The Appropriate Methodologies in Biomechanical Studies Regarding Lateral Extra-Articular Procedures: What We Really Need in the Controlled Laboratory Studies

There remains controversy on the necessity to augment anterior cruciate ligament (ACL) reconstruction with lateral extra-articular procedures for knee stability, such as anterolateral ligament (ALL) reconstruction, anterolateral structure (ALS) reconstruction, and extra-articular tenodesis (LET). As an important experimental research method, previous cadaveric biomechanical studies failed to resolve these disputes, and results from different laboratories seem inconclusive. Although the experimental designs were similar and reasonable in these controlled laboratory biomechanical studies, inconsistent methodologies limited the comparability of different extra-articular procedures. Unless the researchers apply appropriate methodologies in biomechanical studies of lateral extra-articular procedures, that is, consistent methodologies, debates will persist.[1,2]

We applaud the well-performed study published in *Arthroscopy* by Ahn, Koh, McGarry, Patel, Lin, and Lee: "Double-Bundle Anterior Cruciate Ligament Reconstruction With Lateral Extra-Articular Tenodesis Is Effective in Restoring Knee Stability in a Chronic, Complex Anterior Cruciate Ligament-Injured Knee Model: A Cadaveric Biomechanical Study."[3] They demonstrated that an additional LET procedure, a modified superficial Lemaire technique, could improve knee stability after isolated double-bundle (DB) ACL reconstruction. They also reported that DB-ACL reconstruction combined with LET restored intact knee stability in internal rotation, external rotation, and anterior tibial translation laxity.

In contrast to previous studies, a novel deficient model with combined injuries of the anterolateral complex and the posterior horns of the medial and lateral menisci was created in this cadaveric study. As we know, the menisci play an essential role in controlling knee stability, especially in ACL-deficient knees.[4,5] Given the high incidence of associated meniscal pathology with acute or chronic ACL tears,[6] this complex model seems rational to simulate the unstable knee status in ACL-deficient patients. Moreover, in their study, it is worth noting that the quadriceps muscles were loaded according to the physiological cross-sectional area, whereas some femoral soft tissues were proximally dissected, including the iliotibial band (ITB). As an important secondary stabilizer, would adding the ITB load make this creative defective model better mimic the knee instability status? The answer is likely "yes!"

Since Claes and colleagues described "a distinct ligamentous structure" that was termed the ALL of the knee in 2013,[7] numerous cadaveric studies concentrated on the biomechanical effects of ALL or ALS and its related procedures on anterolateral and internal rotational stabilities in ACL-deficient or ACL-reconstructed knees.[2] However, the debate rages on! In these studies, all methodologies seem reasonable and well-documented. The "reasonable" methodologies applied by different research groups worldwide are not necessarily appropriate in controlled laboratory studies, in which a consistent methodology is required if we are united as an orthopedic research community. We believe that the inconsistent methodologies in various laboratory studies have partially resulted in the current controversy.

- First, the graft for the ACL or ALS reconstruction varied in these studies. Although all the grafts for ACL reconstructions in biomechanical studies, such as bone-patellar tendon-bone (BPTB) allografts, tripled or quadrupled semitendinosus, or synthetic nylon graft, seem reasonable,[8] the differences in the grafts could be an interfering factor in the measurement results of extra-articular procedures. For instance, ACL reconstruction with a BPTB graft could restore normal knee stability regardless of existing secondary anterolateral restraints in a robotic study.[9] However, the isolated ACL reconstruction with the quadrupled semitendinosus graft failed to restore knee stability in another robotic study.[10] The importance of a sufficient coverage area of the native ACL footprint in anatomic ACL reconstruction has been emphasized by some researchers to successfully restore normal knee kinematics, which is likely associated with the different biomechanical results of ACL reconstruction with various grafts.[11,12] Furthermore, the grafts for ALS reconstruction included semitendinosus, gracilis, and

polyester tape.[9] The differences in the biomechanical properties of these grafts might be related to the effects of controlling internal rotational instability.

- Second, the testing protocols could not be unified or roughly consistent. The load and torque in the simulated anterior drawer test and internal rotational test are less controversial, whereas the various types of simulated pivot shift tests in these biomechanical studies yield confusing results. Two static loading profiles, namely, 3-degree-of-freedom loads (e.g., 10 N·m or 8 N·m valgus, with 5 N·m or 4 N·m internal rotation, flexion) and 4-degree-of-freedom loads (e.g., 100 N anterior, 1 N·m, or 5 N·m internal rotation, with 7 N·m or 10 N·m valgus, flexion), were both recommended for examining pivot-shift phenomena.[9,13-17] Moreover, dynamic pivot shift tests were also applied in some biomechanical studies, which seem closer to the pivot-shift test in clinical scenarios.[17-19] As a result, the measurement methods of anterolateral stability or subluxation in these pivot shift tests were also different. Therefore, only the use of well-controlled and consistent test protocols in biomechanical studies can help determine which lateral extra-articular procedures are the most suitable for mitigating pivot-shift instability.
- Third, the deficient models used to simulate the anterolateral instability status are not the same. There are two main deficient models created in previous studies: the pure ALL-deficient model[13] and the ALS-deficient model, which were further classified as either "worst scenarios" or not.[14,18,20] The latter model sectioned more lateral capsule and soft tissue around the knees deep to the ITB from the lateral margin of the patellar tendon and anterior margin of the lateral collateral ligament, while the "worst scenarios" included damage to the capsule-osseous fibers of the ITB. Inconsistent deficient models concern us regarding the repeatability of anterolateral instability status in patients that the cadaveric studies have attempted to simulate in various biomechanical studies. Consequently, given the poor repeatability of the deficient models, the results of different extra-articular procedures are somewhat incomparable.

In our previous study, a secondary injury of ALS did not substantially exacerbate the anterior and anterolateral instabilities in ACL-deficient knees in the case of functional ITB.[21] Therefore, what if we simulate more knee dynamic structures to potentially challenge the current ALL- or ALS-deficient models that were commonly used in the present study? Ahn et al. probably provided one reasonable solution in their study, that is, an additional meniscal injury in chronic and complex ACL-deficient knees.[3] More importantly, in recent studies regarding lateral extra-articular procedures, the ITB was kept intact or tensioned to closely reproduce clinical settings.[18,21,22] However, in their study, only the quadriceps muscle was loaded to secure the patellofemoral joint under static tension. We believe that such a chronic model can be optimized after more dynamic muscles are loaded; at least, the tension of the ITB should be maintained. Nevertheless, this research has taken an important step in creating a new deficient model for further investigation in lateral extra-articular procedures in the future.

In laboratory biomechanical studies, a well-controlled and consistent methodology is preferable, which is likely to be the most important advantage compared to clinical studies. Because of the absence of consensus on the methodologies in cadaveric biomechanical studies of the lateral extra-articular procedures, such as deficient models, grafts for ACL or ALS reconstruction, and the test protocols, the discussion and comparison of lateral extra-articular procedures in different groups worldwide have been limited and may not reliably extrapolate to clinical practice. The published biomechanical results of lateral extra-articular procedures should be inspected objectively to determine whether these outcomes were reported under the premise of an acceptable and consistent methodology, or the comparisons in different studies were broadly comparable. Otherwise, these results should be interpreted with caution.

Although the test protocols of Ahn et al.' s study are not exactly the same as those of published studies, the authors deserve credit for drawing attention to the novel deficient model and the muscle loading, which should be considered for application in coming studies regarding lateral extra-articular procedures.[3] Once again, we congratulate Ahn et al. for their excellent work. Biomechanical studies with novelty and quality as those in the current study can aid the progressive unification of the methodologies for a better-controlled laboratory biomechanical study. All of this hard work in biomechanical studies have the same purpose, that is, to improve the outcomes of ACL reconstruction as expected by the entire orthopedic community.

Junjie Xu, M.D.
Jinzhong Zhao, M.D.
Department of Sports Medicine, Shanghai Jiao Tong University Affiliated Sixth People's Hospital, Shanghai, China

Note: The authors report no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

© 2021 by the Arthroscopy Association of North America
https://doi.org/10.1016/j.arthro.2021.06.020

References

1. Hurley ET, Bloom DA, Hoberman A, Anil U, Gonzalez-Lomas G, Strauss EJ, et al. There are differences in knee

stability based on lateral extra-articular augmentation technique alongside anterior cruciate ligament reconstruction [published online January 21, 2021]. *Knee Surg Sports Traumatol Arthrosc*. doi:10.1007/s00167-020-06416-4.
2. Littlefield CP, Belk JW, Houck DA, Kraeutler MJ, LaPrade RF, Chahla J, et al. The anterolateral ligament of the knee: An updated systematic review of anatomy, biomechanics, and clinical outcomes. *Arthroscopy* 2021;37:1654-1666.
3. Ahn JH, Koh IJ, McGarry MH, Patel NA, Lin CC, Lee TQ. Double-bundle anterior cruciate ligament (ACL) reconstruction with lateral extra-articular tenodesis is effective in restoring knee stability in a chronic, complex ACL-injured knee model: A cadaveric biomechanical study. *Arthroscopy* 2021;37:2220-2234.
4. Gupta R, Kapoor A, Mittal N, Soni A, Khatri S, Masih GD. The role of meniscal tears and meniscectomy in the mechanical stability of the anterior cruciate ligament deficient knee. *Knee* 2018;25:1051-1056.
5. Forkel P, von Deimling C, Lacheta L, Imhoff FB, Foehr P, Willinger L, et al. Repair of the lateral posterior meniscal root improves stability in an ACL-deficient knee. *Knee Surg Sports Traumatol Arthrosc* 2018;26:2302-2309.
6. Noyes FR, Barber-Westin SD. Treatment of meniscus tears during anterior cruciate ligament reconstruction. *Arthroscopy* 2012;28:123-130.
7. Claes S, Vereecke E, Maes M, Victor J, Verdonk P, Bellemans J. Anatomy of the anterolateral ligament of the knee. *J Anat* 2013;223:321-328.
8. DePhillipo NN, Cinque ME, Chahla J, Geeslin AG, LaPrade RF. Anterolateral ligament reconstruction techniques, biomechanics, and clinical outcomes: A systematic review. *Arthroscopy* 2017;33:1575-1583.
9. Noyes FR, Huser LE, Levy MS. The effect of an ACL reconstruction in controlling rotational knee stability in knees with intact and physiologic laxity of secondary restraints as defined by tibiofemoral compartment translations and graft forces. *J Bone Joint Surg Am* 2018;100:586-597.
10. Delaloye J-R, Hartog C, Blatter S, Schläppi M, Müller D, Denzler D, et al. Anterolateral ligament reconstruction and modified Lemaire lateral extra-articular tenodesis similarly improve knee stability after anterior cruciate ligament reconstruction: A biomechanical study. *Arthroscopy* 2020;36:1942-1950.
11. Fu FH. Anterolateral structure reconstruction unnecessary with anatomic ACL reconstruction for knee stability: Commentary on an article by Frank R. Noyes, MD, et al.: "The effect of an ACL reconstruction in controlling rotational knee stability in knees with intact and physiologic laxity of secondary restraints as defined by tibiofemoral compartment translations and graft forces". *J Bone Joint Surg Am* 2018;100:e47.
12. van Eck CF, Schreiber VM, Mejia HA, Samuelsson K, van Dijk CN, Karlsson J, et al. "Anatomic" anterior cruciate ligament reconstruction: A systematic review of surgical techniques and reporting of surgical data. *Arthroscopy* 2010;26:S2-S12 (9 Suppl).
13. Nitri M, Rasmussen MT, Williams BT, Moulton SG, Serra Cruz R, Dornan GJ, et al. An in vitro robotic assessment of the anterolateral ligament, part 2: Anterolateral ligament reconstruction combined with anterior cruciate ligament reconstruction. *Am J Sports Med* 2016;44:593-601.
14. Noyes FR, Huser LE, Jurgensmeier D, Walsh J, Levy MS. Is an anterolateral ligament reconstruction required in ACL-reconstructed knees with associated injury to the anterolateral structures? A robotic analysis of rotational knee stability. *Am J Sports Med* 2017;45:1018-1027.
15. Smith PA, Thomas DM, Pomajzl RJ, Bley JA, Pfeiffer FM, Cook JL. A biomechanical study of the role of the anterolateral ligament and the deep iliotibial band for control of a simulated pivot shift with comparison of minimally invasive extra-articular anterolateral tendon graft reconstruction versus modified Lemaire reconstruction after anterior cruciate ligament reconstruction. *Arthroscopy* 2019;35:1473-1483.
16. Marom N, Ouanezar H, Jahandar H, Zayyad ZA, Fraychineaud T, Hurwit D, et al. Lateral extra-articular tenodesis reduces anterior cruciate ligament graft force and anterior tibial translation in response to applied pivoting and anterior drawer loads. *Am J Sports Med* 2020;48:3183-3193.
17. Arilla FV, Yeung M, Bell K, Rahnemai-Azar AA, Rothrauff BB, Fu FH, et al. Experimental execution of the simulated pivot-shift test: A systematic review of techniques. *Arthroscopy* 2015;31:2445-2454.e2.
18. Araki D, Matsushita T, Hoshino Y, Nagai K, Nishida K, Koga H, et al. The anterolateral structure of the knee does not affect anterior and dynamic rotatory stability in anterior cruciate ligament injury: Quantitative evaluation with the electromagnetic measurement system. *Am J Sports Med* 2019;47:3381-3388.
19. Katakura M, Koga H, Nakamura T, Araki D, Nagai K, Nishida K, et al. Biomechanical effects of additional anterolateral structure reconstruction with different femoral attachment sites on anterior cruciate ligament reconstruction. *Am J Sports Med* 2019;47:3373-3380.
20. Inderhaug E, Stephen JM, Williams A, Amis AA. Anterolateral tenodesis or anterolateral ligament complex reconstruction: Effect of flexion angle at graft fixation when combined with ACL reconstruction. *Am J Sports Med* 2017;45:3089-3097.
21. Xu J, Han K, Su W, Jiang J, Yan X, Yu J, et al. A secondary injury of the anterolateral structure plays a minor role in anterior and anterolateral instability of anterior cruciate ligament-deficient knees in the case of functional iliotibial band. *Arthroscopy* 2021;37:1182-1191.
22. Devitt BM, Lord BR, Williams A, Amis AA, Feller JA. Biomechanical assessment of a distally fixed lateral extra-articular augmentation procedure in the treatment of anterolateral rotational laxity of the knee. *Am J Sports Med* 2019;47:2102-2109.

Regarding "The Top 50 Most-Cited Shoulder Arthroscopy Studies"

I was very interested in reading the article by Moore et al., "The Top 50 Most-Cited Arthroscopy Studies,"