



Motor Learning Approaches to Joint Mobility and Stability Strategies for the Knee

**Independent Study
Course 29.2.3**

Andrew D. Lynch, PT, PhD

University of Pittsburgh Department of Physical Therapy
UPMC Centers for Rehab Services at the
Freddie Fu Sports Medicine Center
Pittsburgh, PA

CONTINUING PHYSICAL THERAPY EDUCATION



REFERENCES

1. Eastlack ME, Axe MJ, Snyder-Mackler L. Laxity, instability, and functional outcome after ACL injury: copers versus noncopers. *Med Sci Sports Exerc.* 1999;31(2):210-215.
2. Blalock D, Miller A, Tilley M, Wang J. Joint instability and osteoarthritis. *Clin Med Insights Arthritis Musculoskelet Disord.* 2015;8:15-23. doi: 10.4137/CMAMD.S22147.
3. Fitzgerald GK, Piva SR, Irrgang JJ. Reports of joint instability in knee osteoarthritis: its prevalence and relationship to physical function. *Arthritis Rheum.* 2004;51(6):941-946.
4. Knoop J, Van Der Leeden M, Van Der Esch M, et al. Association of lower muscle strength with self-reported knee instability in osteoarthritis of the knee: results from the Amsterdam Osteoarthritis Cohort. *Arthritis Care Res.* 2012;64(1):38-45. doi: 10.1002/acr.20597.
5. Berthiaume MJ, Raynauld JP, Martel-Pelletier J, et al. Meniscal tear and extrusion are strongly associated with progression of symptomatic knee osteoarthritis as assessed by quantitative magnetic resonance imaging. *Ann Rheum Dis.* 2005;64(4):556-563.
6. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* 2007;35(10):1756-1769.
7. Zebis MK, Andersen LL, Bencke J, Kjaer M, Aagaard P. Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. *Am J Sports Med.* 2009;37(10):1967-1973. doi: 10.1177/0363546509335000. Epub 2009 Jul 2.
8. Boerboom AL, Hof AL, Halbertsma JP, et al. Atypical hamstrings electromyographic activity as a compensatory mechanism in anterior cruciate ligament deficiency. *Knee Surg Sports Traumatol Arthrosc.* 2001;9(4):211-216.
9. Osborne MD, Rizzo TD Jr. Prevention and treatment of ankle sprain in athletes. *Sports Med.* 2003;33(15):1145-1150.
10. Osborne M, Esser S. Chronic ankle instability. In Frontera WR, Silver JK, Rizzo TD Jr. *Essentials of Physical Medicine and Rehabilitation.* 3rd ed. Philadelphia, PA: Elsevier Saunders; 2015.
11. Felson DT, Gale DR, Elon Gale M, et al. Osteophytes and progression of knee osteoarthritis. *Rheumatology (Oxford).* 2005;44(1):100-104.
12. Pottenger LA, Phillips FM, Draganich LF. The effect of marginal osteophytes on reduction of varus-valgus instability in osteoarthritic knees. *Arthritis Rheum.* 1990;33(6):853-858.
13. Wellsandt E, Gardinier ES, Manal K, Axe MJ, Buchanan TS, Snyder-Mackler L. Decreased knee joint loading associated with early knee osteoarthritis after anterior cruciate ligament injury. *Am J Sports Med.* 2016;44(1):143-151. doi: 10.1177/0363546515608475. Epub 2015 Oct 22.
14. Hurd WJ, Snyder-Mackler L. Knee instability after acute ACL rupture affects movement patterns during the mid-stance phase of gait. *J Orthop Res.* 2007;25(10):1369-1377.
15. Tsai LC, McLean S, Colletti PM, Powers CM. Greater muscle co-contraction results in increased tibiofemoral compressive forces in females who have undergone anterior cruciate ligament reconstruction. *J Orthop Res.* 2012;30(12):2007-2014. doi: 10.1002/jor.22176. Epub 2012 Jun 22.
16. Rudolph KS, Axe MJ, Buchanan TS, Scholz JP, Snyder-Mackler L. Dynamic stability in the anterior cruciate ligament deficient knee. *Knee Surg Sports Traumatol Arthrosc.* 2001;9(2):62-71.
17. Selistre LF, Mattiello SM, Nakagawa TH, Goncalves GH, Petrella M, Jones RK. The relationship between external knee moments and muscle co-activation in subjects with medial knee osteoarthritis. *J Electromyogr Kinesiol.* 2017;33:64-72. doi: 10.1016/j.jelekin.2017.01.007. Epub 2017 Jan 18.
18. Gardinier ES, Manal K, Buchanan TS, Snyder-Mackler L. Gait and neuromuscular asymmetries after acute anterior cruciate ligament rupture. *Med Sci Sports Exerc.* 2012;44(8):1490-1496. doi: 10.1249/MSS.0b013e31824d2783.
19. Khandha A, Manal K, Capin J, et al. High muscle co-contraction does not result in high joint forces during gait in anterior cruciate ligament deficient knees. *J Orthop Res.* 2019;37(1):104-112. doi: 10.1002/jor.24141. Epub 2018 Oct 9.
20. Wellsandt E, Khandha A, Manal K, Axe MJ, Buchanan TS, Synder-Mackler L. Predictors of knee joint loading after anterior cruciate ligament reconstruction. *J Orthop Res.* 2017;35(3):651-656. doi: 10.1002/jor.23408. Epub 2016 Oct 17.
21. Piva SR, Fitzgerald K, Irrgang JJ, et al. Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskelet Disord.* 2006;7:33.
22. Rabin A, Kozol Z, Moran U, Efergan A, Geffen Y, Finestone AS. Factors associated with visually assessed quality of movement during a lateral step-down test among individuals with patellofemoral pain. *J Orthop Sports Phys Ther.* 2014;44(12):937-946. doi: 10.2519/jospt.2014.5507. Epub 2014 Oct 27.
23. Joreitz R, Lynch A, Rabuck S, Lynch B, Davin S, Irrgang J. Patient-specific and surgery-specific factors that affect

- return to sport after ACL reconstruction. *Int J Sports Phys Ther.* 2016;11(2):264-278.
24. Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. Biomechanics laboratory-based prediction algorithm to identify female athletes with high knee loads that increase risk of ACL injury. *Br J Sports Med.* 2011;45(4):245-252. doi: 10.1136/bjsm.2009.069351. Epub 2010 Jun 17.
 25. Holden SC, Boreham, Delahunt E. Sex differences in landing biomechanics and postural stability during adolescence: a systematic review with meta-analyses. *Sports Med.* 2016;46(2):241-253. doi: 10.1007/s40279-015-0416-6.
 26. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med.* 2010;38(10):1968-1978. doi: 10.1177/0363546510376053. Epub 2010 Aug 11.
 27. Goerger BM, Marshall SW, Beutler AI, Blackburn JT, Wilckens JH, Padua DA. Anterior cruciate ligament injury alters preinjury lower extremity biomechanics in the injured and uninjured leg: the JUMP-ACL study. *Br J Sports Med.* 2015;49(3):188-195. doi: 10.1136/bjsports-2013-092982. Epub 2014 Feb 21.
 28. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492-501.
 29. Earl JE, Monteiro SK, Snyder KR. Differences in lower extremity kinematics between a bilateral drop-vertical jump and a single-leg step-down. *J Orthop Sports Phys Ther.* 2007;37(5):245-252.
 30. Ortiz A, Capo-Lugo CE, Venegas-Rios HL. Biomechanical deficiencies in women with semitendinosus-gracilis anterior cruciate ligament reconstruction during drop jumps. *PM R.* 2014;6(12):1097-1106. doi: 10.1016/j.pmrj.2014.07.003. Epub 2014 Jul 17.
 31. Gagnon SS, Birmingham TB, Chesworth BM, Bryant D, Werstine M, Griffin JR. Development of a clinician-rated drop vertical jump scale for patients undergoing rehabilitation after anterior cruciate ligament reconstruction: a Delphi Approach. *J Orthop Sports Phys Ther.* 2017;47(8):557-564. doi: 10.2519/jospt.2017.7183. Epub 2017 Jul 6.
 32. Thomee R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2011;19(11):1798-1805. doi: 10.1007/s00167-011-1669-8. Epub 2011 Sep 20.
 33. Gustavsson A, Neeter C, Thomee P, et al. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2006;14(8):778-788.
 34. Fitzgerald GK, Axe MJ, Snyder-Mackler L. A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture. *Knee Surg Sports Traumatol Arthrosc.* 2000;8(2):76-82.
 35. Hurd WJ, Axe MJ, Snyder-Mackler L. A 10-year prospective trial of a patient management algorithm and screening examination for highly active individuals with anterior cruciate ligament injury: Part 1, outcomes. *Am J Sports Med.* 2008;36(1):40-47.
 36. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med.* 1991;19(5):513-518.
 37. Logerstedt D, Grindem H, Lynch A, et al. Single-legged hop tests as predictors of self-reported knee function after anterior cruciate ligament reconstruction: the Delaware-Oslo ACL cohort study. *Am J Sports Med.* 2012;40(10):2348-2356.
 38. Gardiner ES, Di Stasi S, Manal K, Buchanan TS, Snyder-Mackler L. Knee contact force asymmetries in patients who failed return-to-sport readiness criteria 6 months after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2014;42(12):2917-2925. doi: 10.1177/0363546514552184. Epub 2014 Oct 15.
 39. Wellsandt E, Axe MJ, Snyder-Mackler L. Poor performance on single-legged hop tests associated with development of posttraumatic knee osteoarthritis after anterior cruciate ligament injury. *Orthop J Sports Med.* 2018;6(11):2325967118810775. doi: 10.1177/2325967118810775.
 40. Willy RW, Davis IS. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. *J Orthop Sports Phys Ther.* 2011;41(9):625-632. doi: 10.2519/jospt.2011.3470. Epub 2011 Jul 12.
 41. Heiderscheit BC, Chumanov ES, Michalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. *Med Sci Sports Exerc.* 2011;43(2):296-302. doi: 10.1249/MSS.0b013e3181ebef4.
 42. Noehren B, Scholz J, Davis I. The effect of real-time gait retraining on hip kinematics, pain and function in subjects with patellofemoral pain syndrome. *Br J Sports Med.* 2011;45(9):691-696. doi: 10.1136/bjsm.2009.069112. Epub 2010 Jun 28.
 43. Willy RW, Scholz JP, Davis IS. Mirror gait retraining for the treatment of patellofemoral pain in female runners. *Clin Biomech (Bristol, Avon).* 2012;27(10):1045-1051. doi: 10.1016/j.clinbiomech.2012.07.011. Epub 2012 Aug 20.

44. Crowell HP, Davis IS. Gait retraining to reduce lower extremity loading in runners. *Clin Biomech (Bristol, Avon)*. 2011;26(1):78-83. doi: 10.1016/j.clinbiomech.2010.09.003.
45. Ahmed AF. Effect of sensorimotor training on balance in elderly patients with knee osteoarthritis. *J Adv Res*. 2011;2(4):305-311.
46. Lin DH, Lin CH, Lin YF, Jan MH. Efficacy of 2 non-weight-bearing interventions, proprioception training versus strength training, for patients with knee osteoarthritis: a randomized clinical trial. *J Orthop Sports Phys Ther*. 2009;39(6):450-457. doi: 10.2519/jospt.2009.2923.
47. Tunay VB, Baltaci G, Atay AO. Hospital-based versus home-based proprioceptive and strengthening exercise programs in knee osteoarthritis. *Acta Orthop Traumatol Turc*. 2010;44(4):270-277. doi: 10.3944/AOTT.2010.2306.
48. Noyes FR, Mooar PA, Matthews DS, Butler DL. The symptomatic anterior cruciate-deficient knee. Part I: the long-term functional disability in athletically active individuals. *J Bone Joint Surg Am*. 1983;65(2):154-162.
49. Hurd W, Axe M, Snyder-Mackler L. Management of the athlete with acute anterior cruciate ligament deficiency. *Sports Health*. 2009;1(1):39-46.
50. Fitzgerald GK, Axe M, Snyder-Mackler L. Proposed practice guidelines for nonoperative anterior cruciate ligament rehabilitation of physically active individuals. *J Orthop Sports Phys Ther*. 2000;30(4):194-203.
51. Fitzgerald GK, Axe MJ, Snyder-Mackler J. The efficacy of perturbation training in nonoperative anterior cruciate ligament rehabilitation programs for physical active individuals. *Phys Ther*. 2000;80(2):128-140.
52. Chmielewski TL, Hurd WJ, Rudolph KS, Axe MJ, Snyder-Mackler L. Perturbation training improves knee kinematics and reduces muscle co-contraction after complete unilateral anterior cruciate ligament rupture. *Phys Ther*. 2005;85(8):740-749; discussion 750-754.
53. Wellsandt E, Failla MJ, Axe MJ, Snyder-Mackler L. Does anterior cruciate ligament reconstruction improve functional and radiographic outcomes over nonoperative management 5 years after injury? *Am J Sports Med*. 2018;46(9):2103-2112. doi: 10.1177/0363546518782698. Epub 2018 Jun 21.
54. Fitzgerald GK, Piva SR, Gil AB, Wisniewski SR, Oddis CV, Irrgang JJ. Agility and perturbation training techniques in exercise therapy for reducing pain and improving function in people with knee osteoarthritis: a randomized clinical trial. *Phys Ther*. 2011;91(4):452-469. doi: 10.2522/ptj.20100188.
55. Dobson F, Hinman RS, Roos EM, et al. OARSI recommended performance-based tests to assess physical function in people diagnosed with hip or knee osteoarthritis. *Osteoarthritis Cartilage*. 2013;21(8):1042-1052. doi: 10.1016/j.joca.2013.05.002.