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Three dimensional knee kinematics and kinetics in ACL-deficient patients with and without medial meniscus posterior horn tear during level walking

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ABSTRACT

Background: The location of the meniscus tear has been reported to influence kinematics in anterior cruciate ligament deficient (ACLD) knees. Medial meniscus posterior horn tear (MMPHT) often occurred after ACL rupture. Whether MMPHT influences the kinematics and kinetics in ACLD knees has not been reported yet.

Research question: The purpose of this study was to investigate three-dimensional (3D) kinematics and kinetics in ACLD knees with and without MMPHT (ACLD + MMPHT, ACLDs) during level walking.

Methods: Fifteen patients with isolated unilateral ACLD, ten with unilateral ACLD + MMPHT, and twenty-two healthy controls underwent gait testing between January 2014 and December 2016. Participant characteristics, as well as gait parameters, were compared among control, ACLDs and ACLD + MMPHT knees.

Results: Compared to the healthy controls, the ACLD knees with and without MMPHT showed significant extension deficiency at maximum extension (flexion: ACLDs: 7.83 ± 4.3°, ACLD + MMPHT: 11.09 ± 7.8°, control: 3.12 ± 4.6°, $p = 0.005$) and lower extension moments during terminal stance phase of gait. Compared with the healthy controls, significantly increased external tibial rotation during pre-swing phase and lower rotation moments at terminal stance phase were observed in the ACLD + MMPHT knees, but not in the ACLDs knees. No significant differences in gait parameters were observed between ACLDs and ACLD + MMPHT knees during stance phase of walking.

Significance: The ACLD knees with medial meniscus posterior horn tear exhibited extension deficiency, increased external tibial rotation, lower extension and internal rotation moments during the terminal stance phase compared to healthy control knees, presenting a combination of “stiffening gait” and “pivot shift gait” pattern. The ACLDs knees only presented extension deficiency and lower extension moments compared with healthy control knees, presenting a “stiffening gait”. Medial meniscus posterior horn tear did not significantly affect gait patterns during stance of walking in ACLD knees.

1. Introduction

Anterior cruciate ligament (ACL) rupture is a very common sports injury and is associated with an incidence of knee osteoarthritis (OA) over 50% at 10 years after rupture [1]. Patients who suffered ACL rupture experienced higher rates of knee OA at much younger ages compared with non-injured individuals [2,3]. One of the main risk factors for post-traumatic knee OA after ACL rupture is considered as abnormal knee motion in ACL deficient (ACLD) subjects, which has been reported in daily activities even during walking [4,5]. Many investigators [4–8] have found abnormal gait pattern in ACLD knees, such as the “stiffening strategy” gait (extension deficiency and lower range of flexion-extension) [9] or “pivot-shift avoidance” gait (extension deficiency and lower internal rotation moments) [7]. However, most of these studies did not take into consideration of meniscus injuries, which are often combined with ACL rupture. Our previous study [10] indicated that the incidence of medial meniscus injury was 31.1% in the acute, 48.2% in sub-chronic and 78.8% in chronic ACLD knees, and was more frequently located at the posterior horn. Recent studies have started to pay attention to the effects of meniscus injuries on kinematics in ACLD knees. Harato et al. [11] found increased rotational motion during walking in ACLD knees with unstable meniscus injury

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Abbreviations: SP, stance phase of gait; TSP, terminal stance phase of gait; PSP, pre-swing phase of gait; MMPHT, Medial meniscus posterior horn tear; ACLD, ACL deficient

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than those without. Zhang et al. [12] compared kinematics in ACLD knees with medial meniscus and/or lateral meniscus tear and indicated that kinematics of ACLD knees were also influenced by the location of the meniscus tear, showing that medial meniscus injury increased anterior-posterior translation of the femur relative to the tibia in ACLD knees. However, the influence of different locations in the medial meniscus on the kinematics in ACLD knees has not been reported by now. Besides, these studies did not report kinetics alterations.

The aim of the study was to investigate three-dimensional (3D) knee kinematics and kinetics in ACLD patients with and without medial meniscus posterior horn (MMPH) tear (MMPHT) compared with healthy controls. Based on previous research, our hypotheses were 1) ACLD knees with and without MMPHT would present extension deficiency at maximum extension, lower extension and rotation moments during terminal stance phase; 2) ACLD + MMPHT knees would show more tibia rotation instability compared with controls and ACLDs knees.

2. Material and methods

2.1. Participants

Patients ordered with ACL reconstruction from January 2014 to December 2016 at our institute were selected for gait analysis. Ethical approval was obtained from the university's ethics committee and written informed consent was attained from all participants. The ACL rupture was diagnosed by clinical examination, MRI and confirmed during ACL reconstruction surgery by arthroscopy. Fifteen patients with unilateral ACL rupture, cartilage defects less than grade II according to the Outerbridge system [13], and no meniscal injuries were included as the ACLDs group. Ten patients with unilateral ACL rupture, cartilage defects less than grade II, and concomitant MMPH tear were included as the ACLD + MMPHT group. Among them, six were longitudinal tear; two were horizontal tear, and two were complex tear. Those who had injuries in the lateral meniscus or medial meniscus anterior horn were excluded in the ACLD + MMPHT group. All the patients were positive on the anterior drawer test in the injured knees. A control group consisting of 22 participants who had no history of musculoskeletal injury or surgery in the lower extremities and exhibited no measurable ligamentous instability on clinical examination were selected (Table 1). Three groups were considered for the analysis: one group of 10 ACLD + MMPHT knees, one group of 15 ACLDs knees, and one group of 22 control knees (one knee randomly selected per control subject) [14]. None of the participants' characteristics were statistically different among groups (Table 1). Side to side difference in anterior knee laxity for ACLDs and ACLD + MMPHT subjects was measured using KT2000 arthrometer (MRS, KneelaxIII, Holland) at 132 N force. Subjective knee function evaluation included International Knee Documentation Committee (IKDC), Lysholm and Tegner (Table 2).

Table 1
Participant characteristics.

Parameters	Control (22 M)	ACLDs (13 M 2 F)	ACLD + MMPHT (10 M)	p
Age (years)	29.95 ± 4.84	26.87 ± 4.65	27.1 ± 3.67	0.09
Height (cm)	171.8 ± 3.68	176.63 ± 10.61	176.7 ± 5.83	0.5
Weight (kg)	71.7 ± 8.69	78.87 ± 16.9	79.75 ± 11.67	0.37
BMI (kg/m^2)	24.35 ± 3.36	25.32 ± 4.39	25.47 ± 2.9	0.26
Time since injury (months)	~ ~	9.47 ± 11.05	16.6 ± 21.1	0.4

M: male, F: female.

Table 2
Anterior knee laxity and subjective knee function evaluation.

Parameters	ACLDs	ACLD + MMPHT	p
KT2000 side-to-side difference (mm)	3.75 ± 1.97	4.15 ± 2.91	0.6989
Tegner	3.85 ± 1.17	4 ± 1.66	0.9094
Lysholm	66.33 ± 12.41	76.56 ± 13.06	0.0985
IKDC	64.32 ± 7.84	65.19 ± 9.14	0.8409

2.2. Data collection procedure

All participants had a set of markers attached to their lower limbs to track segmental motion during walking. Anatomical markers were optimized based on the validated plug-in-gait model and taped to the following anatomical locations: the anterior and posterior superior iliac spine, medial and lateral femoral epicondyles, malleoli, and medial and lateral sides of the calcaneus, the frontal and lateral aspects of the thigh and the shank, posterior part of the calcaneus, heads of the first, second, and fifth metatarsal bones, base of the first metatarsal bone, and navicular, hallux. 3D coordinate data were collected using an 8-camera motion capture system at a sample rate of 100 Hz (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 completed. The average value of five trails was used for analysis. None of the participants complained about pain during walking.

2.3. Data reduction and analysis

The coordinate data were filtered using a low-pass butter-worth filter at 12 Hz. The ground-reaction force data were filtered using a low-pass butter-worth filter at 100 Hz. Time-series data for the kinematics and kinetics variables were calculated using Visual 3D software (C-motion, Germantown, MD). Joint angles were calculated as cardan angles between adjacent local segments with an order of flexion-extension, adduction-abduction, and internal rotation-external rotation. Joint moments were calculated through an inverse dynamics approach and referenced to the proximal segment. In order to compare our results to the external moments in the literature [8,15], we converted the internal moments to external moments in this study. Therefore, the moments were expressed as external moments. Moments were normalized to body weight and height. For each of the kinematic and kinetic component, 101 discrete points corresponding to 0–100% stance phase at 1% interval were normalized using a cubic spline for statistical analysis. Peak and valley angles and range of motion in the gait cycle and peak and valley moments in the stance phase were calculated. The range of motion was defined as the difference between the maximum and minimum knee angles in the gait cycle.

2.4. Evaluations of muscle strength

In addition, the isokinetic muscle torque of knee extensor and flexor were measured using an isokinetic dynamometer (Con-Trex MJ; Germany) at 60 °/s and 180 °/s. The average of the peak isokinetic muscle moments are presented in Table 3.

2.5. Statistical analysis

Measures of the participant characteristics, as well as each discrete