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Original Article

Physiotherapy Section

Relationship between Eccentric Peak Force and Loading Rate at Three Months after ACL Reconstruction in Athletes and Non Athletes: A Cross-sectional Study

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ABSTRACT

Introduction: Rehabilitation in the first three months is an expedient phase from a static load-bearing to a dynamic one. Understanding of neuromuscular recovery is crucial for preventing secondary injury and delay in return to sport.

Aim: To assess the relationship between Eccentric Peak Force (EPF), Eccentric Peak Force Asymmetry (EPFA), Loading Rate (LR) and Loading Rate Asymmetry (LRA) at three months after Anterior Cruciate Ligament Reconstruction (ACLR) in athletes and non athletes.

Materials and Methods: This study was a cross-sectional study conducted in the Total Healthsums Physiotherapy Centre, New Delhi, India, from January 2026 to April 2026. A total of 30 patients with primary ACLR (16 athletes and 14 non athletes) aged between 20 and 40 years were included as per eligibility criteria. They were performed with isometric squat testing on VALD ForceDecks dual force plates to evaluate EPF, EPFA, LR, and LRA at three months post-ACLR. Two different groups (athletic and non-athletic group) were analysed using an independent t-test or Mann-Whitney U test for parametric or non parametric distribution, respectively. Spearman's test was done to test correlation between EPF, EPFA, LR and LRA.

Results: There was a significant difference in EPFA and LRA between the groups. A positive correlation was observed between EPF and LR across entire sample (rs=0.55, p=0.002) and non athletes (rs=0.56, p=0.035), but no linear relation in athletes. Also, there is no correlation between EPFA and LRA in any group but has linear relation across whole sample (rs=0.39, p=0.030). EPFA and LRA are independent constructs in two groups.

Conclusion: With an increase in force, LR increases in non athletes as well as the entire sample population. There was no significant correlation between force and LR in athletes and between force asymmetry and LRA in both athletes and non athletes.

Keywords: Anterior cruciate ligament, Isometric squat, Limb asymmetry, Return to sport

INTRODUCTION

Neuromuscular deficits persist in the ACL-reconstructed population, increasing the risk of recurrence of injury [1]. Altered movement patterns and compensatory strategies result from neuromuscular impairments. These insufficiencies may be related to the imbalances in the hip and knee muscles [2]. Inter-limb asymmetries are another outcome of ACLR and have been analysed during landing and jumping in a few studies. These studies focused on lower-limb movement patterns [3-5].

To achieve lower limb strength post-ACLR, the bilateral squat, a multi-joint exercise, is generally included in post-ACLR rehabilitation [6-8]. During ACLR rehabilitation, there was inter-limb substitution, through the load shifts to the healthy limb from the affected limb or the load shifts from targeted muscle group, while performing a bilateral squat [7,8]. Knee kinetics and kinematics are assessed during the bilateral squats post-ACLR. It is of the essence to use the bilateral isometric squat as an assessment to compare the asymmetries between the limbs to enhance the knee function post-ACLR [7].

The 'rate' of 'force development' or the LR is the speed at which the force is developed in the contractile unit of the muscle. It is a measure of explosive strength in an athlete [9,10]. Developing a more explosive response may improve the athlete's performance [11]. The LR can be calculated from isometric, concentric, or eccentric muscle force. However, one study shows that intrinsic properties of the muscle and tendons are determined by eccentric force rather than concentric force [11].

The force developed during the descent phase of the squat is known as the EPF [12]. Two studies suggested that EPF has good reliability during loading movements [12,13]. The descent phase, involving eccentric force, requires rapid deceleration to control descent and restore kinetic force through eccentric muscle contraction [14]. So, it is important to work athletes' eccentric muscles to support the dynamic, rapid movements required for returning to sport. The non-athletic population may need a different rehabilitation approach based on their neuromuscular adaptation.

The first three months of rehabilitation are crucial for restoring physical characteristics. It focuses on early weight-bearing and improving joint mobility. It is a transitional phase towards dynamic loading [15]. This phase should emphasise muscle activation patterns, imbalances, and inter-limb asymmetry. There are studies that emphasise strength deficits and asymmetries at six and nine months postoperatively [14,16-18]. However, less literature is available for the early phase of three-month postoperative rehabilitation. A study was performed where asymmetry or Limb Symmetry Index (LSI) as an early predictor in lower limbs of athletes during loading was assessed while performing Sit-To-Stand (STS) at one month postoperative [19]. Another study was done where peak force and LR were assessed at three months during squatting, standing and STS, where they unconsciously underwork on their surgical limb [20]. There are numerous studies on the asymmetries and performance of athletes post-ACLR [14,16-18,21-23], but few distinguish among different asymmetries [24,25]. Also, there is a lot of inconsistency in the methodologies used to investigate these asymmetries [26]. Thus, the main objective was to add to the current knowledge of knee kinetics post-ACLR. The present study aimed to correlate EPF, EPFA, LR and LRA between athletes and non athletes in the initial period of ACLR rehabilitation.

MATERIALS AND METHODS

The present was a cross-sectional study conducted in the Total Healthsums Physiotherapy Centre, New Delhi, India, from January 2026 to April 2026. The Ethics Committee, MRIIRS, Faridabad, Haryana, India, Reference number: EC/2023-24/046-A, approved the study. In compliance with the Helsinki Declaration of 1964, revised in 2013, ethical standards were maintained throughout the study. The study was conducted in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. The independent variable is patient type (athlete or non-athlete), and the dependent variables are EPF, EPFA, LR, and LRA.

Inclusion and Exclusion criteria: The inclusion criteria were: male and female aged between 20 and 40 years; the athletes should have participated in pivoting or cutting sports before the ACLR and had played for at least two years; the surgery for all the patients was done with the primary arthroscopic ACLR with or without meniscectomy of the single limb, the reconstruction was performed using a hamstring tendon, and the duration should be three months post-ACLR. The exclusion criteria were: history of any lower-limb injury or surgery; involvement of both limbs in the injury or surgery; any underlying systemic illness affecting musculoskeletal function, such as thrombosis, pregnancy, epilepsy, cardiovascular disease, or neurological conditions.

Sample size calculation: The sample size was calculated using G*Power (Version 3.1.9.7, Heinrich Heine University, Düsseldorf, Germany). A priori power analysis was performed for a two-tailed bivariate correlation, assuming a moderate effect size (r=0.50), an α error probability of 0.05, and a statistical power of 80%. The analysis indicated that 29 participants were required. Therefore, 30 participants were included in the study to ensure adequate statistical power.

A total of 30 patients (16 athletes and 14 non athletes) were recruited through referrals. Patients were grouped on the basis of their activity levels before ACL injury: athletes who played competitive sports and non athletes who participated in recreational sports less than twice a week.

Study Procedure

All selected patients (athletic and non-athletic groups) underwent ACLR rehabilitation with blood flow restriction training from the 6th week to three months post-ACLR. All the patients were adherent to similar BFR training until the testing. At three months, they were assessed with an isometric squat assessment. The assessor who went for assessment of the outcome measures was blinded; he did not know which group the patients were from.

Testing protocol: On a stationary cycle, a warm-up for 10 minutes was performed before the test by the subjects. The testing protocol was followed according to the VALD Hub Knowledge Base, which is available on the website with the published protocols [27,28]. Dual ForceDecks plates were placed on a flat surface, and both plates were zeroed before each test [27,29]. Isometric squat holding or static squat was performed by asking participants to stand on the centre of the plate with feet shoulder-width apart and at a 90° knee angle. The subjects were asked to hold the position for 2-3 seconds, then perform a maximum contraction for 4-5 seconds. Three trials were performed with a 2-minute break in between, and the superior result was then used for analysis [26,30,31]. A training session was given to each participant to omit learning bias. During the trials given, an auditory cue was provided to the participants. The cue given was "as fast and as hard as possible". All the guidelines were followed according to the manufacturer's guideline manuals. The results were then recorded and noted [31]. Intra-rater reliability {Intraclass Correlation Coefficient (ICC)=0.75–0.97} has been reported to be excellent in healthy individuals [27].

Outcome measures: Isometric squat assessment was analysed using a VALD ForceDecks dual force plate (ForceDecks, FDLite V.2, VALD Performance, Brisbane, Queensland, Australia). The testing was performed using the isometric squat [32,33]. The wireless configuration of two portable uniaxial force plates was used to assess the variables. The patients were asked to stand on the force plates with one foot on each plate, then they were asked to stand without moving for a few seconds for baseline stability. Then, ForceDecks software, installed on an iPad iOS application (Apple, CA, United States), processed the force-time curves to calculate the variables. The ForceDecks system assesses the EPF and LR by calculating the vertical Ground Reaction Forces (GRF), and their asymmetries are calculated within the software through the comparison of affected versus unaffected lower limb vertical GRFs [27-29].

STATISTICAL ANALYSIS

Normality of all variables, including demographic data and outcome measures, was assessed using the Shapiro-Wilk test, kurtosis, and histograms. Normality was assessed using the Shapiro-Wilk test at $p<0.05$ to distinguish between parametric (normal) and non parametric (non normal) distributions of the data. Independent t-test for normal distribution and Mann-Whitney U test for non normally distributed data were used to compare EPF, EPFA, LR and LRA between the ACLR athletes and non-athlete groups. The relationships between LR and EPF, and between LRA and EPFA, were evaluated using the Spearman's correlation coefficient. Spearman's rank correlation was used for a small sample size (N=30) and a non normal distribution of data, as it is more robust to outliers than Pearson's correlation [34]. The magnitude of correlation was inferred as negligible (0-0.3), low (0.3-0.5), moderate (0.5-0.7), high (0.7-0.9), and excellent (0.9-1.0) [35]. All statistical analyses were conducted in IBM Statistical Package for Social Sciences (SPSS) Statistics (Version 31.0, IBM Corp., Armonk, NY, USA). Significance was reported if $p<0.05$. Moreover, the confidence interval was set at 95%. The data were presented as mean±SD.

RESULTS

Demographic and anthropometric characteristics of the subjects are presented in [Table/Fig-1]. The mean and SD demonstrated the quantitative data. Age, height, and weight had a normal distribution, and when tested with an independent t-test, they did not differ significantly between groups. The gender variable had a non-normal distribution and showed no significant difference after the Mann-Whitney test.

The EPF and LRA had normal distributions, while EPFA and LR had non normal distributions [Table/Fig-2]. LRA showed a significant difference (p=0.041) when tested with an independent t-test, whereas EPF showed no significant difference (p=0.321). Applying the Mann-Whitney test, EPFA showed a significant difference (p<0.001), whereas LR showed no significant difference between the groups (p=0.361).

	Athletic Group	Non-athletic Group	Independent t-test	Mann-Whitney U test
Variables	(n=16) Mean±SD	(n=14) Mean±SD	p-value	p-value
Gender (M/F)	11/5	13/1	-	0.100
Age (year)	30.50±7.04	28.64±6.40	0.458	-
Height (cm)	162.00±10.64	165.71±10.22	0.341	-
Weight (kg)	71.50±7.82	76.14±13.65	0.275	-

[Table/Fig-1]: Demographic and anthropometric characteristics of athletic and non-athletic group.
M: Male; F: Female; *: significant difference

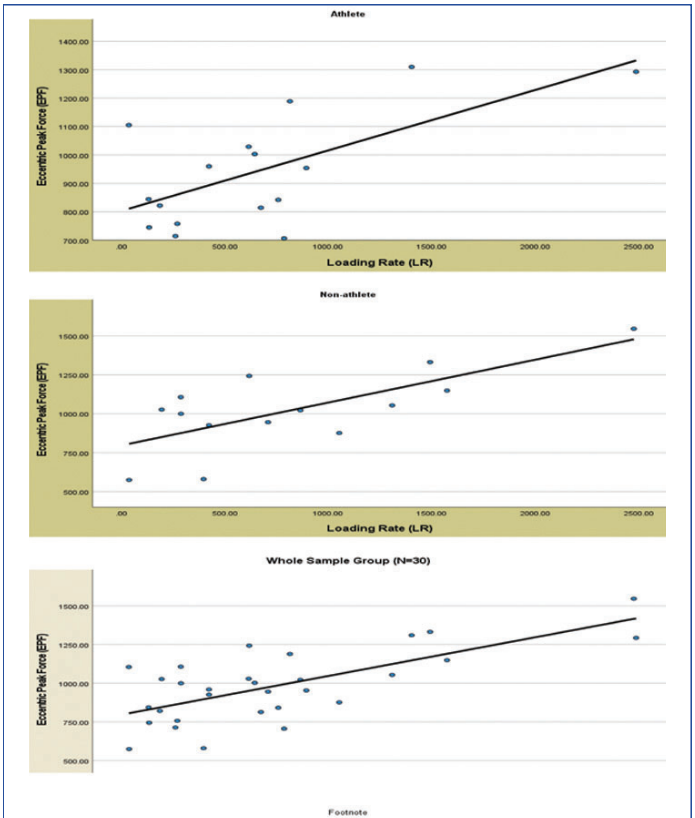
Variables	Athletic Group	Non-athletic Group	Independent t-test	Mann-Whitney U test
	(n=16) Mean±SD	(n=14) Mean±SD	p-value	p-value
EPF	942.99±198.07	1027.46±259.38	0.321	-
EPFA	6.95±3.99	25.96±10.86	-	**<0.001***
LR	657.50±607.57	837.47±680.30	-	0.360
LRA	28.90±21.87	47.62±25.89	**0.041***	

[Table/Fig-2]: EPF, EPFA, LR, and LRA between athletic group and non-athletic group.
EPF: Eccentric peak force; EPFA: Eccentric peak force asymmetry; LR: Loading rate; LRA: Loading rate asymmetry; *: significant difference

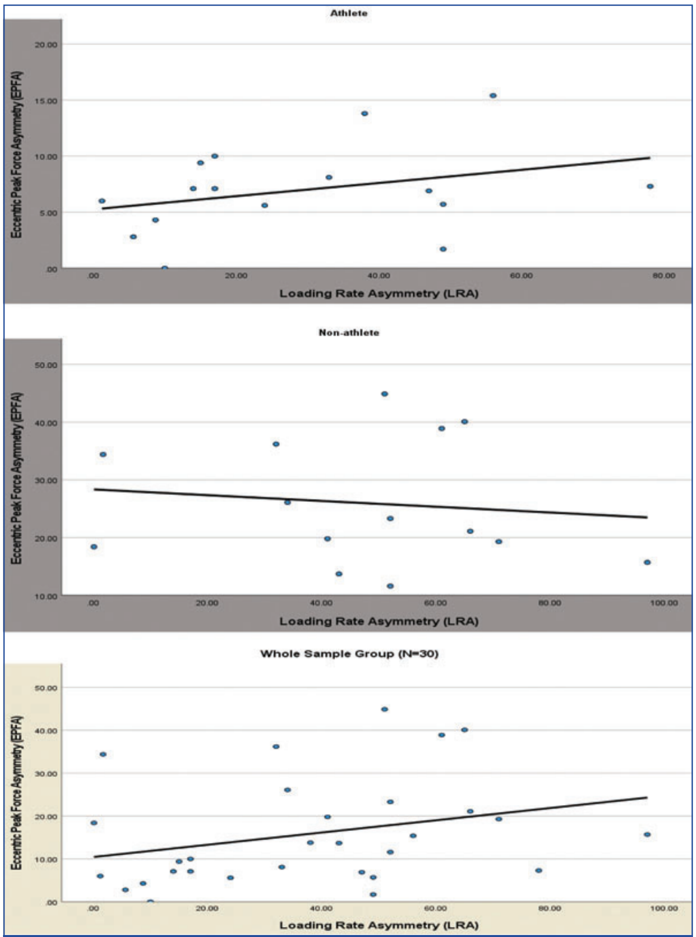
The LR displayed a moderate positive correlation (r_s=0.56, p=0.035) with EPF in the non athletes' group, which is statistically significant. LR is not related to EPF in the athlete group, as indicated by the Spearman's rank correlation test. However, LR and EPF show a moderate, highly significant positive correlation (r_s=0.55, p=0.002) in the Spearman's rank correlation test for all participants. LRA showed no strong linear relationship with EPFA in either group and shows a significantly low correlation across the entire group (r_s=0.39, p=0.030), as assessed by the Spearman's test [Table/Fig-3-5].

Parameters		N	r_s-value	p-value
Group		LR	LR	LR
Athlete	EPF	16	0.388	0.137
Non-athlete	EPF	14	0.565	0.035*
All	EPF	30	0.553	0.002*
		N	r_s-value	p-value
Group		LRA	LRA	LRA
Athlete	EPFA	16	0.368	0.161
Non-athlete	EPFA	14	0.106	0.719
All	EPFA	30	0.397	0.030*

[Table/Fig-3]: Spearman's correlation coefficient for EPF, LR, EPFA and LRA.
EPF: Eccentric peak force; EPFA: Eccentric peak force asymmetry; LR: Loading rate; LRA: Loading rate asymmetry; *: statistical significance; N: Sample size; rs -value: Spearman's rho coefficient value



[Table/Fig-4]: EPF versus LR regression plot for: a) Athlete; b) Non-athlete; c) Whole sample group.



[Table/Fig-5]: EPFA versus LRA regression plot for: a) Athlete; b) Non-athlete; c) Whole Sample Group.

DISCUSSION

The present study demonstrates that an increase in the asymmetry of one variable (EPF) correlates with the asymmetry of another variable (LR) across the entire sample population, but neither group correlates individually. A similar result was demonstrated in Labanca L et al., where asymmetry in STS at the 1st month assessment was used as a predictor of asymmetry in countermovement jump at six months in postoperative ACLR group [19]. This suggests that although a relationship exists, the the sample sizes were too small to detect a statistically significant correlation within the individual groups. Since both groups had low statistical power due to small sample sizes of 16 and 14, the groups' effect sizes are difficult to detect. But when the entire population was combined, the statistical power increased and surpassed the threshold. This indicates that a study with a larger sample size may possibly show a correlation between EPFA and LRA.

The present study demonstrates a significant positive correlation between EPF and LR in the total group (N=30) and in non athletes. This shows that the rate of force development augments with increased strength. Nevertheless, the change is not significant for athletes, depicting that EPF and LR are independent of each other in a trained and elite population. Due to long-term advanced training of elite athletes, the muscle-tendon structure changes by modifying the pennation angles of muscle fibres and increasing tendon stiffness. A stiff tendon independently accelerates and directly augments the force transmitted to the bone [10]. Secondly, this could be due to the 'decoupling effect' in athletes resulting from the training protocol they undergo, which leads to adaptive changes in neural factors that promote more advanced motor learning in the muscles. Motor unit discharge rate (neural determinants) and LR show parallel changes, and muscular capacity, which reflects muscular force, is an independent construct [10]. These are the sport-specific adaptations in athletes. Also, in athletes, increased EPF symmetry can still lead to LR asymmetry, which does not affect performance [36]. Similar observations were made by Forelli F et al., who showed that LR capacity remains incomplete in the late phase of rehabilitation, with eccentric and concentric force remaining deficient, and that eccentric force asymmetry is also hampered at 6 months in post-ACLR patients [14].

Although no study has examined the post-ACLR correlation between EPF and LR, the present study's results align with previous studies assessing asymmetry. A study by de Mille P et al., observed faulty movements in athletes at six months post-ACLR during multifunctional tasks [16]. This study demonstrated that an improvement in performance (force) does not ensure an improvement in the quality of the movement (symmetry) in athletes. As seen in this research, the asymmetries are not correlated and should thus be analysed and rehabilitated separately [37]. The training protocol should be constructed based on the strength deficiencies and imbalances of each muscle, as determined by the assessment. The rehabilitation of non athletes should focus on enhancing muscle strength, which, in turn, will increase LR, as EPF and LR are correlated. However, for athletes, the focus should be on rate of force development interventions with a comprehensive neuromuscular analysis [37]. A study by Chan MS and Sigward S supported the present observation that loading symmetry improves when limb loading is prioritised during rehabilitation [20].

Limitation(s)

The main limitation is the study's duration. At three months, there is a rapid increase in muscle strength as it is still the recovery phase following the acute phase postoperatively. Also, the sample size of the present study is small, and the correlation in the athletic group may not be detected. Future studies with increased sample size and extended follow-up will authenticate these preliminary findings. The 'decoupling effect' discovered post-hoc between EPF and LR is another limitation. There is a risk of data overfitting due to the small sample size, as this correlation was not a priori specified. Thus, these findings should be viewed as hypothesis-generating and exploratory for prospective studies in future to authenticate this effect at three months in post-ACLR athletes. The cross-sectional study design, having a single-time point evaluation and a lack of pre-injury data, is also a limitation of the study, as it prevents establishing causal relationships and determining whether the results are due to the injury or if there was an existing pattern.

CONCLUSION(S)

The present research was conducted to investigate the relationships between EPF and LR, and between EPFA and LRA, in athletes and non athletes post-ACLR. The non athletes showed a significant correlation between EPF and LR, while the athletes did not. Asymmetries in EPF did not correlate to asymmetries in LR or explosive speed (RFD) in either of the groups. However, there was a correlation across the entire study population, as shown by Spearman's rank correlation.

Considering the cross-sectional study design and small sample size, the interpretation and inference of the findings should be approached with caution. However, the results in athletes suggest that both asymmetries may improve if they are assessed and rehabilitated separately. Contrarily, in non athletes, focusing solely on strength (force) may increase the rate of force production. To validate these clinical approaches, future longitudinal studies are required with a larger sample size.

REFERENCES

[1] Hui C, Salmon LJ, Kok A, Maeno S, Linklater J, Pinczewski LA. Fifteen-year outcome of endoscopic anterior cruciate ligament reconstruction with patellar tendon autograft for "isolated" anterior cruciate ligament tear. American Journal of Sports Medicine. 2011;39(1):89-98. Doi: 10.1177/0363546510379975. PubMed PMID: 20962336.

[2] Moiroux-Sahraoui A, Mazeas J, Gold M, Kakavas G, Forelli F. Neuromuscular control deficits after anterior cruciate ligament reconstruction: A pilot study using single-leg functional tests and electromyography. J Funct Morphol Kinesiol. 2025;10(1):98. Doi: 10.3390/jfmk10010098. PMID: 40137350; PMCID: PMC11942642.

[3] Isaac DL, Beard DJ, Price AJ, Rees J, Murray DW, Dodd CAF. In-vivo sagittal plane knee kinematics: ACL intact, deficient and reconstructed knees. Knee. 2005;12(1):25-31. Doi: 10.1016/J.KNEE.2004.01.002 PubMed PMID: 15664874.

[4] Clark RA, Howells B, Feller J, Whitehead T, Webster KE. Clinic-based assessment of weight-bearing asymmetry during squatting in people with anterior cruciate ligament reconstruction using nintendo wii balance boards. Arch Phys Med Rehabil. 2014;95(6):1156-61. Doi: 10.1016/J.APMR.2014.02.024 PubMed PMID: 24642197.

[5] Scarvell JM, Smith PN, Refshanuge KM, Galloway HR, Woods KR. Association between abnormal kinematics and degenerative change in knees of people with chronic anterior cruciate ligament deficiency: A magnetic resonance imaging study. Australian Journal of Physiotherapy. 2005;51(4):233-40. Doi: 10.1016/S0004-9514(05)70004-0 PubMed PMID: 16321130.

[6] Salem GJ, Salinas R, Harding FV. Bilateral kinematic and kinetic analysis of the squat exercise after anterior cruciate ligament reconstruction. Arch Phys Med Rehabil. 2003;84(8):1211-16. Doi: 10.1016/S0003-9993(03)00034-0 PubMed PMID: 12917862.

[7] Sanford BA, Williams JL, Zucker-Levin A, Mihalko WM. Asymmetric ground reaction forces and knee kinematics during squat after anterior cruciate ligament (ACL) reconstruction. Knee. 2016;23(5):820-25. Doi: 10.1016/J.KNEE.2015.11.001 PubMed PMID: 27262213.

[8] Castanharo R, Da Luz BS, Bitar AC, D'Elia CO, Castropil W, Duarte M. Males still have limb asymmetries in multijoint movement tasks more than 2 years following anterior cruciate ligament reconstruction. Journal of Orthopaedic Science. 2011;16(5):531-35. Doi: 10.1007/S00776-011-0118-3.

[9] Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol. 2002;93:1318-26. Doi: 10.1152/japplphysiol.00283.2002.

[10] Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: Physiological and methodological considerations. European Journal of Applied Physiology. Springer Verlag; 2016. p. 1091-1116. doi: 10.1007/s00421-016-3346-6 PubMed PMID: 26941023.

[11] Laffaye G, Wagner P. Eccentric rate of force development determines jumping performance. Comput Methods Biomech Biomed Engin. 2013;16(SUPPL 1):82-83. doi: 10.1080/10255842.2013.815839 PubMed PMID: 23923859.

[12] McNeill C, Beaven CM, McMaster DT, Gill N. Eccentric force-velocity characteristics during a novel squat protocol in trained rugby union athletes- pilot study. J Funct Morphol Kinesiol. 2021;6(2):32. doi: 10.3390/jfmk6020032.

[13] Frohm A, Halvorsen K, Thorstensson A. A new device for controlled eccentric overloading in training and rehabilitation. Eur J Appl Physiol. 2005;94(1-2):168-74. doi: 10.1007/s00421-004-1298-8 PubMed PMID: 15714289.

[14] Forelli F, Moiroux-Sahraoui A, Mazeas J, Ly W, Bialy M, Douryang M, et al. Evaluation of eccentric and concentric force during vertical jump after anterior cruciate ligament reconstruction: A comparative study. BMC Sports Sci Med Rehabil. 2025;17(1):259. doi: 10.1186/s13102-025-01301-4.

[15] Du C, Jiao J, Zhou J, Chow BC, Shi Q, Zhang X, et al. Three-month functional training programme improves knee joint function in athletes post-ACL reconstruction surgery. J Rehabil Med. 2024;56:jrm18701. doi: 10.2340/jrm.v56.18701. PMID: 39291912; PMCID: PMC11418274.

[16] de Mille P, Lewis CL, Nguyen JT, Brown AM, Hannafin JA, Chiaia T. Quality of movement for athletes 6 months after ACL reconstruction. Orthop J Sports Med. 2025;13(5):23259671251324525. doi: 10.1177/23259671251324525.

[17] Saper M. 6- vs 9-month return to sport testing results after ACL reconstruction with quadriceps autograft in adolescent patients. Orthop J Sports Med. 2020;8(4 suppl3):2325967120S00176. doi: 10.1177/2325967120S00176. PMCID: PMC7238678.

[18] Liotta ES, Sugimoto D, Maguire KJ, Kocher MS, Micheli LJ, Heyworth BE. 6-month return to sports testing following ACL reconstruction in adolescents with quadriceps tendon autograft versus hamstring autograft. Orthop J Sports Med. 2020;8(4 suppl3):2325967120S00201. doi: 10.1177/2325967120S00201. PMCID: PMC7238815.

[19] Labanca L, Laudani L, Menotti F, Rocchi J, Mariani PP, Giombini A, et al. Asymmetrical lower extremity loading early after anterior cruciate ligament reconstruction is a significant predictor of asymmetrical loading at the time of return to sport. Am J Phys Med Rehabil. 2016;95(4):248-55. doi: 10.1097/PHM.0000000000000369 PubMed PMID: 26259061.

[20] Chan MS, Sigward S. Prioritizing limb loading improves symmetry during dual-tasking in individuals following anterior cruciate ligament reconstruction. Front Sports Act Living. 2023;5:1090694. doi: 10.3389/fspor.2023.1090694.

[21] Kotsifaki R, Sideris V, King E, Bahr R, Whiteley R. Performance and symmetry measures during vertical jump testing at return to sport after ACL reconstruction. Br J Sports Med. 2023;57(20):1304-10. doi: 10.1136/bjsports-2022-106588 PubMed PMID: 37263763.

[22] Hughes G, Musco P, Caine S, Howe L. Lower limb asymmetry after anterior cruciate ligament reconstruction in adolescent athletes: A systematic review and meta-analysis. J Athl Train. 2020;55(8):811-25. doi: 10.4085/1062-6050-0244-19 PubMed PMID: 32607546.

[23] Teater MA, Schmitt D, Powell DW, Queen RM. Asymmetry in limb stiffness, joint power, and joint work during landing in anterior cruciate ligament reconstruction patients. Sports Health. 2026;18(1):125-35. doi: 10.1177/19417381251338218 PubMed PMID: 40387877.

[24] Stojanović MDM, Andrić N, Stojanovic TJ, Veršić Š, Gonzalez JC. Limb strength and power asymmetries in professional team sport athletes at return-to-sport testing following ACL reconstruction. Medicina (Lithuania). 2026;62(4):654. doi: 10.3390/medicina62040654 PubMed PMID: 42075526.
[25] Peebles AT, Williams B, Queen RM. Bilateral squatting mechanics are associated with landing mechanics in anterior cruciate ligament reconstruction patients. American Journal of Sports Medicine. 2021;49(10):2638-44. doi: 10.1177/03635465211023761 PubMed PMID: 34236927.
[26] Maloney SJ. The relationship between asymmetry and athletic performance: A critical review. J Strength Cond Res. 2019;33(9):2579-2593. doi:10.1519/JSC.0000000000002608.
[27] Collings TJ, Lima YL, Dutaillis B, Bourne MN. Concurrent validity and test–retest reliability of VALD ForceDecks' strength, balance, and movement assessment tests. J Sci Med Sport. 2024;27(8):572-80. doi: 10.1016/j.jsams.2024.04.014 PubMed PMID: 38777737.
[28] McMahon J, Suchomel T, Lake J, Comfort P. Understanding the key phases of the countermovement jump force-time curve. Strength & Conditioning Journal. 2018;40:96-106. doi: 10.1519/SSC.0000000000000375.
[29] Comfort P, Dos'Santos T, Beckham GK, Stone MH, Guppy SN, Haff GG. Standardization and methodological considerations for the isometric midthigh pull. Strength Cond J. 2019;41(2):57-79. doi:10.1519/SSC.0000000000000433.
[30] Bishop C, Read P, Lake J, Loturco I, Dawes J, Madruga M, et al. Unilateral isometric squat: Test reliability, interlimb asymmetries, and relationships with limb dominance. J Strength Cond Res. 2021;35(Suppl 1):S144-S151. doi:10.1519/JSC.0000000000003079.
[31] Bazyler CD, Beckham GK, Sato K. The use of the isometric squat as a measure of strength and explosiveness. J Strength Cond Res. 2015;29(5):1386-92. doi: 10.1519/JSC.0000000000000751 PubMed PMID: 25426517.
[32] Zhang WY, Zhuang SC, Chen YM, Wang HN. Validity and reliability of a wearable blood flow restriction training device for arterial occlusion pressure assessment. Front Physiol. 2024;15:1404247. doi: 10.3389/fphys.2024.1404247.
[33] May AK, Russell AP, Warmington SA. Lower body blood flow restriction training may induce remote muscle strength adaptations in an active unrestricted arm. Eur J Appl Physiol. 2018;118(3):617-27. doi: 10.1007/s00421-018-3806-2 PubMed PMID: 29350278.
[34] de Winter JCF, Gosling SD, Potter J. Comparing the Pearson and Spearman correlation coefficients across distributions and sample sizes: A tutorial using simulations and empirical data. Psychol Methods. 2016;21(3):273-290. doi:10.1037/met0000079.
[35] Schober P, Schwarte LA. Correlation coefficients: Appropriate use and interpretation. Anesth Analg. 2018;126(5):1763-68. doi: 10.1213/ANE.0000000000002864 PubMed PMID: 29481436.
[36] Smajla D, Žitnik J, Šarabon N. Quantification of inter-limb symmetries with rate of force development and relaxation scaling factor. Front Physiol. 2021;12:679322. doi: 10.3389/fphys.2021.679322.
[37] Bishop C, Lake J, Loturco I, Papadopoulos K, Turner A, Read P. Interlimb asymmetries: The need for an individual approach to data analysis. J Strength Cond Res. 2021;35(3):695-701. Doi: 10.1519/JSC.0000000000002729. PMID: 33587548.

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