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Gender differences in the restoration of knee joint biomechanics during gait after anterior cruciate ligament reconstruction

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ABSTRACT

Background: The aim of our study was to evaluate the effects of gender on recovery of knee joint biomechanics over the stance phase of gait after reconstruction of the anterior cruciate ligament (ACL).
Methods: Gait parameters and knee joint kinematics and kinetics were compared in 32 patients (16 male and 16 female) who underwent ACL reconstruction for a unilateral ACL deficiency, with comparison to an age-, height-, and weight-matched Control group. Knee flexion, adduction and tibial rotation angles were measured and knee extension and abduction moment was calculated by inverse dynamics methods.
Results: Females exhibited more tibial external rotation, in both the Control and ACL groups ($P < 0.05$), which was not changed after ACL reconstruction. Prior to reconstruction, sagittal plane biomechanics were changed, in both males and females, compared to the Control groups ($P < 0.05$). These abnormal sagittal plane mechanics were recovered at 12 months, but not six months post-reconstruction.
Conclusions: We identified gender-based differences in tibial rotation that influenced the kinematics and kinetics of the knee over the stance phase of gait, both pre-operatively and post-ACL reconstruction. Evaluation of biomechanical effects of ACL injury, before and after reconstruction, should be separately evaluated for females and males.

1. Introduction

The primary role of the anterior cruciate ligament (ACL) is to limit rotational and anteroposterior translation movement of the tibia relative to the femur. Consequently, injuries to the ACL result in rotational and anteroposterior instability [1]. These

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instabilities are reflected in abnormal patterns of knee joint kinematics during gait in patients with ACL deficiencies, which include: lower sagittal plane range of knee motion; lower peak knee joint angles; higher muscle co-contraction [2]; lower sagittal plane knee moments [3]; increased excursion of external rotation and posterior translation of the femur on the tibia [4–8]. Although ACL reconstruction provides successful clinical outcomes, reconstruction cannot restore the normative kinematics of the knee during gait [9,10].

Females have a roughly three-fold higher risk of sustaining an ACL tear in soccer and basketball, compared to males [11]. Moreover, following ACL reconstruction, female athletes are also at a four-fold higher risk of sustaining a second ACL injury and at a six-fold higher risk of sustaining a contralateral injury than male athletes [12]. Females also generally report worse outcome scores than males on the pain and sport/recreation components of the Knee Injury and Osteoarthritis Outcome Score (KOOS) at one year postoperative [13]. Gender-specific differences in knee-joint kinematics during gait could further influence the recovery of joint kinematics after ACL reconstruction. During gait, uninjured females exhibit lower peak knee flexion angles and higher peak abduction angles than males [14,15]. Uninjured females also exhibit a greater total range of internal–external rotation of the tibia during both non-weight bearing and 40% weight bearing activities [16]. Although gender-specific differences in the kinematics of the knee joint during gait have been identified, studies which have evaluated recovery of joint kinematics after ACL reconstruction in males and females have not considered these gender-specific differences in their evaluation. As an example, Di Stasi et al. compared the sagittal plane mechanics of the knee during gait between males and females, prior to ACL reconstruction and up to six months after surgery, reporting a comparable decrease in knee range of motion, relative to the uninvolved limb, before ACL reconstruction in both genders [17]. However, without direct comparison of the three-dimensional (3D) kinematics of uninjured controls, it is unclear whether the natural pattern of knee joint kinematics during gait was restored to the same extent in males and females after ACL reconstruction.

Gender-based differences in knee joint kinematics during gait between males and females could explain, in part, the higher prevalence of secondary osteoarthritis (OA) after ACL injury and reconstruction. Specifically, females are at a higher risk for knee OA after ACL reconstruction than males [18,19], while males have a relatively higher risk of developing patellofemoral osteophytes [20]. Gait analysis provides a sensitive tool for early identification of changes in knee joint kinematics following ACL injury and reconstruction, which may increase the likelihood of developing of secondary OA [21–23]. Therefore, the purpose of our study was to evaluate the change in knee joint kinematics and kinetics during gait, before and after ACL reconstruction, and to compare the recovery of knee joint kinematics and kinematics between males and females. Our a priori hypothesis stated that there would be gender-specific differences in knee joint biomechanics during gait, both in ACL-injury patients and uninjured controls, and that abnormal kinematics related to ACL reconstruction would be normalized at one year post-reconstruction in both males and females.

2. Material and methods

2.1. Study participants

Prospective participants included both male and female patients who were evaluated at our clinic for a unilateral ACL injury, between April 2013 and December 2014. Prospective participants were screened according to the following inclusion criteria: age <50 years; body mass index (BMI) <35 kg/m^2; no evidence of knee OA on plain radiographs; no medical documentation or radiographic evidence of cartilage injury of the tibiofemoral and patellofemoral joints; absence of self-reported knee pain or apprehension with gait; absence of other lower limb injuries or functional limitations; and absence of neurological diseases. Following screening, our study group was comprised of 32 patients (16 males forming the ACL-M group and 16 females forming the ACL-F group). For comparison, 32 healthy participants, with no history of orthopedic injury or neurological disease, matched for age, height, and weight, were recruited from the community, 16 males forming the Control-M group and 16 females forming the Control-F group.

Our study was approved by the Epidemiologic Study Ethics Review Board of Hiroshima University (approval number: Epd-458-1), and our methods conformed to the Declaration of Helsinki. All participants provided informed consent.

2.2. Operative technique

All ACL reconstructions or augmentations were performed by experienced surgeons using previously reported surgical procedures [24]. ACL augmentation was performed for cases with an ACL remnant >33% of the original ACL, which provided a ligamentous bridge between the tibia and the femur. Augmentation was performed using a quadruple semitendinosus tendon graft. In the absence of sufficient ACL remnant, with ACL reconstruction performed using either a single-bundle or double-bundle technique, depending on the diameter of the quadrupled semitendinosus tendon graft. Details of the reconstruction and augmentation techniques are available in previously published studies [24–28].

2.3. Clinical assessment

Gait analysis and clinical assessment of knee muscle strength and anterior translation of the tibia (ATT) relative to the femur were performed before surgery (pre-operative), and at six and 12 months after ACL augmentation or reconstruction (six months postoperative; 12 months postoperative).

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