THE ISOKINETIC MUSCLE ASYMMETRY OF THE THIGH AT 1 YEAR AFTER ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION WAS SIGNIFICANTLY ASSOCIATED WITH GAIT ASYMMETRY

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The purpose of this study is to clarify the differences of isokinetic thigh muscle strength and gait kinematics and kinetics between the injured legs and uninjured legs and the correlation between muscle strength asymmetry and gait asymmetry 1 year after anterior cruciate ligament reconstruction (ACLR). Twenty-five ACLR patients were enrolled in the Department of Sports Medicine, Peking University Third Hospital. The concentric strength of extensor and flexor muscles at 60°/s, 180°/s on the uninjured side and the injured side were evaluated by isokinetic tests, and the peak values of muscle strength were analysed. Three-dimensional motion information and ground reaction force during gait were collected, and the peaks of joint angle and moments during gait stance phase were calculated by inverse dynamics analysis. The paired-samples T test was used to analyze the differences of gait parameters and isokinetic muscle strength between the injured and uninjured legs. Spearman correlation analysis was used to study the correlation between bilateral symmetry index of isokinetic muscle strength and gait. One year after ACLR, the isokinetic muscle strength peaks of the flexor and extensor muscles on the injured side were significantly lower than those on the uninjured side. Compared with the uninjured side, the injured side showed insufficient knee extension at the time of maximum knee extension during stance phase, and the peak extension moment decreased significantly. Significant correlations were found between isokinetic muscle strength asymmetry of knee and gait asymmetry.

KEYWORDS： Anterior cruciate ligament reconstruction; Isokinetic muscle strength; Walking; Kinematics; Kinetics

INTRODUCTION: Anterior cruciate ligament (ACL) rupture is a common injury of the knee, accounting for approximately 50% of knee sports injuries (Musahl & Karlsson, 2019). ACL rupture induces joint instability, destroys biomechanical homeostasis of the joint, and affects motor ability. ACL reconstruction (ACLR) is an important method for the treatment of ACL rupture, which can effectively improve joint stability and motor function. However, even with satisfactory stability achieved by reconstructive surgery (Okafor et al., 2014), the rate of re-injury within two years after returning to exercise after ACLR was six times higher than that in the healthy control group (Paterno, Rauh, Schmitt, Ford, & Hewett, 2014).

Previous studies have found that even when walking, kinematic and dynamic asymmetry still exists after ACLR. Gait asymmetry is an important factor causing articular cartilage degeneration after ACLR (Owusu-Akyaw et al., 2018) and high risk of reinjury. Studies have shown that muscle weakness after ACLR is very common, and the symmetry of quadriceps muscle strength is a major component of the criteria for returning to exercise after ACLR (Adams, Logerstedt, Hunter-Giordano, Axe, & Snyder-Mackler, 2012), and muscle strength asymmetry is also significantly correlated with secondary cartilage degeneration after ACLR (Wang et al., 2015). Significant correlation has been found between strength asymmetry and gait asymmetry (Schmitt, Paterno, Ford, Myer, & Hewett, 2015; Shi et al., 2019). Most of the previous studies only analyzed the relationship between isometric force or concentric force of quadriceps femoris and gait, and the results of different studies were inconsistent (Arhos,

Capin, Buchanan, & Snyder-Mackler, 2021). Therefore, the present study will further comprehensively compare the differences of isokinetic thigh muscle strength and gait kinematics and kinetics between the injured legs and uninjured legs, and analyze the correlation between the asymmetrical strength of isokinetic muscles and the asymmetrical gait after ACLR, in order to provide theoretical guidance for the rehabilitation and motor function of ACLR, and reduce the risk of ACL re-rupture and secondary osteoarthritis. The hypotheses were that the injured legs would present significant lower thigh muscle strength than the uninjured legs, the injured legs present significant alterations in gait kinematics and kinetics compared with the injured legs, the LSI of thigh muscle strength would show significant correlation with the gait parameters.

METHODS: Twenty-five ACLR patients were enrolled in the Department of Sports Medicine, Peking University Third Hospital. Data of isokinetic muscle strength test one year after ACLR were collected using an isokinetic dynamometer (Con-Trex MJ; Germany). Subjects were also asked to complete practice repetitions once or twice prior to each test series, separated by 90 seconds rest intervals. The concentric strength of extensor and flexor muscles at 60°/s, 180°/s on the uninjured side and the injured side were measured respectively, and the peak value of muscle strength was analyzed. 3D coordinate data were collected using an 8-camera motion capture system at a sample rate of 120Hz (Vicon MX, Oxford Metrics, UK). Ground-reaction forces were collected using two embedded force plates at a sampling rate of 1000 Hz (AMTI, Advanced Mechanical Technology Inc., Watertown, Massachusetts, USA). After the standing trial, all subjects were asked to walk from a specified point so that one of his/her foot would unintentionally walk on the first force place and the other would walk on the second force plate. A successful trial was characterized as each foot stepping on the force plates at a self-selected speed. Once five successful gait trials were recorded, the data collection was complete. The average value of five trails was used for analysis. None of the participants complained about pain during walking. The peaks of three-dimensional joint angle and moments during gait stance phase were calculated by inverse dynamics analysis. The limbs symmetry index (LSI) was used to evaluate gait and muscle strength asymmetries. The LSI of each parameter was defined as $Y_{injuried\ leg}/Y_{injured\ leg}$. The paired-samples T test was used to analyze the difference of gait parameters and isokinetic muscle strength peaks between the injured legs and uninjured legs. Spearman correlation analysis was used to study the correlation between LSI of isokinetic muscle strength and gait. All the statistics analyses were performed in SPSS version 25 (IBM).

RESULTS: One year after ACLR, the peaks of the isokinetic flexor and extensor strength on the injured side were lower than those on the uninjured side (60°/s extensor concentric, the injured side: (1.22 ± 0.4) $Nm{\cdot}kg^{-1}$, uninjured side: (1.73 ± 0.42) $Nm{\cdot}kg^{-1}$, bilateral difference: (-0.5 ± 0.39) $Nm{\cdot}kg^{-1}$, $P < 0.01$; 60°/s flexor concentric, injured side: (0.84 ± 0.19) $Nm{\cdot}kg^{-1}$, uninjured side: (1.05 ± 0.23) $Nm{\cdot}kg^{-1}$, bilateral difference: (-0.21 ± 0.14) $Nm{\cdot}kg^{-1}$, $P < 0.01$). Compared with the uninjured side, the injured side showed insufficient knee extension at the time of maximum knee extension during stance phase (injured side: (5.25 ± 4.17) °, uninjured side: (2.24 ± 3.11) °, bilateral difference: (3.01 ± 2.44) °, $P < 0.01$), and the peak extension moment decreased (injured side: (0.1 ± 0.09) $Nm{\cdot}kg^{-1}{\cdot}m^{-1}$, (0.15 ± 0.07) $Nm{\cdot}kg^{-1}{\cdot}m^{-1}$, (-0.05 ± 0.06) $Nm{\cdot}kg^{-1}{\cdot}m^{-1}$, $P < 0.01$). One year after ACLR, the LSI of 180°/s isokinetic extensor concentric strength was correlated with the LSI of peak flexion moment. The LSI of 60°/s isokinetic extensor concentric strength was correlated with the LSI of peak internal rotation moment. One year after ACLR, LSI of 180°/s concentric flexor strength was correlated with LSI of peak flexion during stance phase. (Table 1)

Table 1 Correlation between isokinetic muscle strength LSI of and gait biomechanics LSI one year after ACL reconstruction

	60˚/s concentric extensor		60˚/s Concentric flexor		180˚/s Concentric extensor		180˚/s Concentric flexor	
	R	*P*	*R*	*P*	*R*	*P*	*R*	*P*
Peak flexion moment	0.192	0.357	0.212	0.310	.449*	0.024	0.185	0.377
Peak extension moment	-0.043	0.838	-0.219	0.292	-0.013	0.951	0.181	0.387
First peak adduction moment	0.232	0.265	0.216	0.299	0.135	0.521	0.035	0.867
Second peak adduction moment	0.139	0.507	0.118	0.575	0.113	0.590	0.031	0.884
Peak external rotation moment	-0.249	0.230	0.017	0.936	-0.301	0.144	0.078	0.712
Peak internal rotation moment	.421*	0.036	0.015	0.945	0.258	0.214	0.025	0.907
Peak Flexion during stance	0.319	0.120	0.254	0.221	0.387	0.056	.462*	0.020
Peak Extension during terminal stance	0.158	0.449	-0.032	0.881	-0.232	0.264	-0.167	0.425
Flexion at heel strike	-0.035	0.870	0.164	0.434	-0.228	0.274	0.154	0.463
Peak Adduction during stance	0.013	0.951	0.130	0.536	0.007	0.974	0.157	0.454
Peak Abduction during stance	0.075	0.723	-0.300	0.145	-0.030	0.887	-0.351	0.086
Peak Internal rotation during terminal stance	0.019	0.927	-0.029	0.890	0.015	0.942	0.012	0.953
Peak external rotation during terminal stance	-0.167	0.425	-0.176	0.400	-0.010	0.962	0.115	0.583

* R values when P < 0.05

DISCUSSION: In this study, it was found that one year after ACL reconstruction, the LSI of 180°/s isokinetic extensor knee muscle strength was significantly correlated with the peak flexion moment LSI. The LSI of the 60°/s isometric concentric extensor knee muscle was significantly correlated with the peak internal rotation moment LSI. One year after ACL reconstruction, the LSI of 60°/s isokinetic flexion muscle strength was significantly correlated with the LSI of peak flexion angle during stance phase.

Shi et al. (Shi et al., 2019) found similar results in their study, that the asymmetry of isometric quadriceps strength was significantly correlated with the asymmetry of peak knee flexion angle during stance phase. The asymmetry of isometric quadriceps strength was significantly correlated with the asymmetry of peak knee extension moment during mid-stance period. Arhos et al. (Arhos et al., 2021) found that there was no significant correlation between quadriceps force symmetry and gait asymmetry in patients who received standard-based rehabilitation treatment after ACLR, whose quadriceps symmetry index reached over 80% and completed re-exercise training. Once ACLR patients have undergone standard-based rehabilitation and motor training, equilateral quadriceps strength symmetry may not be the primary driver of gait asymmetry. However, the criteria for inclusion in this study was a very high quadriceps symmetry index of 80%, and most real-world patients did not meet this criterion. Therefore, one year after the inclusion of real-world ACLR patients in this study, it was found that the asymmetry of isokinetic muscle strength was significantly correlated with gait asymmetry. Matthew et al. (Abourezk et al., 2016) found that patients with hamstring asymmetry 3 years after ACLR had lower internal rotation of the femoral bone in the load-bearing period than the symmetric group, and higher tibial external rotation at initial landing of running than the symmetric group. Interestingly, although there was no significant difference in gait parameters

related to isokinetic gait, there was a significant correlation between the symmetry index of muscle strength and the symmetry index of gait parameters.

CONCLUSION: Compared with the uninjured side, the injured side showed lower peaks of the isokinetic flexor and extensor strength, insufficient peak knee extension during stance phase and decreased peak extension moment, one year after ACLR. There is a significant correlation between isokinetic muscle strength asymmetry of knee and gait asymmetry. This study suggests that ACLR patients still need regular rehabilitation training to improve muscle strength and motor function 1 year after ACLR, to reduce the risk of reinjury and secondary injury.

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