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The pelvifemoral rhythm in cam-type femoroacetabular impingement

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ABSTRACT

Background: There is growing evidence that femoroacetabular impingement is a potentially important risk factor for the development of early idiopathic osteoarthritis in the nondysplastic hip. Understanding of affected joint kinematics is a basic prerequisite in the evaluation of mechanical disorders in a clinical and research oriented setting. The aim of the present study was to compare pelvifemoral kinematics between subjects diagnosed with femoroacetabular impingement and healthy controls.

Methods: The authors collected motion data of the femur and pelvis on a total of 43 hips – 19 cam impingement hips and 24 healthy controls – using a validated electromagnetic tracking device. The pelvifemoral rhythm in supine position was defined during both active and passive hip flexion and statistically compared between both groups.

Findings: A significant increase in posterior pelvic rotation was observed during active hip flexion in the femoroacetabular impingement group compared with the control group ($P < 0.001$). During passive hip flexion, however, posterior pelvic rotation between the impingement group and the controls did not differ significantly ($P = 0.628$).

Interpretation: Posterior pelvic rotation during active high-end hip flexion is increased in femoroacetabular impingement, indicating the presence of an active compensational mechanism that decreases the extent of harmful joint conflict during high-flexion activities.

1. Introduction

Femoroacetabular impingement (FAI) is a relatively new concept, unfolding a mechanism for the development of early labrum and cartilage lesions of the hip (Ganz et al., 2003). With an increased understanding of the condition and the recognition of FAI as a highly prevalent pathology, especially in sports, the literature dealing with the subject has grown exponentially. To date, FAI is recognized as a likely cause of young adult osteoarthritis in Caucasian subjects (Ganz et al., 2003, 2008; Reid et al., 2010). It is defined as a premature or repetitive contact between the acetabular rim and proximal femur, potentially resulting in damage to the joint. Underlying and predisposing anatomical variations have been identified, in particular, an increased coverage by the acetabulum (pincer-type impingement) and/or decreased sphericity of the femoral head (cam-type impingement) (Ganz et al., 2003; Kassarjian et al., 2007; Lavigne et al., 2004; Tannast et al., 2007b).

Affected subjects usually report a history of pain in the groin or in the greater trochanter region, extending to the lateral side of the thigh, with activities of daily living (e.g. sitting, stair climbing, squatting, driving) and sporting activities (e.g. soccer, swimming, cycling, rowing) requiring substantial hip flexion (Clohisy et al., 2009; Ganz et al., 2003). The range of movement in the hip joint is typically decreased, and movements requiring high hip flexion in combination with adduction and/or internal rotation are most frequently affected among symptomatic patients (Clohisy et al., 2009; Ganz et al., 2003; Ito et al., 2004).

Hip flexion – or the approximation of the anterior thigh to the anterior trunk – is achieved through movement of the femur on the pelvis, posterior tilting of the pelvis (rotation in the sagittal plane) and concurrent flattening of the lumbar spine (Congdon et al., 2005). The relationship between posterior pelvic rotation and hip flexion has been studied during active, passive and weight-loaded movements in normal subjects who are supine, standing and suspended (Bohannon, 1982; R. Bohannon et al., 1985; R.W. Bohannon et al., 1985; Dewberry et al., 2003; Murray et al., 2002). In each of these studies, posterior pelvic rotation has been found to clearly add to the overall hip flexion. This apparently synergistic relationship between femur flexion and posterior pelvic rotation during hip flexion has become known as “pelvifemoral rhythm,” as in the more familiar “scapulohumeral rhythm,” which relates to the shoulder (Dewberry et al., 2003; Elia et al., 1996; Murray et al., 2002). Until now, pelvifemoral rhythm remained uninvestigated in FAI, and the question as to whether any changes in coordination mechanisms of the body operate during hip flexion remained unanswered. Identification of possible existing differences in pelvifemoral kinematics is also important in light of the increasing use of patient specific predictive models for cartilage and labrum damage based on collision detection through motion simulation (Audenaert et al., 2011a; Bedi et al., 2011; Tannast et al., 2007a). These protocols presume

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pelvic kinematics during open kinetic chain motions of the hip to be the same in patients as in healthy controls.

The main purpose of this study was to investigate posterior pelvic rotation during hip flexion in FAI patients compared with controls and thereby reveal possible differences in pelvic kinematics. Secondly, we wanted to find out whether potential differences in pelvifemoral rhythm represent an active mechanism or, if such is the result of passive factors including the mechanical conflict itself. To do so, we applied a kinematic protocol and system of measurement that had specifically been designed and validated for use in FAI (Audenaert et al., 2011b, 2012a).

2. Methods

2.1. Subjects

The study was designed as a case–control study comprising: (1) cam impingement patients and (2) healthy controls. All subjects were men aged 18–35 years recruited between 1 January 2009 and 31 August 2012. The study was approved by the local ethics committee and all participants signed an informed consent. In the absence of similar studies, a preliminary pilot study of 8 cam impingement hips and 8 control hips was performed to estimate the effect size. This allowed for a sample size calculation based on the following parameters: effect size (=3.1°), standard deviation ($\sigma = 2.5°$), type II error rate ($\beta = 0.2$) and type I error rate ($\alpha = 0.05$). A minimum sample size of 9 hips per subgroup was calculated to identify any significant difference in pelvic kinematics in FAI patients compared with controls. The study population comprised a total of 43 hips: 19 cam impingement hips (17 patients) and 24 healthy hips (12 controls). The patient group consisted of 11 right hips (8 dominant-sided) and 8 left hips (3 dominant-sided).

Patients were recruited from cam-type FAI patients scheduled for arthroscopic treatment. In an attempt to decrease the risk for selection bias based on differences in training levels between patients and healthy controls, only subjects engaged in recreational-level sport activities were included in the study. Recreational-level sport activities were defined as a maximum of 4 h weekly sports and no competitional activity. All patients presented with typical clinical signs of FAI, such as limited internal rotation in 90° of flexion, groin/lateral hip pain and a painful anterior impingement test (groin pain elicited by passively moving the hip in flexion, adduction and internal rotation). The screening procedure was also aided by standard diagnostic imaging (radiography and arthro-MRI), revealing an increased alpha angle, and finally, the diagnosis was confirmed during the actual arthroscopic procedure.

Healthy controls were recruited from the University Hospital personnel and from students by means of posters and emails requesting to volunteer for the study. They were screened and selected on the basis of a negative history of groin or lateral hip pain, the absence of positive impingement testing, and, bilaterally, an alpha angle of <50° on anteroposterior imaging and Dunn views (45° hip flexion, neutral rotation and 20° abduction). Alpha angle measurements were performed according to the original description by Notzli et al. (2002). Patients and controls with solitary pincer-type impingement (positive cross-over sign) or hip dysplasia (center-edge angle < 28°) were excluded. Table 1 summarizes the selection criteria for both the patient and control subgroups. Different radiographic parameters, which indicated FAI or which might have an influence on the condition, were measured in each subject in a standardized fashion: alpha angle, caput-collum-diaphyseal angle and lateral center-edge angle. In addition, demographic variables (age, height, weight and BMI) were recorded.

Table 1
Selection criteria for patient and control subgroup. CE angle, center-edge angle.

Patients (19 hips, 17 subjects)	Controls (24 hips, 12 subjects)
	
Male	
Aged 18–35 years	
CE angle between 28 and 40°	
Negative cross-over sign	
Recretional level sports only	
History of groin pain	No history of groin pain
Pain on impingement testing	No pain on impingement testing
Alpha angle > 55°	Alpha angle < 50°
Cam type impingement confirmed on volumetric imaging	Healthy volunteer

2.2. Protocol

Kinematic measurements were performed using the Fastrak electromagnetic tracking system (Polhemus, Colchester, VT, United States). The system uses magnetic field pulses to track the position and orientation of individual sensors relative to a satellite transmitter. A microprocessor controls the transmitting and sensing signals and converts them into position and orientation data with 6 degrees of freedom relative to a global Cartesian coordinate system projected by the magnetic transmitter. The system specifications regarding measurement accuracy at close measurement range of the transmitter are 0.8 mm and 0.15 degrees for position and orientation, respectively, according to the manufacturers. Accuracy studies have confirmed that positional and orientational static measurement errors are smaller than 2% for measurements at close range, i.e. at a distance of 70 cm from the transmitter (Day et al., 2000; Milne et al., 1996).

Previously, the same authors performed an in vitro validation and reliability study of electromagnetic skin sensors for the evaluation of end range of motion positions of the hip. Kinematic data from sensors screwed into the bone of cadaver hips were compared to the data registered synchronously by sensors attached to the skin. This study revealed that angular root mean square (RMS) errors averaged 3.2° (SD 3.5°) and 1.8° (SD 2.3°) in the global reference frame for the femur and pelvic sensors, respectively (Audenaert et al., 2011b). This measurement protocol has recently been applied in a case–control study evaluating end range motion in FAI (Audenaert et al., 2012a).

Patients and controls were evaluated in a supine position on a wooden investigation table, 1 m in height. In order to avoid any distortion of the positional data, we ensured that there were no ferromagnetic materials nearby, and the transmitter was placed close to the test subject (<0.2 m), parallel to the table. A supine examination position was preferred, to separate posterior pelvic rotation from other variables such as weight shifts during hip flexion, proprioceptive counterbalancing or lumbar involvement. A unilateral femoral sensor and a contralateral pelvic sensor were used simultaneously for all experiments. The pelvic skin sensor was securely fixed over the contralateral superior–anterior iliac spine. The femoral skin sensor was fixed rigidly to a specially designed distal femoral orthosis in order to decrease measurement errors caused by skin movement. Furthermore, the sensor cables were taped rigidly to the skin on the side of the trunk in order to prevent any inadvertent movements of the sensor during the course of the investigation. Data readings were observed at a frequency rate of 40 Hz. A third sensor, equipped with a stylus, was used to digitize palpable bony points on the pelvis and femur. These digitized points were used to define the local coordinate system for the pelvis and femur, and comprised the lateral and medial femoral epicondyles and the anterior and posterior iliac spines. All landmarks were digitized in supine position. The posterior iliac spines were accessed through an opening in the wooden investigation table. Femoral and pelvic movements were then