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Effect of tibial plateau leveling osteotomy on patellofemoral alignment: A study using canine cadavers

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ABSTRACT

Tibial plateau leveling osteotomy (TPLO) has been shown to alter the biomechanics of the femorotibial joint; however, the effect of TPLO on patellofemoral (PF) joint alignment remains unknown. The purpose of this study was to evaluate PF joint kinematics before and after cranial cruciate ligament (CrCL) transection and following TPLO in a cadaveric stifle model with set patellar tendon load, tested in passive range of motion at 90°, 105°, 120°, 135° and 150° of flexion. The PF joint poses were measured on mediolateral projection radiographs using a two-dimensional computer digitization technique. In the subluxated CrCL-deficient stifle, the PF joint had an increase in patellar tilt angle. In the reduced CrCL-deficient stifle treated by TPLO, there was distal and caudal displacement of the patella relative to the femur and a decreased patellar tilt angle. The estimated patellar moment arm following TPLO was not different from the control stifle. On the basis of these results, TPLO alters PF joint kinematics. The changes in PF joint alignment induced by TPLO may be a biomechanical factor predisposing to patellar tendonitis following TPLO.

Introduction

The stifle is a complex, diarthrodial, synovial joint that allows motion in three planes (Korvick et al., 1994). The primary function of the femorotibial (FT) joint is to carry the axial load across the stifle. The patellofemoral (PF) joint has the important function of increasing the mechanical advantage of the extensor mechanism (Kaufer, 1971). The patella acts as a pulley mechanism to improve the efficiency of stifle extension; it increases the moment arm of the quadriceps mechanism by lengthening the distance between the quadriceps muscle force and the center of flexion–extension rotation of the stifle (Kaufer, 1971). The considerable retropatellar force developed during contraction of the extensor mechanism also contributes to both FT and PF joint stability (Kaufer, 1971). Although stifle biomechanics has been extensively researched in dogs, few studies have focused on PF joint kinematics (Guerrero et al., 2011). Cranial cruciate ligament (CrCL) transection alters both the kinematics and contact mechanics of PF and FT joints (Guerrero et al., 2011). These changes may predispose to PF joint osteoarthritis in dogs with CrCL insufficiency.

Alterations in kinematics and contact mechanics of the FT joint have been reported in CrCL-deficient stifles treated with tibial plateau leveling osteotomy (TPLO) (Kim et al., 2009, 2010). Using pressure sensors placed under the medial and lateral meniscus, contact pressures in the medial and lateral compartment were altered following TPLO, raising the concern that abnormal cartilage loading may contribute to progression of osteoarthritis (Kim et al., 2009). Despite the extensive body of research on the biomechanics of TPLO, only the FT joint has been taken into consideration; the effect of TPLO on PF joint kinematics has not been evaluated. It is conceivable that the geometrical alteration of the stifle following TPLO may also affect PF joint biomechanics.

Patellar tendonitis is one of the most common complications after TPLO and may cause lameness within the first 2 months after surgery (Carey et al., 2005; Mattern et al., 2006). Histopathological changes in the tendon are non-inflammatory and are similar to those identified in human beings with patellar tendonitis; hence, excessive loading of patellar tendon secondary to altered biomechanics after TPLO has been implicated as a possible underlying cause (Carey et al., 2005). Ultrasonographic evaluation of patellar tendonitis following TPLO has shown that thickness and area measurements of the patellar tendon increase when the postoperative tibial plateau angle is <6°, suggesting that tibial plateau rotation may contribute to patellar tendonitis following TPLO (Mattern et al., 2006). Other biomechanical parameters, such as alteration of patellar tilt or patellar moment arm, may be important factors in the development of patellar tendonitis, as reported in human patients (Tyler et al., 2002).

The aim of the present study was to evaluate PF joint kinematics before and after CrCL transection, and following TPLO, in a cadaveric stifle model. We hypothesized that both CrCL transection and

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TPLO would alter PF joint kinematics. We also hypothesized that the patellar tendon moment arm following TPLO would be different from the normal stifle. To test our hypotheses, we measured PF joint poses in normal cadaveric stifles, following CrCL transection and following TPLO on mediolateral radiographs of the stifle using a custom computer digitization technique.

Materials and methods

Specimens

The study was approved by the Institutional Animal Care and Use Committee, College of Veterinary Medicine, University of Florida (approval number 200802287, date of approval 2 November 2009). Seven pelvic limbs were collected from four adult mixed-breed dogs that were euthanased for reasons unrelated to the study. The specimens were wrapped in saline (0.9% NaCl)-soaked towels and stored at −20 °C, then thawed to room temperature for testing. All musculature except for the gastrocnemius muscle was removed from the limbs. The joint capsule and ligaments around the stifle joint were preserved. Tissues were kept moist throughout the preparation and data collection periods by spraying the specimens with saline solution.

Joint preparation

The limbs were prepared according to a previously described cadaver model (Shelburne et al., 2011). A double loop of size-zero polydioxanone (PDS, Ethicon) was placed in the quadriceps muscle, immediately proximal to the patella, and a 3.5 mm cortical screw (Synthes) was placed cranially and proximally on the femur. A tension spring (Hillman) was used to connect the screw to the patellar suture, mimicking the quadriceps mechanism and maintaining a constant tension on the patellar tendon over a full range of motion. Three 1 mm diameter holes were drilled in the center of the medial cortex along the length of the tibial and femoral diaphyses, where the proximal and distal holes were positioned at one- and two-thirds of the length of the tibia and femur. These holes were used to define the longitudinal axes of the bones during testing and radiography for measuring the stifle joint flexion angle.

Prior to radiography, radial osteotomy of the proximal tibia was performed with a 24 mm biradial saw blade, as described previously (Slocum and Slocum, 1993). A 3.5 mm cortical screw was placed across the osteotomy site in lag fashion from the tibial tuberosity, with the tibial plateau in a sham position (no tibial plateau rotation). A 3.2 mm negative profile end-threaded pin (Medium SCAT pin, Imex Veterinary) was placed in the craniomedial aspect of the tibial plateau segment to facilitate plateau rotation during radiography. With the osteotomy in the original position (no tibial plateau rotation), each specimen was placed in a custom radiolucent frame by use of two 4.0 mm threaded bolts placed from medial-to-lateral in the tibial diaphysis and one 4.0 mm threaded bolt placed in a similar fashion in the proximal femoral diaphysis. The frame was designed to maintain the limb in the same position when obtaining radiographs over a range of motion from 150° to 90°, in 15° increments. The frame was also used to control alignment of the FT joint in reduction or cranial tibial subluxation following CrCL transection (Fig. 1).

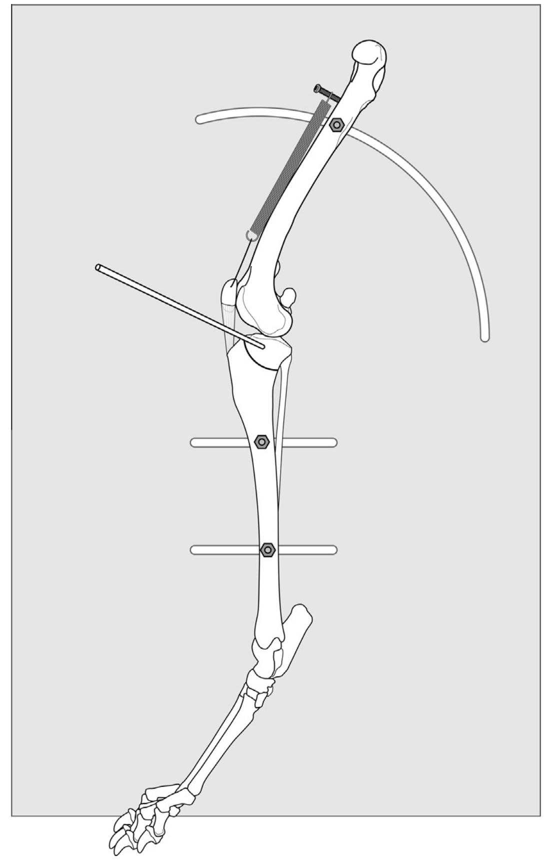

Fig. 1. Diagram of the specimen set up for radiography. A tension spring was used to connect a cortical screw placed proximocranially on the femur to a loop of suture placed in the quadriceps muscle, mimicking the quadriceps mechanism and maintaining a constant tension on the patellar tendon. Radial osteotomy of the proximal tibia was performed and a negative profile end-threaded pin was placed in the tibial plateau segment to facilitate plateau rotation during radiography. A custom radiolucent frame was used to maintain the limb in the same position when obtaining radiographs over a range of motion, as well as to control alignment of the femorotibial joint in reduction or cranial tibial subluxation following cranial cruciate ligament transection.

Radiography

The radiographic beam was centered over the stifle joint and collimated to include the entire tibia and femur. With the aid of a computed radiography system (Kodak Directview 5.2, Carestream Health), a series of mediolateral projection radiographs of the stifle with an intact CrCL was obtained at flexion angles of 150°, 135°, 120°, 105° and 90°. Images were stored in standard imaging format (DICOM, NEMA). With each specimen mounted to the radiolucent frame, a plastic goniometer was used to measure stifle joint flexion angles by aligning each arm with the marks on the tibial and femoral diaphyses. Stifle joint flexion angle was measured on each radiograph to ensure the acquired image was within 5° of the targeted angle. Tibial plateau angle was measured by use of methods described elsewhere (Reif et al., 2004).

Keeping the stifle anchored to the frame, the CrCL was transected via a craniomedial arthrotomy site and radiographs at flexion angles of 150°, 135°, 120°, 105° and 90° were obtained after inducing cranial tibial subluxation. To induce stifle joint subluxation, the tibia was displaced cranially relative to the femur with the aid of the radiolucent frame, maintaining the hock in flexion (tibial compression test). This manipulation induced the maximal amount of cranial tibial subluxation possible. Radiographs were then performed with the tibial plateau segment rotated caudally to produce a tibial plateau angle of 6°; the rotated plateau segment was stabilized with a 1.6 mm Kirschner wire. Before taking radiographs of the CrCL-deficient stifle treated by TPLO, the tibia was reduced manually with the jig to completely eliminate subluxation. Hence, each stifle joint was radiographed through a full range of motion before and after CrCL transection, and following TPLO.

Radiographic analysis

Patellofemoral joint kinematics were evaluated with a computer digitization technique based on a custom written computer program using Matlab (MathWorks), described elsewhere (Guerrero et al., 2011). The location and orientation of the patella were measured according to a femur fixed reference frame. Bony landmarks were repeatedly identified in each radiographic image to establish the cranio-caudal axis, proximo-distal axis and coordinate reference point of the femur and patella according to previously published methods (Kurosawa et al., 1985; Abel et al., 2003; Mostafa et al., 2009). To calculate the femur reference point, the best-fit circle centers at the posterior condyle were averaged, and the center was used as center of rotation of the stifle (O'Brien et al., 2009). Estimated patellar tendon moment arm, measured in millimeters, was defined as the perpendicular distance from the femur reference point to the line of action of the patellar tendon (Fig. 2A). Patellar tilt, measured in degrees, was defined as the angle between the long axis of the distal femur and patella longitudinal axis (Fig. 2B).

Statistical analysis

The patellar tilt angle, cranio-caudal and proximo-distal patellar translation and estimated patellar tendon moment arm as a function of stifle flexion angle were compared between the normal CrCL (control), the CrCL-deficient and the TPLO-treated conditions. All changes in position of the patella were measured as displacement from the neutral position. Separate two-way analysis of variance (ANOVA) repeated measures were run for comparisons using statistical software (Prism, GraphPad Software). The independent variables were flexion angle and stifle status. A P value of 0.05 was used to determine significance.