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Primary functions of the quadratus femoris and obturator externus muscles indicated from lengths and moment arms measured in mobilized cadavers

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ABSTRACT

Background: The small muscles of the pelvis and hip are often implicated in painful conditions. Although the quadratus femoris and obturator externus are usually described as external rotators of the hip, little is known about how they change their lengths and moment arms during human movement. Therefore, more precise measurements defining the positions and directions for their maximal strength and stretch are needed to better describe their functions and guide the clinical approach to pain.

Methods: Repeated measurements of the muscle lengths and range of motion were obtained using wires simulating dissected muscles on human cadaver hips. The lengths were measured at every 15° of flexion with and without maximal range of ab/adduction, rotation, and combinations of the two motions. Measurements were obtained from normal hips ($n = 3$), and movement–lengthening relations were later differentiated into movement–moment arm relations.

Findings: The quadratus femoris showed maximum lengthening by flexion, adduction or abduction, and internal rotation, with the largest moment arms observed for extension in the deduced force–length efficient range of 60–90° flexion. The obturator externus showed maximum lengthening by extension, abduction, and internal rotation, with the largest moment arms observed for flexion and adduction in the deduced force–length efficient range around the hip's neutral position.

Interpretation: Our findings indicate that maximal strength of the quadratus femoris muscle will be delivered in a flexed position towards extension, while maximal strength of the obturator externus muscle will be delivered in an extended position towards flexion and adduction.

1. Introduction

MRI findings in athletes show that the quadratus femoris (QF) and obturator externus (OE) are amongst the most frequently injured muscles in the hip (Ansede et al., 2011) and that these injuries are regularly undiagnosed by clinicians (O'Brien and Bui-Mansfield, 2007). Most often, injuries of the QF and OE muscles are found in elite athletes of hamstring- and groin-risky sports such as tennis, soccer, badminton, and ice hockey (Ansede et al., 2011; O'Brien and Bui-Mansfield, 2007). These small pelvic–hip muscles can cause considerable disability and pain in the buttocks, groin, and hip (Kim et al., 2013; Tosun et al., 2012; Travell and Simons, 2009) with symptoms fitting the clinical diagnoses of low back pain (O'Neill et al., 2002), sacroiliac joint pain (Schwarzer et al., 1995), and hip joint pain (Khan et al., 2004). Rehabilitation programs addressing these disorders typically involve the stretching and strengthening of specific muscle groups. Diagnostic precision and therapeutic efficacy, however, depend on a thorough understanding of the muscle function in various anatomical positions.

There is a lack of consensus regarding how the QF and the OE are maximally stretched (Dalmau-Carolà, 2010; Evjenth and Hamberg, 1993; Kim et al., 2013) or how specific movements change the lengths of these muscles. The movement–lengthening relation is of particular functional importance because the muscle contraction force greatly depends on the muscle length, as demonstrated in isolated animal fibers (Gordon et al., 1966; Hill, 1953) and whole muscle–tendons in living humans (Hof, 2003; Maganaris, 2003). Consequently, the hip positions used for testing the peak strength (force × moment arm) should be directed according to how the muscles change length between various positions because this relationship greatly affects the in vivo strength

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(Cibulka et al., 2010) and reflects the moment arms (An et al., 1984; Delp et al., 1999).

Moment arms for the QF and OE beyond the anatomical position have previously been reported in three cadaver studies, including one empirical study (n = 4) (Delp et al., 1999) and two computer-simulations (n = 2) (Dostal et al., 1986; Pressel and Lengsfeld, 1998), indicating that these muscles can move the hip in all directions except internal rotation. Although the instantaneous moment arm equals the slope of the movement–lengthening curve (An et al., 1984; Delp et al., 1999), the moment arm data do not demonstrate muscle lengthening. The only available comprehensive measurements of the movement–lengthening relations of the QF and OE are from a cadaver pilot study published in Norway (n = 3) (Samuelsen et al., 1996). These researchers reported the QF as a primary muscle for extending the flexed hip, whereas they reported the OE as a primary flexor and adductor of the extended hip. Classically, these muscles are categorized as primary external rotators of the hip in the basic anatomical position (Neumann, 2010; Paulsen et al., 2011; Standring et al., 2008), although earlier reports indicated that the QF is outside its length–force efficient range and that the OE has a small external rotation moment arm (Dostal et al., 1986; Pressel and Lengsfeld, 1998; Samuelsen et al., 1996) in that position. Improved knowledge about the position and direction of maximal strength of the QF and OE is needed to better understand the primary function of these muscles.

To shed light on the primary functions of the QF and OE (defined as their maximal strength and stretch directions and positions), we measured how relevant human movements lengthen these muscles in anatomically normal cadavers. We specifically addressed how the QF and OE are 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). The movement–lengthening relations were later mathematically differentiated into movement–moment arm relations.

2. Methods

The Norwegian Regional Committee for Medical and Health Research Ethics, Southeast Region approved the study (2011/2612). Three anatomically normal pelvis–hip specimens from Caucasian cadavers (one female aged 59 years and two males aged 68 and 70 years) were used. The methodological approach is explained in detail in Vaarbakken et al. (2014) but key methodological features are summarized below together with pertinent details regarding the QF and the OE muscles.

2.1. Radiographs

Cadavers were screened by radiography, and only those with normal radiographs were included in the study. Bone configurations of the dissected specimens were subsequently characterized by CT imaging, where normality was demonstrated for all of the hips except for a borderline anterior offset ratio for hip 2 and a borderline anterior offset by alpha angle for hip 3 (Vaarbakken et al., 2014).

2.2. Preparations

Professional preparators embalmed the cadavers within one to three days post mortem. The specimens that were evaluated included the lower lumbar spine, pelvis and both lower extremities. The external rotators and hip capsules were exposed and isolated by the removal of all the surrounding soft tissues. The muscles were cut near their insertions to allow for natural movement of the hips and accurate placement of the muscle-simulating strings.

To model the QF and OE, two brass wires per muscle were tied to eye screws placed at the periphery of the bony origins, superior and inferior for the QF (Fig. 1A) and medial and lateral for the OE (Fig. 1B). At the QF insertion, additional eye screws were placed to allow for wire tightening and measurements to be made (against the screws) as the hips were moved to new positions. At the OE insertion, a hole for the wires was drilled through the femur before an aluminum eyelet was attached laterally in the femoral socket as a contact point for the caliper. Reference collar points of metal were then pinched onto the lateral part of the wires to denote the distance-to-screw or distance-to-hole values. To control the rotation of the hip, a 30-cm aluminum rod was inserted through the epicondyles (Fig. 1C and D). The left hips were used for piloting and sensitivity testing (Vaarbakken et al., 2014), and the right

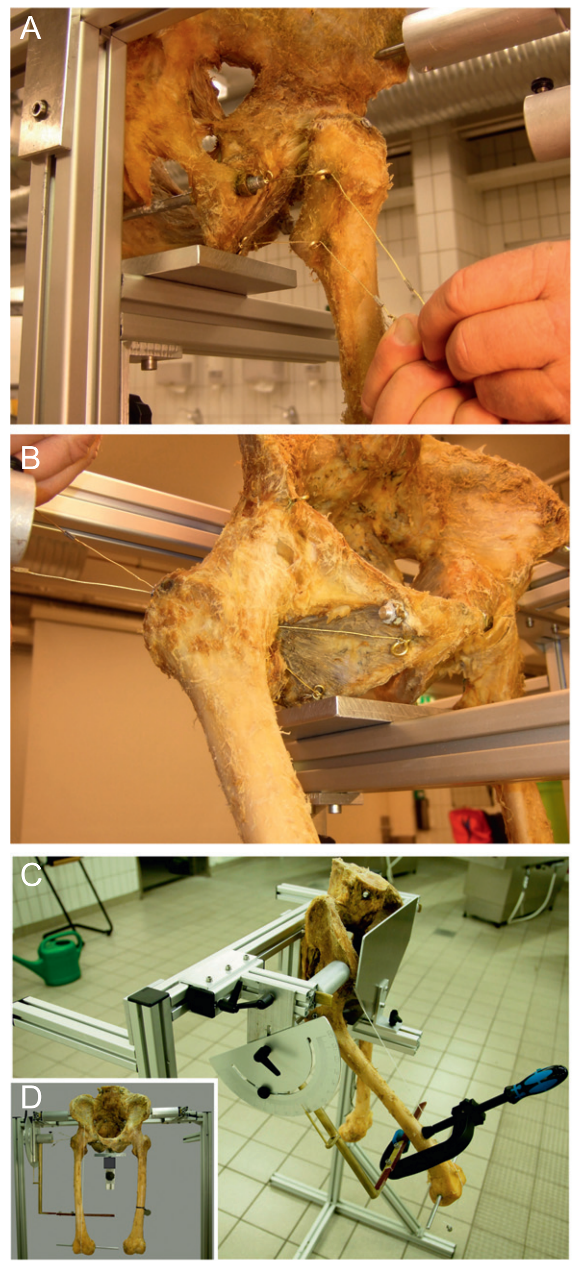

Fig. 1. Hip specimen, with muscle-strings, fixed in a custom-made frame equipped with an angle-dial for measuring flexion. (A) Posterolateral view of the superior and inferior string modeling the quadratus femoris. (B) Anterolateral view of the medial and lateral string modeling the obturator externus. (C) Superolateral view of the femur with the epicondylar rod fixed upon the flexion arm, right fixator-post, and removable frontal plate (for the spina iliaca anterior superior and pubic orientation). (D) Anterior view of the iliac fixator bolts (adjustable for width and depth), tuber ischii plate (adjustable for height), and string used for measuring ab/adduction.