ligament reconstruction with gracilis and semitendinosus tendons: a review. Curr Rev Musculoskelet Med, 2011. 4(2): p. 73-7.
22. Lazar, T.P., et al., Long-term radiographic comparison of tibial plateau leveling osteotomy versus extracapsular stabilization for cranial cruciate ligament rupture in the dog. Vet Surg, 2005. 34(2): p. 133-41.
23. Agneskirchner, J.D., et al., Effect of high tibial flexion osteotomy on cartilage pressure and joint kinematics: a biomechanical study in human cadaveric knees. Winner of the AGA-DonJoy Award 2004. Arch Orthop Trauma Surg, 2004. 124(9): p. 575-84.
24. Dejour, H. and M. Bonnin, Tibial translation after anterior cruciate ligament rupture. Two radiological tests compared. J Bone Joint Surg Br, 1994. 76(5): p. 745-9.
25. Giffin, J.R., et al., Effects of increasing tibial slope on the biomechanics of the knee. Am J Sports Med, 2004. 32(2): p. 376-82.
26. Fening, S.D., et al., The effects of modified posterior tibial slope on anterior cruciate ligament strain and knee kinematics: a human cadaveric study. J Knee Surg, 2008. 21(3): p. 205-11.
27. Voos, J.E., et al., Effect of tibial slope on the stability of the anterior cruciate ligament-deficient knee. Knee Surg Sports Traumatol Arthrosc, 2012. 20(8): p. 1626-31.
28. McLean, S.G., et al., The relationship between anterior tibial acceleration, tibial slope, and ACL strain during a simulated jump landing task. J Bone Joint Surg Am, 2011. 93(14): p. 1310-7.
29. Nelitz, M., et al., Increasing posterior tibial slope does not raise anterior cruciate ligament strain but decreases tibial rotation ability. Clin Biomech (Bristol, Avon), 2013. 28(3): p. 285-90.
30. Martineau, P.A., S.D. Fening, and A. Miniaci, Anterior opening wedge high tibial osteotomy: the effect of increasing posterior tibial slope on ligament strain. Can J Surg, 2010. 53(4): p. 261-7.
31. Petrigliano, F.A., et al., The effect of proximal tibial slope on dynamic stability testing of the posterior cruciate ligament- and posterolateral corner-deficient knee. Am J Sports Med, 2012. 40(6): p. 1322-8.
32. Hudek, R., et al., Novel measurement technique of the tibial slope on conventional MRI. Clin Orthop Relat Res, 2009. 467(8): p. 2066-72.
33. Anderson, A.F., R.B. Snyder, and A.B. Lipscomb, Jr., Anterior cruciate ligament reconstruction. A prospective randomized study of three surgical methods. Am J Sports Med, 2001. 29(3): p. 272-9.
34. Sonnery-Cottet, B., et al., Outcome of a Combined Anterior Cruciate Ligament and Anterolateral Ligament Reconstruction Technique With a Minimum 2-Year Follow-up. Am J Sports Med, 2015. 43(7): p. 1598-605.
35. Sonnery-Cottet, B., et al., Anterolateral Ligament Expert Group consensus paper on the management of internal rotation and instability of the anterior cruciate ligament - deficient knee. J Orthop Traumatol, 2017. 18(2): p. 91-106.

Received: 10 October 2020
Accepted: 19 November 2020
Correspondence:
Paolo Di Benedetto, MD, PhD
Dipartimento di Area Medica – Università degli Studi di Udine
Clinica Ortopedica
Azienda Sanitaria Universitaria Friuli Centrale
P.le S.Maria della Misericordia, 15 - 33100 Udine
Tel. +39 0432 559464
Fax +39 0432 559298
E-mail: paolo.dibenedetto@uniud.it