The Knee xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

The Knee

Validation of varus stress radiographs for anterior cruciate ligament and posterolateral corner knee injuries: A biomechanical study☆

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ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form 30 June 2016
Accepted 3 July 2016
Available online xxxx

Keywords:
Anterior cruciate ligament (ACL)
Posterolateral corner (PLC)
Varus instability
Stress radiographs

ABSTRACT

Purpose: The purpose of this study was to determine the effect of isolated anterior cruciate ligament (ACL) insufficiency on the radiographic varus stress test, and to provide reference data for the increase in lateral compartment opening under varus stress for a combined ACL and PLC injury.

Methods: Ten cadaveric lower extremities were fixed to a jig in 20° of knee flexion. Twelve Newton-meter (Nm) and clinician-applied varus loads were tested, first with intact knee ligaments, followed by sequential sectioning of the ACL, fibular collateral ligament (FCL), popliteus tendon and the popliteofibular ligament (PFL). Lateral compartment opening was measured after each sequential sectioning.

Results: Maximum increase in lateral compartment opening for an isolated ACL deficient knee was 1.06 mm with mean increase of 0.52 mm ($p = 0.021$) for the clinician-applied load. Mean increase in lateral compartment opening in an ACL and FCL deficient knee compared to the intact knee was 1.48 mm ($p < 0.005$) and 1.99 mm ($p < 0.005$) for the 12-Nm and clinician-applied loads, respectively, increasing to 1.94 mm ($p < 0.005$) and 2.68 mm ($p < 0.005$) with sectioning of the ACL and all PLC structures.

Conclusions: Anterior cruciate ligament deficiency contributes to lateral compartment opening on varus stress radiographs though not sufficiently to confound previously established standards for lateral ligament knee injuries. We did not demonstrate the same magnitude of lateral compartment opening with sectioning of the PLC structures as previously reported, questioning the reproducibility of varus stress radiographic testing among institutions. Clinicians are cautioned against making surgical decisions based solely on current standards for radiographic stress examinations.

Published by Elsevier B.V.

1. Introduction

The contribution of posterior lateral corner (PLC) structures to varus and rotational stability of the knee is well documented [1–3]. It is also recognized that a PLC injury results in increased varus force on the anterior cruciate ligament (ACL) in both intact and reconstructed states, contribute to ACL reconstruction failure [3].

To guide surgical decision-making, cadaveric studies by LaPrade et al. developed objective radiographic guidelines quantifying lateral compartment opening in knees with PLC injuries [2]. Based on this literature, a radiographic side-to-side difference of lateral knee compartment opening with clinician-applied varus stress of only 2.7 mm is indicative of an isolated fibular collateral ligament (FCL) injury of the knee. A difference of 4.0 mm is indicative of a complete PLC injury. Additionally, lateral compartment opening further increases 2.6 mm with clinician-applied varus stress when the anterior cruciate ligament (ACL) is incompetent in addition to a complete PLC injury [2].

Current studies insufficiently describe an isolated ACL injury's objective radiographic contribution to varus instability of the knee [2, 4]. If the ACL significantly contributes to varus instability, an isolated ACL injury may lead to false positives on varus stress tests, potentially resulting in unnecessary PLC ligament reconstructions. Following the publication of these radiographic guidelines there was an increase in PLC reconstructions at our institution. We chose our order of sectioning based on a clinical concern that the ACL contributes significantly to varus stability resulting in false positives on varus stress radiographs after isolated ACL injury [5].

The purpose of this study was to determine the effect of isolated ACL insufficiency on the radiographic varus stress test, and to provide reference data for the measured increase in lateral compartment

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http://dx.doi.org/10.1016/j.knee.2016.07.001
0968-0160/Published by Elsevier B.V.

opening under varus stress of a PLC injury with an associated ACL injury, hypothesizing that that isolated ACL insufficiency increases lateral compartment opening sufficiently to falsely indicate a lateral sided knee ligament injury on varus stress radiographs.

2. Materials and methods

The methodology of this study conformed to the previously published study design of LaPrade et al. and was approved by our Institutional Review Board [2].

2.1. Specimen preparation

Ten fresh-frozen non-paired cadaveric lower extremities (eight from male and two from female donors) with no history of prior knee surgery, no evidence of ligament injury on clinical examination and no evidence of osteoarthritis on radiographic examination were utilized for this study. No specimens were excluded from the study. Confirmation of cruciate ligament integrity was performed during limb preparation. Keeping with previous study design, non-paired knees were utilized because side-to-side variability between knees is minimal [2,6,7]. Lower extremities were sectioned mid-thigh and left intact distally. The specimens remained frozen until the night before testing and were then allowed to thaw at room temperature. All soft tissues were removed 15 cm proximal to the knee joint, completely exposing the proximal femur, and superficial soft tissue on the lateral aspect of the knee was removed, leaving the underlying fascia intact. A fascial-splitting posterolateral approach as described by Terry and LaPrade provided access to the posterolateral structures of the knee [8]. The FCL, popliteus tendon and PFL were identified and tagged for later sectioning. A mini medial parapatellar arthrotomy was used to isolate the ACL and to confirm its integrity. All access incisions were closed prior to testing.

2.2. Biomechanical testing

A custom built radiolucent jig with a 20-degree angle at the knee articulation was utilized for testing. Lower extremities were secured by their femurs through two tunnels separated by 5 cm with rigid external fixation pins while placing the joint line at the apex of the jig (Figure 1A and B). A 20-degree knee flexion angle was utilized based on the current International Knee Documentation Committee (IKDC) reporting guidelines for lateral compartment opening [9]. A radiopaque ruler placed under the proximal part of the tibia at the joint line was utilized as a magnification correction guide. The jig was firmly attached to two metal tables with clamps leaving space for a fluoroscopy machine (Siemens Arcadis Varic, Model #08080017, 1024 × 1024 pixels; Erlangen, Germany), which was angled perpendicular to the joint line. Appropriate anterior–posterior fluoroscopic images were obtained, ensuring symmetrical appearances of the femoral and tibial condyles with the medial one half of the fibular head superimposed by the tibia. Two loads were applied to each of the five testing conditions. Each specimen was tested in the intact state and after sequential sectioning of the ACL followed by the individual components of the posterolateral corner of the knee (FCL, popliteus tendon and PFL).

Loading conditions mirrored those of the study by LaPrade et al. [2]. First, a standard 12 Newton-meter (Nm) varus moment was applied with a S-type Load Cell (Interface, Scottsdale, Arizona) perpendicular to the tibia, 25 cm distal to the joint line. The second load was a manual, clinician-applied varus stress, with one hand at the medial femoral condyle and other hand just proximal to the lateral malleolus. This was performed by an orthopedic sports medicine faculty member to reproduce varus stress testing as performed in a clinic setting. Radio-opaque numbers were used for labeling. Each of 5 testing conditions was repeated 3 times for both loads with fluoroscopic images taken each time for a total of thirty radiographic images per knee (Figure 2).

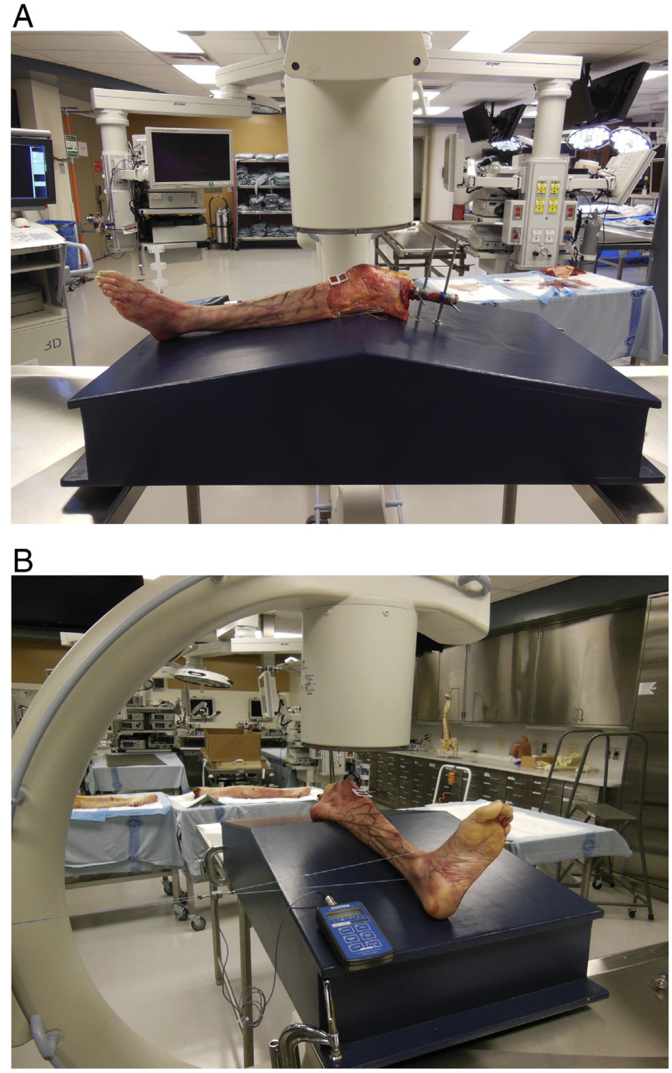

Figure 1. A and B: Radiolucent varus stress testing setup secured between two tables allowing positioning of a fluoroscopy machine. A left lower extremity has been stripped of proximal soft tissues and the femur secured to the jig with the tibia remaining free to move in all planes. The force meter device is present on the table.

2.3. Data analysis

Images were stored and accessed through OsiriX (Geneva, Switzerland), an open-source picture archiving and communication system (PACS). Lateral compartment opening was determined by measuring, in pixels, the shortest distance from the subchondral osseous surface of the most distal part of the lateral femoral condyle to the associated tibial plateau, irrespective of articular cartilage thickness [2]. A reference ratio using the radio-opaque ruler permitted conversion to millimeters with values recorded to the 100th decimal place.

2.4. Intraobserver repeatability and interobserver reproducibility

As described above, three examiners measured the amount of lateral compartment gapping on the set of 300 radiographs on two separate occasions to determine intraobserver repeatability. Interobserver reliability was calculated between the three examiners including a faculty musculoskeletal radiologist, an orthopedic sports medicine faculty

Please cite this article as: McDonald LS, et al, Validation of varus stress radiographs for anterior cruciate ligament and posterolateral corner knee injuries: A biomechanical stu..., Knee (2016), http://dx.doi.org/10.1016/j.knee.2016.07.001