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Lengths of the external hip rotators in mobilized cadavers indicate the quadriceps coxa as a primary abductor and extensor of the flexed hip

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ABSTRACT

Background: The primary function of the external rotators of the hip is inadequately described. The descriptions for peak strength and stretch take no account of how these muscles change their length during normal movement. The latter relationship is known to greatly influence contraction forces and reflect moment arms. The aim of the present study was to indicate positions and directions for peak strength and stretch of piriformis and obturator internus (including the gemelli), collectively defined as the quadriceps coxa, by measuring their changes in length due to normal movements.

Methods: Repeated measurements of muscle lengths and range of motions were acquired from dissected muscles on human cadaver hips. We measured at every 15° of flexion with and without adding end ab/adduction, rotations, and combinations thereof. Measurements were taken in three normal hips (1 female aged 59 years, 2 males aged 68 and 70 years) using a custom-engineered frame, electronic calipers, goniometer, and a string muscle model. Movement–lengthening relations were differentiated into movement–moment arm relations.

Findings: The piriformis and obturator internus were maximally lengthened (35 and 30 mm) by 105° flexion and 10° adduction and relaxed by extension and abduction. With significant moment arms for extension and abduction in the movement–lengthening range deduced as force-efficient, our findings indicate peak strength by extension and abduction at 60° to 90° flexed positions.

Interpretation: This cadaver study indicates that the quadriceps coxa is a primary abductor and extensor from flexed positions, a strength function which may be of major importance in rising and propulsive motions.

1. Introduction

Disability and pain in the buttock are common symptoms of patients with low back pain (O'Neill et al., 2002), sacroiliac joint pain (Schwarzer et al., 1995), and hip joint pain (Khan et al., 2004). Pain in the buttock region can also be caused by the external rotators of the hip (Meknas et al., 2009; Travell and Simons, 2009). Rehabilitation typically involves stretching and strengthening of specific muscle groups, and diagnostic accuracy and therapeutic efficacy depend on a thorough understanding of muscle function in various anatomical positions. However, there is little knowledge about how specific movements change the lengths of the external rotators in the hip joint. Consequently, the muscles' primary function, or position and direction of peak strength, is uncertain, as muscle length greatly influences the contractile force of fibers in animals (Gordon et al., 1966; Hill, 1953) and muscle–tendon units in living humans (Maganaris, 2003; Neumann et al., 1988). Furthermore, there is a lack of consensus on how to maximally stretch the external rotators (Evjenth and Hamberg, 1993; Lee et al., 2011; Sahrmann, 2002).

The positions used to test the peak strength (force × moment arm) of the external rotators should be guided by how the muscle lengths change between positions, as this relationship empirically affects strength (Cibulka et al., 2010) and reflects moment arms (An et al., 1984; Delp et al., 1999). Moment arms for the external rotators have been reported by three cadaver studies, one empiric (n = 4) (Delp et al., 1999) and two computer-simulations (n = 2) (Dostal et al., 1986; Pressel and Lengsfeld, 1998), indicating these muscles to have a role as abductors, extensors, and rotators of the flexed hip. Although the instantaneous moment arm equals the slope of the movement–

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lengthening curve (An et al., 1984; Hughes et al., 1998; Payne et al., 2006), moment arm data from single planes do not demonstrate muscle lengthening.

The only broadly measured movement–lengthening relationship of the external rotators is from a cadaver pilot study published in Norwegian (n = 3) (Samuelsen et al., 1996), where flexion was framed as the most important functional movement compounded with lengthening ab/adductions and rotations at regular intervals. By reversing the lengthening curves, the piriformis and the obturator internus (with the two gemelli) were reported as a single primary muscle for extending and abducting the flexed hip. The single muscle was named the quadriceps coxa (QC) due to overlapping functions, insertions, and innervations (Standring et al., 2008). Traditionally, these muscles are classified as primary external rotators of the hip in the anatomical position (Neumann, 2010; Paulsen et al., 2011). However, the findings from the pilot study of Samuelsen et al. (1996) indicate that testing peak strength of the external rotators in that direction from the anatomic basic position is misleading, as the muscles were reported to be shortened and outside their most efficient working range.

To further elucidate the peak strength and stretch functions of the external rotators of the hip, we acquired systematic measurements of how normal human movements lengthen these muscles in anatomically normal cadavers. Specifically, we addressed how the piriformis (PIR) and the obturator internus with the two gemelli (OI) can be stretched and relaxed in response to extension–flexion (one-dimensional), ab/adduction during flexion and rotations during flexion (two-dimensional), and combined ab/adductions and rotations during flexion (three-dimensional). Resulting movement–lengthening relations were later mathematically differentiated to movement–moment arm relations.

2. Methods

The study was approved by the Norwegian Regional Committee for Medical and Health Research Ethics, Southeast Region (2011/2612).

This study is based on three anatomically normal pelvis–hip specimens from Caucasian corpses (one female aged 59 years and two males aged 68 and 70 years) who had no history of either osteoarthritis or diseases involving the lower limbs as well as normal hip joints as assessed by conventional radiography.

2.1. Radiographs

To exclude cadavers with obvious hip pathology, bone deformities, and evidence of previous surgery, pre-measurement radiographs of whole corpses were acquired using a mobile instrument and pipe (Mobilett Plus, models 01158815 and 06185172, Siemens, Munich, DE). To characterize bone configurations in dissected specimens, post-measurement computed tomography (CT) images were obtained (GE VCT, model 5124069, General Electric, Milwaukee, WI, USA). An experienced musculoskeletal radiologist interpreted the obtained images.

2.2. Preparations

The corpses used had been embalmed by professional preparators within one to three days post mortem. Infusion of 10–15 l of a fixation solution (16% formaldehyde, 4% glycerin, 40% ethyl alcohol, and 40% water) was pressurized (138 kPa) into the right femoral artery over a period of 48 h. The formalin fixed corpses had been stored in an alcohol solution (40% ethyl alcohol in water) for 6–12 months before pelvic–femur specimens were obtained by transection of the spine at the L4–L5 level. External rotators and hip capsules were exposed and isolated by the removal of all surrounding soft tissues.

To control the rotation of the hip, each specimen was placed supine in the anatomical position, and a hole was drilled from the lateral to medial femoral epicondyles to allow for the insertion of a 30 cm aluminum rod (Fig. 1A). The external hip rotator muscles were cut 0.5 cm from the insertion site distally to allow for natural movement of the hips and accurate placement of the muscle-strings.

To model the PIR and OI, single inelastic brass wires were tied to eye screws, placed at the midpoint of the bone-origin of the longest muscle fibers, and screwed to the underlying bone. Wires were placed under the remaining muscles near the pelvis. Holes were drilled through the center of the insertions and the underlying femoral bone to allow the wires to be tightened after the hips were moved to new positions.

Aluminum eyelets were attached laterally in the femoral sockets as contact points for the caliper. After moving the joints through the full range of motion (RoM) to indicate maximal lengthening, collar reference points were pinched on the lateral part of the wires to denote the distance-to-hole values (Fig. 1B). To enable maneuvering the hips over the full RoMs, controlled cuts were made in the capsules.

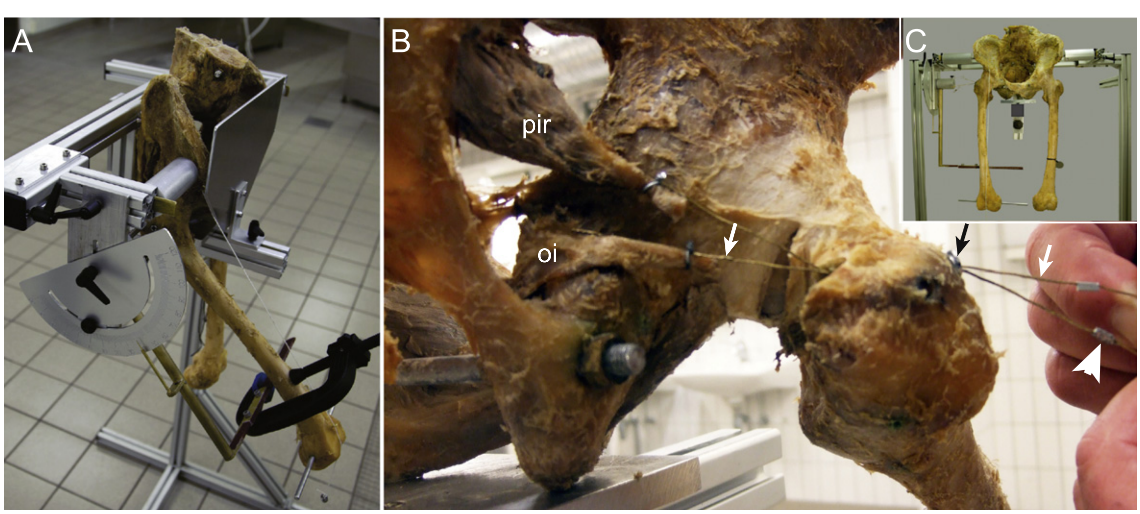

Fig. 1. Hip with muscle-strings fixated in a custom-made frame containing an angle-dial on its flexion arm (for measuring flexion). (A) Anterosuperolateral view showing the flexion axis of the flexion arm, the right fixator-post, the frontal plate (for the spina iliaca anterior superior and pubic orientation), and the epicondylar rod. (B) Posterolateral view showing the piriformis string with its collar (white arrowhead), the obturator internus string (white arrows), and the bone plug or eyelet (black arrow). (C) Anterior view showing both iliac fixator posts (adjustable for width and depth), the pubic plate (adjustable for height), and the string used while measuring ab/adduction.