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# Gait analysis of national athletes after anterior cruciate ligament reconstruction following three stages of rehabilitation program: Symmetrical perspective

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ABSTRACT

This study aimed to objectively evaluate changes in gait kinematics, kinetics and symmetry among anterior cruciate ligament (ACL) reconstructed athletes during rehabilitation. Twenty-two national athletes with ACL reconstruction and 15 healthy athletes were recruited for the study. Gait data were collected between the weeks 4–5, 8–9, and 12–13 post-operation using three-dimensional motion analysis system. Five separate components, including knee range of motion (ROM), vertical ground reaction force (VGRF), their symmetries and knee extension moment were evaluated. One way and repeated measure multivariate analysis of variance (MANOVA) were used to analyze the knee ROMs. The VGRF and extension moment were tested using repeated measure ANOVA and independent sample *t*-test. Findings indicated significant alterations in all measured components between patients' Test 1 and control group. Repeated measure analysis revealed significant effect for time in components of knee angular and VGRF ($P < 0.001$), their symmetry index ($P = 0.03$) and knee extension moment ($P = 0.045$). Univariate outcomes demonstrated significant improvement in the injured limb's stance and swing ($P < 0.001$), and single-stance ($P = 0.005$) ROMs over time. Symmetry indexes of stance and swing ROM, and VGRF reduced significantly by 26.3% ($P = 0.001$), 17.9% ($P < 0.001$), and 31.9% ($P = 0.03$) respectively. After three months, symmetry indexes of single-stance ROM and VGRF along with operated knee extension moment were the only variables which showed significant differences with control group. The rehabilitation program allowed national athletes to restore the operated limb's gait parameters except knee extension moment by 12–13 weeks post-reconstruction; however, more time is required to normalize single-stance ROM and VGRF asymmetries.



## 1. Introduction

Anterior cruciate ligament (ACL) injuries are reported as the most prevalent knee injury sustained due to involvement in sport activities [1]. ACL has a significant role in knee joint biomechanics as it limits anterior tibial translation in respect to the femur, when the knee is moderately flexed [2]. After ACL tear the subjects would experience knee joint effusion, restricted range of motion (ROM), gait abnormalities, and reduced quadriceps strength [3–5]. Decreased knee extension moments have been found to be associated with quadriceps weakness [6–8] termed the "Quad-Avoidance" gait [9], resulting in reduced functional performance [10].

Surgical reconstruction is the main treatment offered following ACL rupture [11,12] especially for athletes who are involved in high level sport activities [12] with the hope of reducing persistent knee instability and re-establishing mechanical properties of the knee. Alteration in lower extremity joint kinematics and kinetics has been reported following ACL reconstruction during walking. Decreased knee ROM during the stance and swing phases of walking and deteriorated strength of the knee joint flexor and extensor muscles have also been reported in ACL-reconstructed patients within the first year after surgery [13–20].

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Rehabilitation of the reconstructed knee is common process following surgery with the aim of restoring knee stability and range of motion. Progression to sport-specific exercises of rehabilitation protocol is highly dependent on outcome of the first three months of rehabilitation program in restoring the altered gait parameters as a crucial clinical milestone. However, lack of objective measurements in commonly used clinical functional tests lead to uncertain evaluation of ACL-reconstructed subjects with reference to whether they can recover the pre-injury gait characteristics within three months post-surgery and proceed to more complicated activities. Additionally, gait symmetrical changes of national athletes are less clear in a short period of time post ACL reconstruction following rehabilitation. So, gait analysis within the first three months of rehabilitation may provide quantitative assessment tool for rehabilitation specialist to modify phases of rehabilitation program based on individual's progression. In other words, quantifying symmetrical changes in knee biomechanics of ACL-reconstructed athletes within 12 weeks post-reconstruction may help clinicians in tracking recovery following surgery and enable the therapist to proactively tailor phases of rehabilitation protocol in accordance to the athletes' improvements reflected in the studied gait parameters.

This study aimed to quantify changes in knee angular and ground reaction force variables and their symmetries along with alteration in knee extension moment among national ACL-reconstructed athletes early after surgery and at two follow-up tests. We hypothesized that the knee ROMs, ground reaction force, their symmetries and knee extensor moment would improve significantly over time. It was also hypothesized that there would be no significant differences in the variables between the patients and healthy subjects by three months post-operation and patients would exhibit better movement pattern during whole gait cycle.

## 2. Methods

### 2.1. Subjects

This study was carried out with 22 ACL-reconstructed patients and a control group of 15 healthy subjects, who were national athletes, represented country in competition at the international level individually or for the team events. The control group consisted of 9 males and 6 females with no history of lower limb injuries or surgery that may influence walking. The mean age was $21.5 \pm 1.0$ years, height $1.66 \pm 0.07$ m, and body mass $61.7 \pm 11.3$ kg. The ACL-reconstructed group consisted of 13 males and 9 females who were involved in the following sports until the injury occurred: swimming, $N = 1$; hockey, $N = 2$; basketball, $N = 2$; taekwondo, $N = 2$; judo, $N = 1$; football, $N = 8$; futsal, $N = 3$; badminton, $N = 1$; karate, $N = 1$; athletic, $N = 1$. Type of their reconstruction was hamstring graft done within the first three months after injury. Subjects were omitted if they had previous injury in the reconstructed or contralateral knee. The mean age was $23.6 \pm 5.4$ years, height $1.69 \pm 0.09$ m, and body mass $66.0 \pm 13.8$ kg.

All patients completed an identical rehabilitation protocol which was specifically developed by National Sports Institute (ISN) rehabilitation center for national athletes. The one-year rehabilitation protocol was divided into nine post-operative phases. The early five phases was covered with general exercises for all subjects in the first three months without considering type of sports, while the next phases became more specific based on athletes' demands and the sports they were involved in. Phase 1 was 1–2 weeks; phase 2, 3–4 weeks; phase 3, 5–6 weeks; phase 4, 7–8 weeks; and phase 5, 9–12 weeks after reconstruction. Each phase included range of motion, muscle strengthening and stretching, balance training, and aerobic conditioning exercises; modalities such as cryotherapy along with running program for phase 5. Patients started the rehabilitation program within the first three days of reconstruction and none of them encountered complication throughout rehabilitation.

### 2.2. Instrumentation and procedures

ACL-reconstructed subjects were tested in three periods following reconstruction with respect to timelines of rehabilitation program. The initial test was conducted in a session between the 4th and the 5th weeks post-surgery within few days of free walking without having crutches. The second test was performed between the 8th and the 9th weeks and the third one was carried out between the 12th and 13th weeks post reconstruction. Data for healthy subjects were collected in one occasion similar to the patient group. Kinematic data were acquired utilizing an 8-camera three-dimensional (3-D) motion analysis system (CORTEX 2.5, Motion Analysis Corporation, Santa Rosa, USA) sampling at 60 Hz in the direction of the 13 m walkway *x*-axis. Kinetic data were simultaneously collected at 60 Hz with a two-component force plate (AMTI model, $40 \times 60$ cm) embedded within the center of walkway. Totally, 26 half-inch reflective markers with pedestal were attached on the subject's bony landmarks according to Helen Hayes Marker Set [21] to track lower extremity motion. Markers were placed over the medial and lateral femoral condyle, the medial and lateral malleolus; bilaterally over: the posterior calcaneus, the lower thigh and shank below the mid-point, the anterior superior iliac spine, the tip of the acromion process, the lateral epicondyle of the humerus, the point between the 2nd and 3rd metatarsals, and centered between the radius and ulna. Two markers were also located at the sacrum (L5-sacral) and offset. After a static trial the four markers over on medial malleolus and femoral condyles were removed, and subjects were guided to start dynamic trials barefoot along the pathway at their intentional walking speed. Fifteen walking trials were captured bilaterally for every subject in each test.

### 2.3. Data management

Reflective markers were digitized in Cortex software from heel contact of the right foot prior to contacting the first force plate until heel contact of the left foot after contacting the second force plate. A 4th-order Butterworth low-pass filter at cutoff frequency of 6 Hz was used to smooth the signal by removing the noise. Kinematic and kinetic data were calculated with Orthotrak software (6.6, Motion Analysis Corporation, Santa Rosa, USA), a gait analysis program designed to consolidate the 3-D trajectories into kinematic and kinetic format profiles. Walking velocity was also derived from foot contact events. The timing of the kinematic and kinetic profiles was normalized as a percentage of a single complete (100%) gait cycle. Data from the seven best trials in which speed did not vary by $\pm 5\%$ from the average, foot would contact the center of the force plate in a regular stride, and all markers detected by cameras, were averaged for each subject at each test and the means were used for analysis. In the current study, we defined five separate components: (a) sagittal plane knee angles and (b) its symmetry each including three variables; (c) vertical ground reaction force and (d) its symmetry; and (e) knee extension moment. The measured knee angles were stance knee range of motion (ROM), swing knee ROM, and single-stance knee excursion angle. Stance and swing ROMs were defined as the difference between the maximum and minimum knee angles through the stance and swing phases of gait respectively. Single-stance ROM was calculated by the knee angle traversed from the knee maximum flexion after initial contact to knee minimum flexion before heel rise. Vertical ground reaction force (VGRF) was averaged during the stance phase of gait cycle and maximum knee