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Effects of hip joint transverse plane range of motion with a modeled effusion and capsular tear: A cadaveric study

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ABSTRACT

Background: Multiple factors contribute to range of motion of the hip joint in the transverse plane: bony anatomy, hip capsule, corresponding ligaments, articular labrum, ligamentum teres, and negative intra-articular pressure. We hypothesized that violation of the negative pressure of the hip and simulation of an effusion would increase range of motion in the transverse plane in a cadaver model.
Methods: Ten hip specimens were obtained and dissected with the femur and iliac wing mounted in a custom joint-testing rig in neutral position. Specimens were tested at 0 and at 90° of flexion with 1.5 Nm internal and external rotational torque. Three conditions were assessed: (1) intact specimen, (2) an effusion modeled by a 10 ml saline infusion, and (3) a capsular tear.
Findings: The modeled effusion decreased rotational range of motion limits in both 0 and 90° of flexion, with a greater effect on the specimens at 0° flexion in external rotation with 4.1° less external rotation ($p = 0.009$). A modeled capsular tear increased rotational motion limits in 0° of flexion in both internal and external rotation and in 90° flexion in internal rotation only ($p < 0.025$).
Interpretation: An effusion may decrease the rotation of the hip, and a capsular tear may increase its rotation. This should be considered in hips with traumatic capsular tears or arthroscopic portals.

1. Introduction

The osseous structures about the hip impart a significant amount of innate stability to the hip joint; the spherical femoral head is normally well constrained within the concave acetabulum. However, the contributions of the surrounding soft-tissue structures cannot be over-emphasized. The acetabulum is deepened by the surrounding fibrocartilaginous labrum, which not only imparts mechanical stability to the joint but also forms a seal surrounding the femoral head that controls the egress of joint fluid from the peripheral compartment. This unique suction-effect function of the labrum stabilizes the joint by resisting distraction (Crawford et al., 2007; Dwyer et al., 2014; Polkowski and Clohisy, 2010; Shu and Safrab, 2011). The hip capsule, with its internal and external fibers, provides static stability by passively restraining hip motion (Hewitt et al., 2002). The internal zona orbicularis acts as a “locking ring” around the femoral neck to prevent distraction (Ito et al., 2009) and is thought to contribute to the “screw-home” mechanism of capsular tightening that provides stability in terminal extension (Torry et al., 2006; van Arkel et al., 2015). The external ligaments, including the iliofemoral, pubofemoral, and ischiofemoral ligaments, have been shown to restrain external rotation, external rotation in extension, and internal rotation, respectively (Bayne et al., 2014; Bedi et al., 2011; Martin et al., 2008; Myers et al., 2011; van Arkel et al., 2015). In addition, the muscles surrounding the hip, including the iliocapsularis, gluteal, and iliopsoas muscles, among others, provide dynamic stability with contraction (Bedi et al., 2011; Torry et al., 2006).

Disruption of any of these can disrupt the balance among the many structures that contribute to stability and lead to pain, further damage to surrounding structures, recurrent instability, and possibly further destruction of the hip joint leading to early degeneration. Traumatic dislocation can lead to bony, capsular, or labral disruption. Moorman et al. (2003) described a classic triad of hemarthrosis, posterior acetabular lip fracture or labral tear, and iliofemoral ligament disruption in a series of dislocations in American football players demonstrating the importance of these structures to hip stability. Atraumatic instability from conditions of generalized laxity such as Marfan and Ehlers-Danlos syndromes, as well as microtrauma with repetitive hip twisting in certain sports, can lead to attenuation of the anterior capsular ligaments, labral injury, chondral injury, and even recurrent microinstability (Bedi et al., 2011; Philippon and Schenker, 2005; Shindle et al., 2006; Shu and Safrab, 2011; Torry et al., 2006).

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The number of hip arthroscopies performed has increased dramatically in recent years (Montgomery et al., 2013). Many of these procedures involve the use of small to wide capsulotomies and capsulectomies to treat complex intra-articular pathology. Disruption of the capsule with these approaches has been implicated in postoperative instability leading to joint destruction and even dislocation after hip arthroscopy (Matsuda, 2009; Mei-Dan et al., 2012). Hip arthroscopy was cited as the cause of the development of end-stage arthritis requiring total hip replacement in one patient (Mei-Dan et al., 2012). These adverse events after hip arthroscopic have generated discussion about the utility of capsular closure in preventing instability (Bedi et al., 2011; Kelly et al., 2005). To determine the effect of multiple portals piercing the capsule during hip arthroscopy or the residual effects of an effusion on the hip joint and transverse plane limits of motion, we designed a cadaver biomechanical study. We hypothesized that venting the capsule with a small capsular incision or insufflation of the joint with normal saline to simulate a joint effusion would disrupt the negative intra-articular pressure and increase the range of motion limits in the transverse plane in both flexion and extension thereby possibly leading to possible instability with extremes of motion.

2. Materials and methods

2.1. Specimen preparation

After IRB approval was obtained for the study, five pairs of cadaver hip specimens (donor ages ranging from 28 to 82 years) were obtained from local and statewide sources. The specimens were bisected to generate two hip specimens per cadaver for a total of five left and five right hemi-pelvises. Each femur was transected to 215 mm inferior to the anterior acetabular rim. Specimens were stripped of all surrounding skin and soft tissue including muscle, down to the capsular layer, which was meticulously retained in its entirety to maintain integrity of the surrounding ligamentous joint capsule. Next, the femur was potted in a coupling to mount into the joint testing jig (Mihalko and Whiteside, 2004) and the iliac wing was resected from just above the anterior superior iliac spine (ASIS) through the greater sciatic notch and then potted in a testing jig coupling using urethane epoxy. Each specimen was then mounted with the ASIS coupling locked in place and the femur fixed in 5° of valgus to simulate neutral position in the coronal plane. The coordinates of the testing machine were set up according to Joint Coordinate System (JCS) guidelines and previously reported hip testing using this joint testing machine (Mihalko and Whiteside, 2004; Wu et al., 2002).

2.2. Biomechanical testing

Specimens were tested with the femur at 0° of flexion (Fig. 1) and at 90° of flexion (Fig. 2). To maintain joint contact during testing, a 30 N vertical force was placed on the femur. Next, a 1.5 Nm internal and external rotational torque was applied about the femoral axis at 0 and 90° of flexion while the pelvis was fixed. This torque was applied three times at each position to condition the specimen tissue, and the third iteration was used as the normal reference test. Changes in the deflection curve from neutral rotation in both 0 and 90° of flexion were then recorded for both internal and external rotation. After all specimens were tested, they were injected with 10 cm^3 of saline into the joint capsule to simulate a traumatic effusion and all tests were repeated and recorded. This was followed by a stab incision with a #11 scalpel along the superior capsule at the 12 o'clock position parallel to the acetabular labrum to vent the capsule and completely release and drain the saline. This was done to simulate the position of a commonly used capsulotomy during hip arthroscopy. Finally, each alteration was subjected to the same loads and positions as the intact hip specimen. The deflection in degrees at 1.5 Nm in each direction as referenced from the normal neutral position was then compared in the transverse plane to determine the laxity change of the joint capsule in 0 and 90° of flexion. Repeatability testing has shown to be within 0.5° for the testing platform.

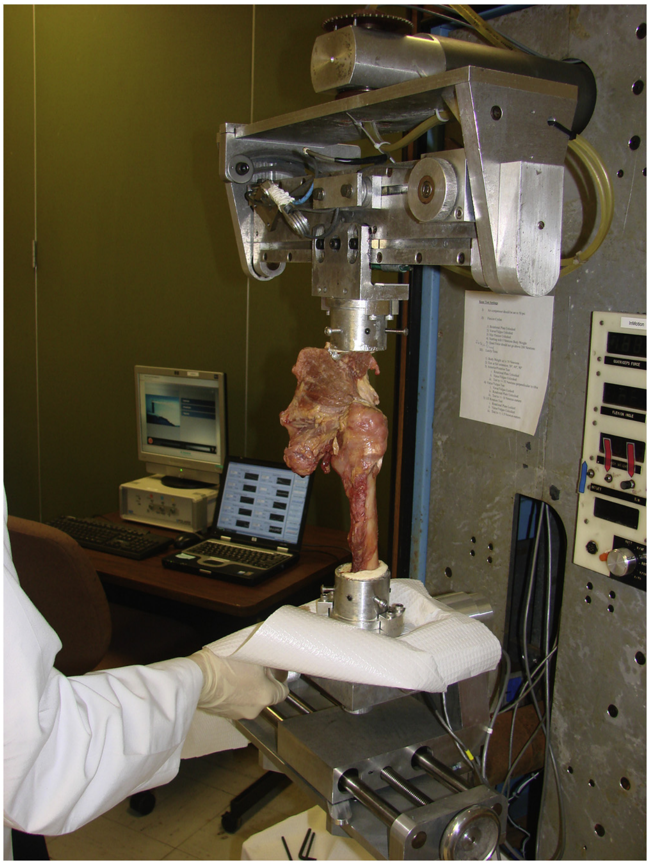

Fig. 1. Anatomic hip specimen in the joint simulator being tested in 0° of extension.

2.3. Statistical analysis

A two-tail Wilcoxon paired signed rank test with a Bonferroni correction was used to determine statistical significance. With a Bonferroni correction, a p-value of <0.025 was considered significant.

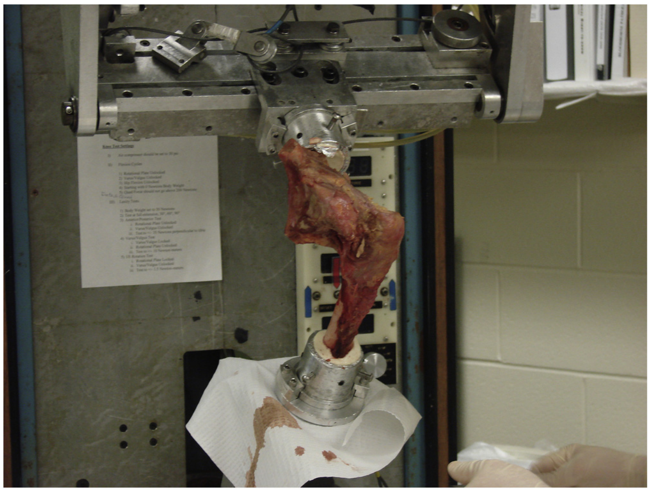

Fig. 2. Anatomic hip specimen in joint simulator being tested at 90° of flexion.