CLINICAL ARTICLE

Whether Patients with Anterior Cruciate Ligament Reconstruction Walking at a Fast Speed Show more Kinematic Asymmetries?

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Objective: Knee kinematic asymmetries after anterior cruciate ligament reconstruction (ACLR) are correlated with poor clinical outcomes, such as the progression of knee cartilage degenerations or reinjuries. Fast walking in patients with knee conditions may exacerbate knee kinematic asymmetries, but its impact on ACLR patients is uncertain. The aim of this study is to investigate if fast walking induces more knee kinematic asymmetries in unilateral ACLR patients.

Methods: This cross-sectional study enrolled 55 patients with unilateral ACLR from January 2020 to July 2022. There were 48 males and seven females with an average age of 30.6 ± 6.4 years. Knee kinematic data were collected at three walking speeds: self-selected, fast (150% normal), and slow (50% normal). A 3D knee kinematic analysis system measured the data, and self-reported outcomes assessed comfort levels during walking. We used SPM1D for two-way repeated ANOVA and posthoc paired *t*-tests to analyze kinematic differences in groups.

Results: In fast walking, ACLR knees exhibited more transverse kinematic asymmetries than intact knees, including greater external rotation angle (1.8°, 38%–43%; gait cycle [GC], $p < 0.05$ & 1.8–2.7°, 50%–61% GC, $p < 0.05$) and increased proximal tibial translation (2.1–2.5 mm, 2%–6% GC, $p < 0.05$ & 2.5–3.2 mm, 92%–96% GC, $p < 0.05$). Additionally, ACLR knees showed greater posterior tibial translation than intact knees (3.6–3.7 mm, 7%–8% GC, $p < 0.05$) during fast walking. No posterior tibial translation asymmetries were observed in slow walking compared to normal walking levels. ACLR knees have the most comfortable feelings in slow walking speed, and the most uncomfortable feelings in fast walking speed levels (29%).

Conclusions: Fast walking induces additional external tibial rotation and proximal and posterior tibial translation asymmetries in ACLR patients. This raises concerns about long-term safety and health during fast walking. Fast walking, not self-selected speed, is beneficial for identifying postoperative gait asymmetries in ACLR patients.

Key words: ACLR; Gait; Kinematic Asymmetries; Walking Speed

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Introduction

Anterior cruciate ligament (ACL) rupture is a common sports injury, and its incidence is increasing.[1] In the United States, more than 250,000 ACL injuries occur per year,[2] and anterior cruciate ligament reconstruction (ACLR) is the main treatment for ACL rupture. However, ACLR did not fully restore normal joint mechanics to prevent post-traumatic osteoarthritis (PTOA) or reinjuries of knee joint.[3] Patients with ACLR knees exhibit altered knee walking kinematic patterns compared with uninjured contralateral knees or healthy patients.[4] In a long period after surgery, the knee function was not fully recovered, which was manifested as abnormal knee external flexion moments and knee adduction moments.[5] Unilateral ACLR results in the asymmetries of vertical ground reaction force and muscle activity at different stages of the gait cycle.[6] These gait asymmetries were not considered to be associated with pure quadriceps muscle strength improvement.[7]

In daily life, fast walking is a more demanding activity than normal speed walking, and it is necessary to increase the flexion and extension range of motion to adapt to such activities. Most patients with ACL injury have a high-intensity exercise habit, and patients need to return to sports after ACL reconstruction. The fast speed levels of walking were shown to be a challenging issue for patients with knee diseases.[8,9] Previous studies have reported that those who walk fast show more kinetic asymmetries after ACLR,[10,11] but the 3D kinematics of ACLR patients at different speeds has not been studied. Recently, we used 3D motion capture to discover the asymmetry of fast walking in patients with ACL deficiency,[12] which led us to wonder if this deficit is fully addressed by ACL reconstruction. In addition, walking speeds are associated with incidences of knee collagen breakdown and osteoarthritis.[13,14] This study describes the relationship between walking speed and knee 3D kinematics during gait after ACLR, which enable us to analyze joint degeneration and injury. We hypothesize that fast speed levels could result in more knee kinematic asymmetries in patients with ACLR.

The purpose of this study was to explore knee 3D kinematics alterations at different walking speed levels. It could provide a better reference to analyze the influencing factors that may lead to PTOA, and provide clinical guidance to clinicians and rehabilitation practitioners.

Methods

Demographic Characteristics

The inclusion criteria for patients were the following: (1) patients diagnosed with complete unilateral ACL tear before surgery; (2) patients after single bundle anatomical ACLR surgery. Patients were excluded if they (1) had multiple ligament injuries before or after surgery, such as medial/lateral collateral ligament, posterior cruciate ligament, and other injuries; (2) their injuries were accompanied by severe meniscus tear and unable to be repaired, with more than 1/5 of the unilateral meniscus to be resected; (3) were older than 50 years old or diagnosed as a knee osteoarthritis patient; (4) had previous history of major surgeries or trauma; (5) had neuromuscular diseases that affect normal walking, movement, and other functions, such as myelitis, lumbar disc herniation, and so forth; (6) needed to walk with the help of external objects such as crutches; (7) had other diseases that affect motor function; (8) had a positive drawer test or Lachman test; (9) were unable to follow-up with the experimenter to complete the experiment.

Finally, 55 patients (48 males and seven females) were included in the study. The demographic data of this cohort were normally distributed: age, 30.6 ± 6.4 years; height, 173.5 ± 6.6 cm; weight, 72.7 ± 10.1 kg; BMI, 24.1 ± 2.8 kg/m^2. Gait kinematics data were collected at review 1 year after surgery, and the mean interval between operations was 22.7 ± 20.0 months.

Surgical Procedures

All the ACLR surgeries were performed by the team of the chief surgeon. The ACLR operation was performed with the semitendinosus/gracilis autograft of the injured side of the patient. Under arthroscopy, the femoral tunnel was drilled at the anteromedial position of 120° knee flexion, the femoral eccentric guide was used to locate the femoral insertion of the ACL, the guide pin was drilled at two points, the lateral femoral cortex was drilled with a 4.5-mm drill bit, and the length of the bone tunnel was measured. An 8-mm hollow drill bit was used to drill the bone tunnel about 10 mm from the lateral femoral outlet. The tibial locator was set at 45° to locate the tibial insertion of the ACL. The midpoint was located at the new medial side of the anterior cruciate ligament stump. A guide pin was drilled, and an 8-mm hollow drill was selected to open the tibial bone tunnel through the guide pin. Kirschner's needle is utilized to guide the graft into the bone canal. The ACL graft was secured to the femur using an Endobutton (Smith and Nephew, Andover, Massachusetts, USA). High-strength sutures were used to bind the tibial stump of the anterior cruciate ligament to the reconstructed ligament and to check that the graft did not move during extension and flexion, and did not impinge with the front and lateral when straightening. The tendon was tensioned outside the tibial canal while the knee joint flexion and extension were performed 10 times. Subsequently, the graft was fixed at a 30° knee flexion angle by means of bioresorbable interference screws (DePuy Mitek, Raynham, Massachusetts, USA). Following fixation, the Lachman test and anterior drawer test were conducted with negative results.

Kinematic Knee Data and Patient-Reported Outcome

Gait Measurement System

Kinematic knee measurements were obtained from participants using a three-dimensional (3D) motion capture gait system called Opti_Knee, developed by Innomotion in Shanghai, China.[15] The gait system consisted of various components, including a navigation stereo infrared tracking device (NDI Polaris Spectra; Northern Digital Inc), a high-speed optical camera (Basler aca640–90uc; Basler AG), two sets of markers, a handheld digital probe, and a treadmill. The sampling rate of the gait system was set at 60 Hz. Previous reports indicated that the gait system exhibited an accuracy level of 0.3 mm root mean square (RMS) and a repeatability of less than 1.3° in rotation and 0.9 mm in translation.[16,17] A high-speed camera was utilized to simultaneously record and identify the gait cycles (GC) of the subjects, who walked on the treadmill while their knee kinematics were being recorded and calculated in real-time.(Figure 1).

Experiment Approach

Each participant underwent a 5 min adaptation period on a motorized bi-directional treadmill set at a level surface. The normal walking speed for each individual was determined through a gradual increase in treadmill speed, starting from a slow pace of 1 km/h. The speed was continuously increased until the subject reported that it surpassed their preferred walking speed. This procedure was repeated three times, and the average speed (3.0 ± 0.3 km/h) obtained from these trials was defined as the normal walking speed. Subsequently, slower walking speed (50% of normal walking speed) and faster walking speed (150% of normal walking speed) were calculated based on this average speed.

Data Collection and Processing

The data collecting procedure was as follows: (1) Two sets of markers were fastened to the subject, and a handheld digitizing probe was used to identify bony landmarks to set up a personalized 3D coordinate system of the tibia relative to the femur with the subject in a neutral standing position[15]; (2) ACLR subjects were sequentially tested at three speeds, walking at the normal speed, the slow speed, and the fast speed; (3) before data collection, subjects walked on the treadmill for 1 min to ensure gait stability, after which kinematic data were recorded (as illustrated in Figures 2–7) for a duration of 15 s, approximately encompassing 15 gait cycles (GCs); (4) during the collection of kinematic data at different speeds, subjects were asked if they experienced any knee discomfort, and such instances were recorded; (5) a 5-min interval was provided between tests at different gait speeds for each ACLR subject to mitigate the influence of previous tests and potential fatigue effects; (6) these trials collected not only ACLR knee joints from patients, but also contralateral healthy knee joints from each patient as controls.

The system automatically averaged the kinematics from all the gait cycles (about 15 cycles) into an averaged gait cycle. The kinematic knee data included three angular parameters and three translational parameters. The three angular parameters were adduction/abduction angle (degrees, °), flexion/extension angle (degrees, °), and internal/external rotation angle (degrees, °). The three translational parameters were posterior tibial translation (millimeters, mm), proximal tibial translation (millimeters, mm), and medial/lateral tibial translation (millimeters, mm).

Statistical Analysis

To assess the normality of demographic data (age, height, weight, and BMI) for the ACL reconstruction (ACLR) subjects, the Shapiro–Wilk test was performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA). The significance level was set at 0.05. To investigate whether different walking speeds could induce increased gait asymmetry, the statistical parametric mapping with 1D (SPM1D) for two-way repeated analysis of variance (ANOVA) and posthoc paired *t*-test was utilized to evaluate kinematic differences among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The analysis was conducted using the SPM1D package available for MATLAB (version 0.4.8, http://www.spm1d.org). SPM1D employs Random Field Theory and assumes smooth, one-dimensional Gaussian Fields to examine statistical inferences for a set of 1D measurements.[18]

Sample Size Determination

When there was a significant kinematic difference detected in the gait cycle between the ACLR limb with the intact limb,

FIGURE 1 (A) Anatomical landmarks of the femur and tibia were identified using a handheld probe prior to acquisition of kinematic data. (B) Kinematic data collected while the subject was walking on a treadmill.

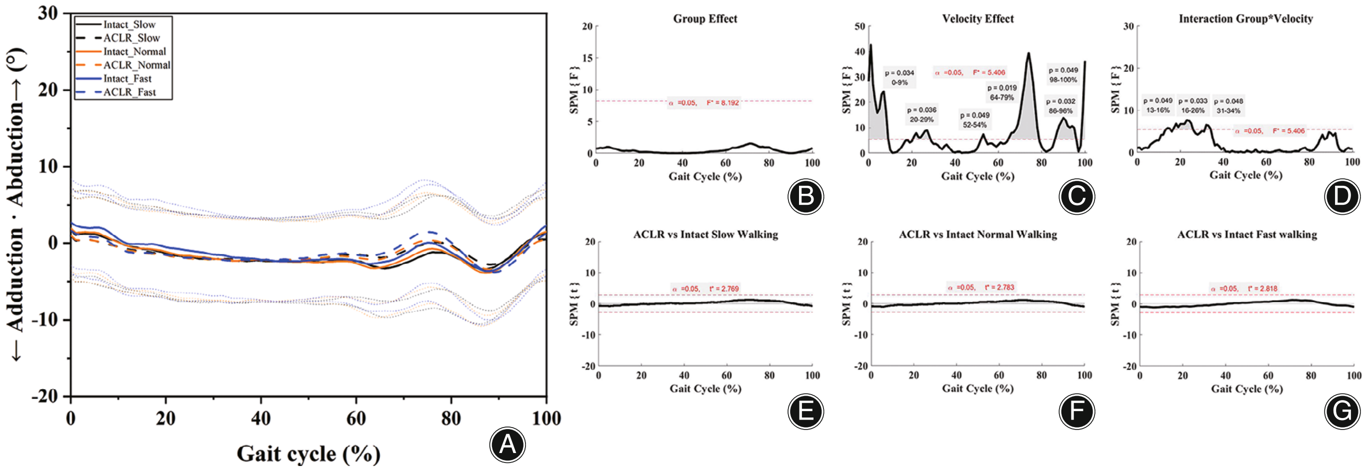

FIGURE 2 Walking adduction/abduction angle alterations of ACLR patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between ACLR and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and anterior cruciate ligament reconstruction (ACLR) leg versus intact leg at three walking speeds. The statistical methods were statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

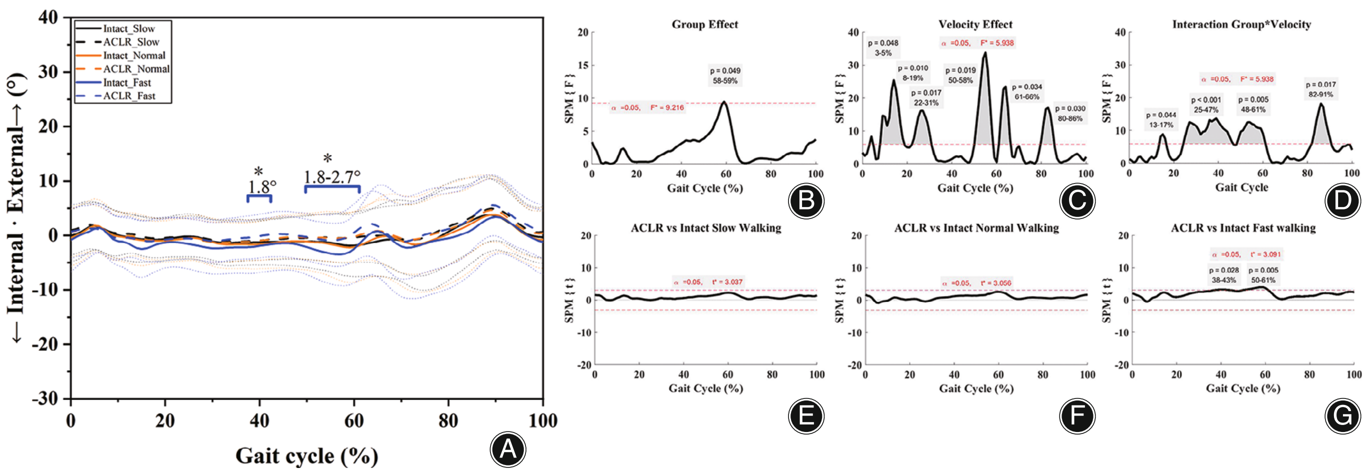

FIGURE 3 Walking internal/external tibial rotation angle alterations of ACLR patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between anterior cruciate ligament reconstruction (ACLR) and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The statistical methods were statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

the range of average value of the kinematic difference (lowest value to highest average value of the difference of each percent of the gait cycle) during the affected parts of the gait cycle, the exact affected parts of gait cycle percentage, and the exact *p*-value is reported in the results. Two-way repeated ANOVA and post-hoc *t*-tests was used to compare the average range of motion (ROM) of the intact and ACLR knee joints under the influence of three different speeds, and the difference between the average ROM among them was recorded (Figure 8). The ACLR technique was aimed to restore the anteroposterior translation of knees, therefore the ROM of anteroposterior translation was selected to calculate the power via PASS version 15.0 (NCSS, Kaysville, Utah, USA). The study was two (intact knees vs. ACLR knees) *three (fast vs. normal vs. slow speed) type. The average anteroposterior ROM of intact knees was 24.6 mm. The average anteroposterior ROM of control knees was 20.5 mm. The average anteroposterior ROM of ACLR knees at fast speed level was 25.2 mm, the average anteroposterior ROM of ACL deficiency patients while walking at normal speed

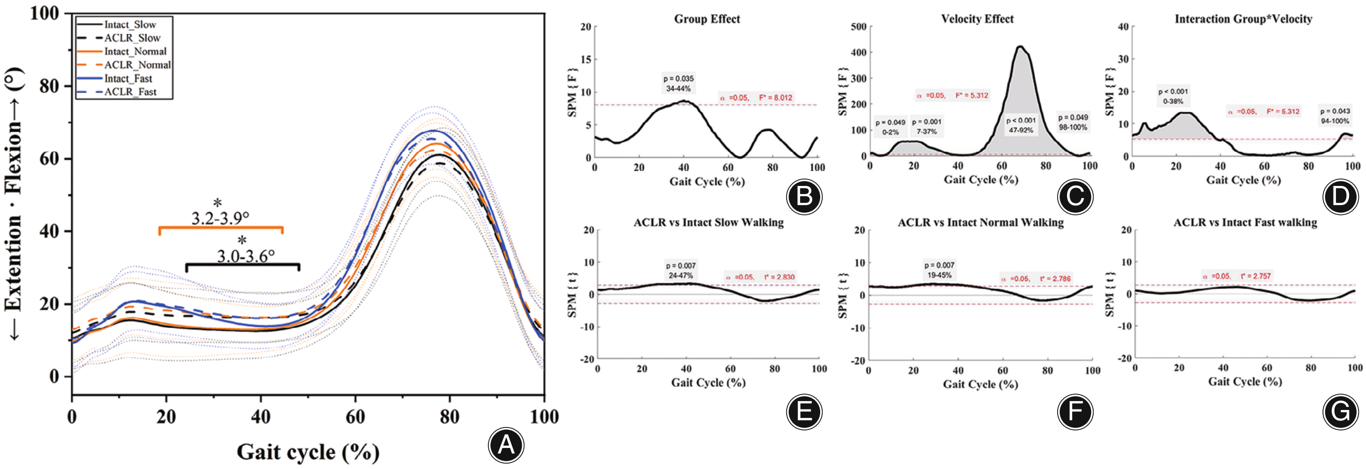

FIGURE 4 Walking flexion angle alterations of anterior cruciate ligament reconstruction (ACLR) patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between ACLR and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The statistical methods were statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

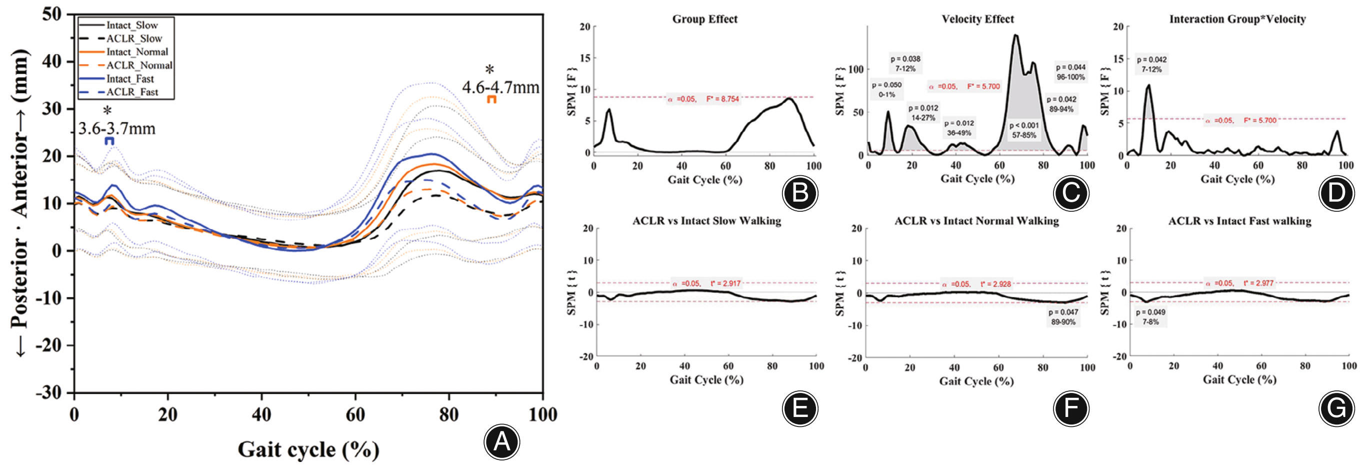

FIGURE 5 Walking anteroposterior tibial translation alterations of anterior cruciate ligament reconstruction (ACLR) patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between ACLR and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The statistical methods were statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

level was 22.0 mm, and the average anteroposterior ROM of ACL deficiency patients while walking at slow speed level was 20.5 mm. With the sample size of 55 subjects, this study achieves 100% power to test factor B1 if a Geisser–Greenhouse Corrected *F*-test is used with a 5% significance level and the actual effect standard deviation is 2.050 (an effect size of 0.9), achieves 100% power to test group, velocity and group × velocity interaction a 5% significance level, respectively. Therefore, the recruited number of subjects met the sample size requirement for this study.

Result

The Patients Reported Outcomes at Three Walking Speeds

Knee discomfort occurred in 29% of patients during fast walking (150% normal working speed). This discomfort did not occur during the slow walking (50% normal walking speed) and the normal walking speed. The patients experiencing knee discomfort perceive symptoms of ACLR knee instability while engaging in fast walking.

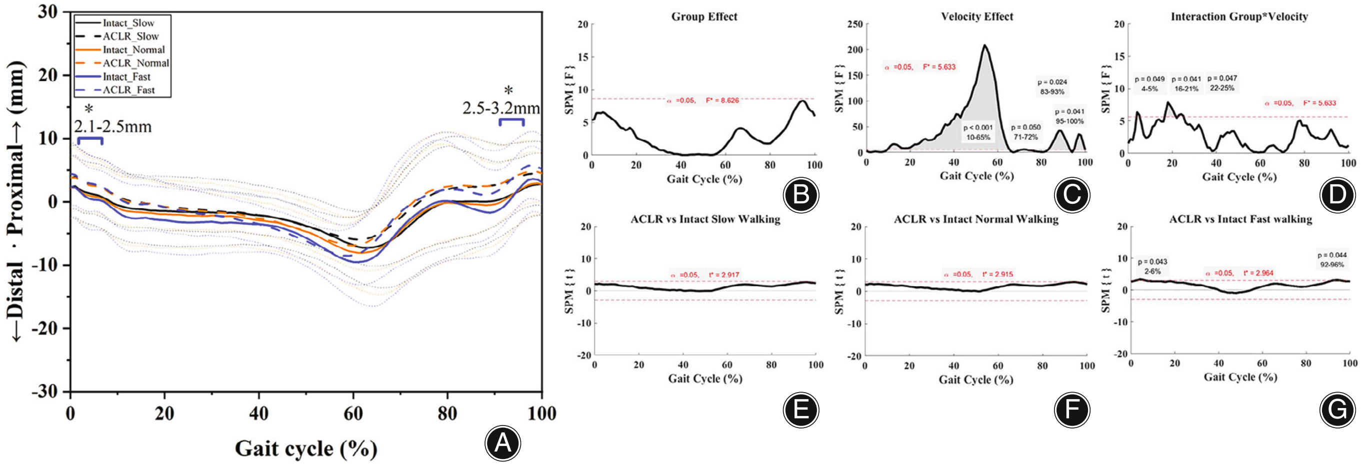

FIGURE 6 Walking proximal tibial translation alterations of anterior cruciate ligament reconstruction (ACLR) patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between ACLR and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The statistical method was statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

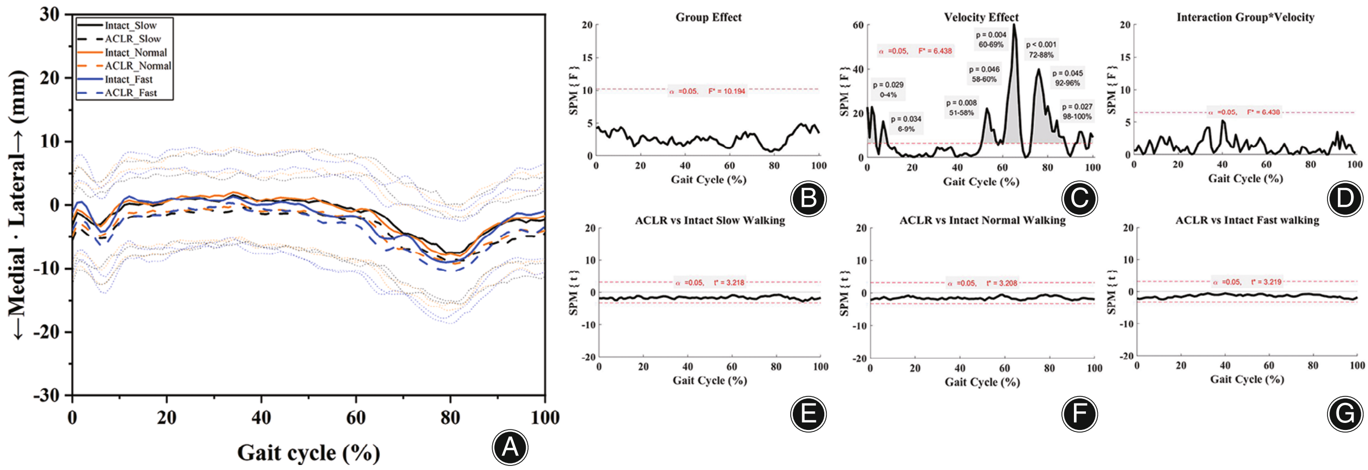

FIGURE 7 Walking medial/lateral tibial translation alterations of anterior cruciate ligament reconstruction (ACLR) patients at three different speed levels (normal/slow/fast). Chart (A) shows the kinematic comparison between ACLR and intact limbs during one gait cycle at three different speed levels (normal/slow/fast). Charts (B–G) show the kinematic differences during one gait cycle among various groups: group, velocity, group × velocity interaction, and ACLR leg versus intact leg at three walking speeds. The statistical methods were statistical parametric mapping with 1D (SPM1D) paired *t*-test. *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

The Influence of Walking Speed on Gait Symmetry in Patients with Unilateral ACLR

The effects of walking speed on 6DOF knee kinematics of ACLR knees and intact knees were summarized in Figures 2–7. Gait asymmetries during fast walking included increased posterior tibial translation at 7%–8% of the gait cycle (GC), increased external rotation angle (38%–43% GC, 50%–61% GC), and increased proximal tibial translation (2%–6% GC, 92%–96% GC). ACLR knees showed knee extension insufficiency (19%–45% GC) and increased posterior tibial translation (89%–90% GC) during normal walking. ACLR knees showed knee extension insufficiency (24%–47% GC) during slow walking.

Sagittal Plane

In the sagittal plane, the knee extension angle of ACLR knees was found to be 3.0–3.6° smaller than that of intact knees during 24%–47% of slow walking gait cycles ($p < 0.05$,

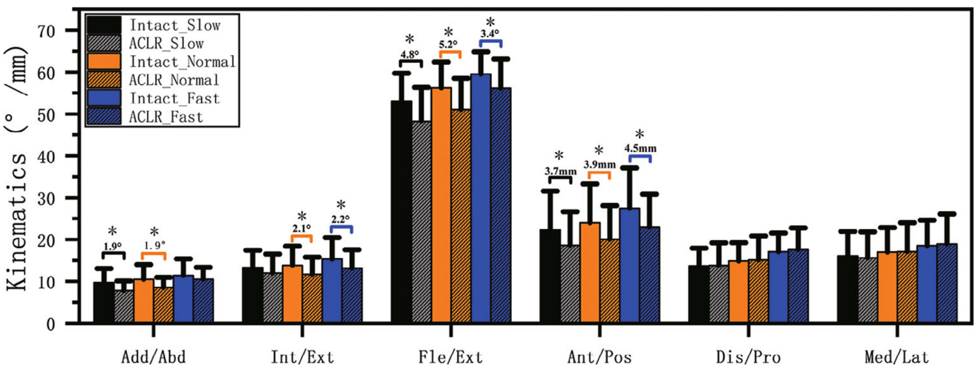

FIGURE 8 The range of motion of adduction/abduction angle, internal/external tibial rotation angle, flexion angle, anteroposterior tibial translation, proximal tibial translation, and medial/lateral tibial translation of anterior cruciate ligament reconstruction (ACLR) patients during walking at three different speed levels (normal/slow/fast). *: Significant kinematic differences of ACLR patients between the ACLR limb and the intact one ($p < 0.05$).

Figure 4A,E). The ACLR knees showed less extension angle than intact knees at normal speed walking (19%–45% GC, 3.2–3.9°, $p < 0.05$, Figure 4A,F). In contrast, gait asymmetry of flexion/extension angles of ACLR knees was not shown during fast walking. ACLR knees had a greater posterior tibial translation than the intact knees at normal speed (89%–90% GC, 4.6–4.7 mm, $p < 0.05$, Figure 5A,F). ACLR knees had increased posterior tibial translation than intact knees at fast walking (7%–8% GC, 3.6–3.7 mm, $p < 0.05$, Figure 5A,G). However, gait asymmetry of posterior tibial translation of ACLR knees was not shown at slow walking. We found that the range of motion (ROM) of the flexion angle of the ACLR leg was smaller than that of the intact leg at three walking speeds (the slow speed [4.8°, $p < 0.05$]/the normal speed [5.2°, $p < 0.05$], the fast speed [3.4°, $p < 0.05$], Figure 8). The ROM of the anteroposterior translation of ACLR legs was smaller than that of the intact legs at three walking speeds (the slow speed [3.7 mm, $p < 0.05$]/the normal speed [3.9 mm, $p < 0.05$], the fast speed [4.5 mm, $p < 0.05$], Figure 8).

Coronal Plane

In the coronal plane, there was no significant difference in adduction/abduction angle (Figure 2) and medial/lateral translation (Figure 7) between the ACLR knees and the intact knees during different speeds of gait. When patients walked at the normal (1.9°, $p < 0.05$) and the slow (1.9°, $p < 0.05$) speeds, the ACLR side had significantly smaller ROM of adduction/abduction angle than the intact side (Figure 8).

Transverse Plane

In the transverse plane, gait asymmetry was found at fast walking, but not at slow and normal walking speeds. ACLR knees at fast walking speed had a larger external rotation angle than the intact knees (38%–43% GC, 1.8°, $p < 0.05$; 50%–61% GC, 1.8–2.7° $p < 0.05$, Figure 3A,G) and greater proximal tibial translation (2%–6% GC, 2.1–2.5 mm, $p < 0.05$; 92%–96% GC, 2.5–3.2 mm, $p < 0.05$, Figure 6A,G). During fast walking, the ACLR limb had a reduced mean ROM of internal and external rotation compared with the intact side (2.1°, $p < 0.05$). During the normal speed walking speed, there was the same significant difference (2.2°, $p < 0.05$; Figure 8).

Discussion

Main Finding of the Study

The results of knee kinematics showed that gait asymmetries at fast walking were manifested in two dimensions: sagittal plane (increased posterior tibial translation) and transverse plane (greater external rotation angle and greater proximal tibial translation). ACLR knees exhibited gait asymmetries in the sagittal plane at slow walking (knee extension insufficiency) and normal walking (knee extension insufficiency and increased posterior tibial translation). In addition, our results showed that ACLR patients exhibited more knee discomfort (29%) and more gait asymmetries during fast walking.

The patients passed the anterior drawer test and the Lachman test before the test, and no positive results were found, which indicates that the gait test under rapid movement has higher sensitivity in evaluating knee stability.

Comparing the Results with Previous Studies

Sagittal Plane

In the sagittal plane, ACLR knees had increased posterior tibial translation than intact knees at fast walking. Previous studies have found increased anterior tibial translation in patients with ACL deficiency compared with healthy controls, which is due to quadriceps femoris directly affecting knee joint movement by altering patellar tendon tension.[19,20] The results indicate that the asymmetries in anterior tibial translation during normal exercise intensity are resolved by the ACLR technique. Conversely, the posterior tibial translation increased during fast walking, which may be due to the greater limiting effect of the reconstructed ACL on anterior tibial displacement during fast walking, exceeding the effect of the quadriceps femoris. When the walking speed increases, the increased posterior tibial translation after ACLR is shown. The abnormal anteroposterior translation was significantly correlated with knee cartilage degeneration.[21–24] The increased posterior tibial translation may also cause articular cartilage damage in ACLR patients.

Transverse Plane

In the transverse plane of the knee joint, ACLR knees increased external tibial rotation angle and proximal tibial translation at fast walking. Other studies have shown the greater external rotation angle of the knee on the reconstructed leg may suggest that the rotational stability of the lower extremity is not sufficiently controlled after ACLR.[25] The anterior cruciate ligament in the well-known limit excessive joint rotation plays an important role.[25] Due to the rapid movement increasing load ligament reconstruction, ACLR does not fully control the rotation of the lower limbs after stability. In other words, fast walking could stimulate rotation deficiency in ACLR patients. Maybe, fast walking could be used to identify rotation deficiency of ACLR patients in the future. Moreover, previous studies have found that increased load levels lead to increased proximal translation, which is a description of the knee joint space,[26] and we also observed narrowed knee joint space during fast walking. The narrowness of the knee joint space during fast walking may be due to the protective tension of the affected limb muscles of the patient under high load. A cross-sectional study showed a significant association between joint space narrowing and knee pain, which may cause adverse effects on the knee joint.[27] However, more relevant work should be done to test the possibility.

ACLR knees exhibited extension insufficiency at slow walking, extension insufficiency, and increased posterior tibial translation at normal walking. According to Shabani et al.,[28] ACLR knees still showed a deficit of extension compared with healthy control knees. A meta-analysis statistic found that external knee-extensor moments were smaller in the ACLR group from 10 to 40 months after ACLR.[8] The reconstructed knees had a significantly smaller knee flexion angle and less quadriceps strength than the contralateral knees.[29] Therefore, this deficit of extension in our study could be due to quadriceps weakness. These results were similar to the results during normal and slow walking, in which sagittal gait asymmetry was observed. Indeed, mild atrophy of the quadriceps femoris muscle of ACLR knees was also observed in our study. However, we did not detect a significant extension deficit of ACLR knees at fast walking. The difference in flexion/extension angles was not apparent during fast movement due to adequate muscle mobilization.

Coronal Plane

Previous investigations have reported less coronal plane of knee kinematics in patients with ACLR. These studies suggested that ACLR patients did not exhibit significant gait asymmetry in the coronal plane.[25,30] We only found significant differences in the ROM of adduction and abduction during normal and slow walking speeds. Previous studies also showed sagittal plane biomechanics, rather than the knee adduction moment, appear to be more relevant in ACLR patients.[31]

The Strengths and Limitations of this Study

Our study revealed that the ACLR knees face a more challenging knee kinematics environment during fast walking. Furthermore, this finding may provide a practical method for researchers and clinicians to identify gait asymmetries of ACLR patients in fast walking status. Early identification of gait asymmetry is helpful for doctors to guide the postoperative rehabilitation treatment of ACLR patients. When the patient has asymmetry in fast walking after surgery, the patient should be guided to wear the corresponding brace or muscle patch to protect the ACLR limb, and targeted exercise training should be carried out according to the gait asymmetry dimension to reduce the occurrence of sports injuries. There are some limitations of this study that should be noted. In the present study, more men than women were recruited. This may have introduced a gender bias into the study. However, recruited by gender characteristics is consistent with ACL deficiency prevalence of gender differences.[32]

Conclusion

Overall, we found that more feelings of discomfort and walking kinematic asymmetries of ACLR patients were found in fast walking. It has been reported that such gait asymmetry may increase the risk of KOA or reinjuries.[31,33]

Author Contributions

Huahao Lai: Writing, methodology. Xiaoling Chen: Writing, investigation. Wenhan Huang: Investigation. Zhenyan Xie: Investigation. Yuan Yan: Investigation. Ming Kang: Investigation. Yu Zhang: Methodology. Jiehua Huang: Methodology. Xiaolong Zeng: Conceptualization, experimental design, statistical analysis.

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Ethics Statement

The study was approved by the independent ethics committee (IEC No. 2019-226H-1) of Guangdong Provincial People's Hospital. Informed consent was obtained from each participant. The participants were recruited from January 2020 to July 2022.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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