An Increased Iliocapsularis-to-rectus-femoris Ratio Is Suggestive for Instability in Borderline Hips

Running title: Iliocapsularis-to-rectus Ratio

Pascal Cyrill Haefeli MD, Simon Damian Steppacher MD, Doris Babst MD, Klaus-Arno Siebenrock MD, Moritz Tannast MD
Department of Orthopaedic Surgery, Inselspital, University of Bern, Bern, Switzerland

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Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

K.-A. Siebenrock ✉
Department of Orthopaedic Surgery
Inselspital, Freiburgstrasse
3010 Bern, Switzerland
email: klaus.siebenrock@insel.ch

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Abstract

Background The iliocapsularis muscle is an anterior hip structure that appears to function as a stabilizer in normal hips. Previous studies have shown that the iliocapsularis is hypertrophied in developmental dysplasia of the hip (DDH). An easy MR-based measurement of the ratio of the size of the iliocapsularis to that of adjacent anatomical structures such as the rectus femoris muscle might be helpful in everyday clinical use.

Questions/purposes We asked (1) whether the iliocapsularis-to-rectus-femoris ratio for cross-sectional area, thickness, width, and circumference is increased in DDH when compared with hips with acetabular overcoverage or normal hips; and (2) what is the diagnostic performance of these ratios to distinguish dysplastic from pincer hips?

Methods We retrospectively compared the anatomy of the iliocapsularis muscle between two study groups with symptomatic hips with different acetabular coverage and a control group with asymptomatic hips. The study groups were selected from a series of patients seen at the outpatient clinic for DDH or femoroacetabular impingement. The allocation to a study group was based on conventional radiographs: the dysplasia group was defined by a lateral center-edge (LCE) angle of < 25° with a minimal acetabular index of 14° and consisted of 45 patients (45 hips); the pincer group was defined by an LCE angle exceeding 39° and consisted of 37 patients (40 hips). The control group consisted of 30 asymptomatic hips (26 patients) with MRIs performed for nonorthopaedic reasons. The anatomy of the iliocapsularis and rectus femoris muscle was evaluated using MR arthrography of the hip and the following parameters: cross-sectional area, thickness, width, and circumference. The iliocapsularis-to-rectus-femoris ratio of these four anatomical parameters was then compared between the two study groups and the control group. The diagnostic performance of these ratios to distinguish

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dysplasia from protrusio was evaluated by calculating receiver operating characteristic (ROC) curves and the positive predictive value (PPV) for a ratio > 1. Presence and absence of DDH (ground truth) were determined on plain radiographs using the previously mentioned radiographic parameters. Evaluation of radiographs and MRIs was performed in a blinded fashion. The PPV was chosen because it indicates how likely a hip is dysplastic if the iliocapsularis-to-rectus-femoris ratio was > 1.

Results The iliocapsularis-to-rectus-femoris ratio for cross-sectional area, thickness, width, and circumference was increased in hips with radiographic evidence of DDH (ratios ranging from 1.31 to 1.35) compared with pincer (ratios ranging from 0.71 to 0.90; $p < 0.001$) and compared with the control group, the ratio of cross-sectional area, thickness, width, and circumference was increased (ratios ranging from 1.10 to 1.15; p ranging from 0.002 to 0.039). The area under the ROC curve ranged from 0.781 to 0.852. For a one-to-one iliocapsularis-to-rectus-femoris ratio, the PPV was 89% (95% confidence interval [CI], 73%-96%) for cross-sectional area, 77% (95% CI, 61%-88%) for thickness, 83% (95% CI, 67%-92%) for width, and 82% (95% CI, 67%-91%) for circumference.

Conclusions The iliocapsularis-to-rectus-femoris ratio seems to be a valuable secondary sign of DDH. This parameter can be used as an adjunct for clinical decision-making in hips with borderline hip dysplasia and a concomitant cam-type deformity to identify the predominant pathology. Future studies will need to determine whether this finding can help clinicians determine whether the borderline dysplasia accounts for the hip symptoms with which the patient presents.

Level of Evidence: Level III, prognostic study.

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Introduction

The iliocapsularis muscle is a small hip muscle that originates at the anteroinferior iliac spine and the anteromedial hip capsule and inserts distal to the lesser trochanter [29]. Although its true function is still unknown [29], it may function as an anterior stabilizer of the hip or a tightener of the hip capsule in flexion [1, 15,29]. In hips with developmental dysplasia of the hip (DDH), the iliocapsularis muscle typically also functions to oppose the typical anterosuperior migration of the femoral head. As a result of the femoral head instability resulting from DDH, the iliocapsularis hypertrophies in hips with DDH when compared with hips with acetabular overcoverage [1].

Based on these observations, determining the size of the iliocapsularis muscle might be helpful in young patients with hip symptoms with both features of borderline hip dysplasia (defined as a lateral center-edge [LCE] angle between 20° and 25° [3, 24]) and subtle cam-type deformities. In these hips, it is often unclear which pathomechanism is the leading cause for the patients' symptoms [3]: subtle instability resulting from dysplasia or impingement from a cam lesion. Previously reported indirect indicators for a relevant instability are hypertrophy of the labrum, the presence of labral ganglia, a decentration of the femoral head on the radial MR imaging slice, decreased head sphericity and epiphyseal index, and an increased epiphyseal angle [9, 20].

A diagnostic test based on the size of the iliocapsularis would be an additional adjunct for decision-making in these challenging hips. However, previously defined absolute measures for the iliocapsularis muscle hypertrophy (cross-sectional area, thickness, width, circumference [1]) are of little use in everyday clinical practice, because these may be driven more by the size and sex of the patient than by the pathology itself. Assessing the size of the iliocapsularis muscle compared with adjacent anatomical structures--that is, calculating the ratio of the size of this muscle to nearby, easily measured structures on MRI--would be more beneficial. We have observed that the rectus femoris muscle could potentially serve as such a reference, because the size of the rectus femoris remains relatively unchanged in patients with various hip pathologies [4, 8, 11], in particular in its proximal aspect [5].

We therefore asked (1) whether the iliocapsularis-to-rectus-femoris ratio for cross-sectional area, thickness, width, and circumference is increased in hips with DDH when compared with a set of hips with relative acetabular overcoverage and asymptomatic hips; and (2) what is the diagnostic performance of this ratio for the four evaluated parameters to distinguish dysplastic from pincer hips?

Patients and Methods

We retrospectively compared the anatomical dimensions of the iliocapsularis and rectus femoris muscles between two study groups with different acetabular coverage with a control group of asymptomatic patients. The local institutional review board approved this study. The first study group consisted of 45 patients with 45 symptomatic hips resulting from deficient acetabular coverage (dysplasia group). The second study group consisted of 37 patients with 40 symptomatic hips with as a result of excessive coverage (pincer group). The groups were selected from a series of 421 patients (480 hips) with DDH or pincer-type femoroacetabular impingement (FAI), who were seen at our outpatient clinic from November 1997 to October 2006. We excluded 42 patients (48 hips) with a history of known hip disorders (eg, Legg-Calvé-Perthes disease), two patients (two hips) with muscle disorders (eg, muscle dystrophy), 79 patients (90 hips) with previous hip surgery, six patients (six hips) with skeletally

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immature hips (Stage 4 or less, according to Risser [16]), 12 patients (14 hips) with advanced osteoarthritis (Stage 2 or greater, according to Tönnis [27]), and 51 patients (58 hips) with incomplete or nondigital radiographic documentation [1]. This left 229 patients (262 hips). The allocation to one of the two study groups was then based on the conventional radiography only. The dysplasia group was defined by a LCE angle less than 25° [12] with a minimum acetabular index of 14° measured on an AP pelvic radiograph [28] (Fig. 1). The pincer group was defined as hips with a LCE angle exceeding 39° on the AP pelvic radiograph [22, 28] (Fig. 1). One hundred forty-seven patients (177 hips) did not meet these radiographic criteria, leaving 82 patients (85 hips) for evaluation, 45 patients (45 hips) for the dysplasia group and 37 patients (40 hips) for the pincer group. Among the 45 hips with hip dysplasia, there were 43 hips with Grade 1 and two hips with Grade 2 according to Crowe [2]. The demography of these patients is comparable to other series available from the literature [18, 19]. Based on chart review, none of the involved patients had an underlying neurological or muscular disease.

As a control group of asymptomatic patients, we added 26 patients (30 hips) who had been selected from a series of 117 patients (150 hips) with MRI involving the hip from our institutional picture archiving and communication system between July 2010 and March 2013. Most of these MRIs were taken for nonorthopaedic reasons. The following exclusion criteria were applied: known hip disease or pain or previous hip trauma (33 patients, 38 hips), age younger than 16 years (20 patients, 35 hips), THA (10 patients, 11 hips), previous surgery (six patients, eight hips), and incomplete data (22 patients, 28 hips). The demographic factors of all three groups did not differ for sex, side, height, weight, or body mass index (Table 1). The control group was older ($p < 0.001$).

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AP pelvic radiographs were performed according to a previously described standardized technique [25] for both study groups. The patient was placed in a supine position with internally rotated legs to compensate for femoral antetorsion. The film-focus distance was 1.2 m and the central beam was directed to the midpoint between the symphysis and a line connecting the anterosuperior iliac spines [25]. One observer (DB) assessed the acetabular morphology on AP pelvic radiographs using previously developed and validated software, Hip^{2}Norm (University of Bern, Bern, Switzerland) [23, 26, 30].

MR arthrography in both study groups was routinely obtained according to a standardized technique [10] with a flexible surface coil after fluoroscopic-guided intraarticular injection of saline-diluted gadolinium-DTPA (Dotarem 1:200; Guerbert AG, Paris, France). The axial proton density-weighted sequences with a slice thickness of 4 mm and a slice-to-slice distance of 4.8 mm were used for measurements.

For the first question, one of us (PCH) blinded to the groups measured four variables to assess the anatomical dimensions of both the iliocapsularis and rectus femoris muscles on one MR axial slice at the level of the femoral head center (Fig. 2). This level was chosen for three reasons. First, it is easy to define. Second, the maximum hypertrophy of the iliocapsularis muscle is present at this level [1]. Third, the rectus femoris muscle is evaluated close to its origin, making measurement less susceptible to changes in the more distal bulk of the muscle. The following four previously defined study variables [1] were evaluated: cross-sectional area, thickness, width, and circumference. In detail, the outlines of both the iliocapsularis and rectus femoris muscles were defined manually (Fig. 3). Based on the outline of the muscle, the cross-sectional area and the circumference were calculated automatically. The muscle thickness was measured along a radial line passing through the femoral head center (Fig. 3).

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The width was measured perpendicular to the thickness (Fig. 3). Prior investigation has shown both excellent reproducibility with an intraclass correlation coefficient (ICC) ranging from 0.90 to 0.95 and a good reliability with an ICC ranging from 0.80 to 0.88 [1]. We then compared the iliocapsularis-to-rectus-femoris ratio for each variable between the two study groups. Commercially available software, Osirix (Version 6.0; Geneva, Switzerland), was used for analysis [17].

For the second question, we evaluated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and the accuracy for the four study parameters between the dysplastic and the pincer group based on a standard 2 x 2 table. For reasons of practicability, we arbitrarily used an iliocapsularis-to-rectus ratio of one to one. In addition, we calculated the ratio for each study variable with a PPV of 100%, which would define the threshold for the iliocapsularis-to-rectus ratio above which only dysplastic hips would be identified. In addition, we performed a receiver operating characteristic (ROC) curve to evaluate the overall predictive performance of each study variable.

Normal distribution was confirmed with the Kolmogorov-Smirnov test. We used analysis of variance to compare demographic, radiographic, and the anatomical parameters among the three groups. To compare binominal demographic data of the three groups, the Kruskal-Wallis test was used. Results were expressed as mean with SD and range. We calculated the 95% confidence interval for the 2 x 2 tables. The power analysis was performed using G*Power [6] (Version 3.1.9.2; University of Düsseldorf, Düsseldorf, Germany) based on the primary research question (differences in the iliocapsularis-to-rectus-femoris ratio for the cross-sectional area) and with the following parameters: α error 0.05, β error 0.80, a reported

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cross-sectional area of 2.5 cm^2 for the iliocapsularis muscle, an assumed cross-sectional area of 1.8 cm^2 for the rectus femoris muscle, and a SD of 0.6 cm^2 [1]. This resulted in a minimal sample size of 78 hips (39 hips for each group). Statistical analysis was performed using MedCalc® (Version 14.12.0; MedCalc Software bvba, Ostend, Belgium).

Results

The iliocapsularis muscle showed an increased thickness, width, and circumference in the dysplasia group compared with both pincer and control groups (p ranging from < 0.001 to 0.026; Table 2). The cross-sectional area of the iliocapsularis muscle was increased in the dysplasia group compared with pincer ($p < 0.001$) but did not differ compared with the control group ($p = 0.464$; Table 2). The rectus femoris muscle showed a decreased cross-sectional area, thickness, width, and circumference in the dysplasia group compared with the pincer group (p ranging from 0.001 to 0.045) but showed no difference compared with the control group (p ranging from 0.330 to 0.967; Table 2). The iliocapsularis-to-rectus-femoris ratio for cross-sectional area (Fig. 4), thickness, width, and circumference differed among the three study groups (p ranging from < 0.001 to 0.039; Table 2). The highest ratios were found in the dysplasia group ranging from 1.31 to 1.35 for the four study parameters (Table 2). The lowest ratios were found in the pincer group with ratios ranging from 0.71 to 0.90 (Table 2).

With the sample numbers available, we could not determine the best parameter (cross-sectional area, thickness, width, and circumference) for differentiating between the dysplastic and the pincer group based on a standard 2 x 2 table where we evaluated sensitivity, specificity, PPV, NPV, and overall accuracy. Similarly, area under the curve (AUC) values for ROC curves were fair to good, but were similar for all four parameters. Using our chosen one-to-one iliocapsularis-to-rectus ratio, we found sensitivities ranging from 71% to 80%, specificities ranging from 75% to 90%, and NPVs ranging from 71% to 78%. We found a PPV of 89% (95% confidence interval [CI], 73%-96%) for cross-sectional area (indicating that hip dysplasia was present in 89% of symptomatic hips), 77% (95% CI, 61%-88%) for thickness, 83% (95% CI, 67%-92%) for width, and 82% (95% CI, 67%-91%) for circumference (Table 3). Overall accuracy ranged from 74% to 80%. When we adjusted the iliocapsularis-to-rectus ratio to achieve a PPV of 100% for each test parameter, we found a ratio of > 1.08 for cross-sectional area, > 1.49 for thickness, > 1.26 for width, and > 1.28 for circumference. The greatest area under the ROC curve was found for width (AUC 0.852) followed by circumference (AUC 0.849), cross-sectional area (AUC 0.844), and thickness (AUC 0.781; values between 0.80 and 0.90 are considered to reflect good accuracy, whereas values between 0.70 and 0.80 are considered fair.

Discussion

It can be difficult to define the predominant pathophysiological problem in symptomatic hips with features of both borderline DDH and cam-type FAI. The treatment of these challenging hips is therefore controversial. Dependent on the predominant pathomechanism, the surgical treatment involves various options such as hip arthroscopy, surgical hip dislocation, and/or periacetabular osteotomy [3]. With predominant hip instability resulting from DDH, acetabular reorientation is the preferred treatment. With predominant impingement resulting from subtle femoral head-neck asphericity, open or arthroscopic offset creation is typically indicated. A diagnostic test to facilitate this decision would helpful for preoperative decision-making. Based on a previous pilot study, the iliocapsularis muscle showed increased absolute dimensions in dysplastic hips that can potentially be used as an indirect sign for DDH/instability [1]. However, because these absolute values are of little use in everyday

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clinical practice, we evaluated the diagnostic value of the relative size of the iliocapsularis muscle in relation to the rectus femoris muscle to distinguish between dysplasia and pincer hips. The iliocapsularis muscle showed an increased thickness, width, and circumference in the dysplasia group compared with both pincer and control groups. We found that an increase of the iliocapsularis cross-sectional area of more than 8% and a thickness of more than 150% in comparison to the rectus femoris muscle is highly indicative for DDH.

This study has several limitations. First, the iliocapsularis-to-rectus-femoris ratio for the four evaluated parameters should not be used to screen for DDH in epidemiologic studies. The increased iliocapsularis-to-rectus ratio is a result of the dysplasia (and the femoral head instability) and not the cause of it. Second, the patients we studied were a highly selected group, and our findings may not reflect either our patients as a whole or patients in other practice settings. Although we have compared the ratio to asymptomatic patients, we will use this ratio for decision-making in symptomatic patients only and caution against uncritical adoption of this measurement tool in making clinical decisions. Third, we are unable to exclude all potential causes for muscle hypertrophy and atrophy in this retrospective study. For example, it is possible that some patients use athletic training regimens, which preferentially load certain muscle groups. However, based on our comprehensive chart review, we can ensure that none of the mostly young patients had a previously diagnosed muscular or neurological disease, and it is unlikely that any suffered from severe systemic disease or cachexia. Third, the anatomical dimensions of the two investigated muscles could not be assessed over their entire course. This was the result of the protocol of the MR arthrography that was defined for intraarticular pathologies. However, the size of the rectus in particular remains relatively constant at the level of the hip. Fourth, we cannot provide a time-related correlation between the duration of the symptoms of the patients and the relative size of the iliocapsularis muscle.

We found an increased iliocapsularis-to-rectus-femoris ratio in hips with DDH (Table 2) for all four evaluated variables indicating the consistency of our findings. The iliocapsularis-to-rectus ratio of our control group of asymptomatic patients was decreased compared with the dysplastic hips and increased compared with the pincer group. In a pincer hip, dynamic stability of the iliocapsularis muscle seems to be less important as a result of the static stability given by the excessively covered acetabulum. This results in a decreased size of the iliocapsularis muscle even compared with asymptomatic hips. This lends support to the validity of our results and emphasizes the proposed function of the iliocapsularis muscle as a hip stabilizer. Although general atrophy of the periarticular hip muscles has been observed in end-stage osteoarthritis [7, 13, 14], isolated relative changes of muscle dimensions with hip pathologies are rarely reported in the literature [15, 21]. One of the few reports describes a reactive hypertrophy of the tensor fascia latae muscle in hips with an ipsilateral abductor tendon tear [21]. In this study, the relative size of the cross-sectional area of the tensor fascia latae muscle was compared with the sartorius muscle. The suggested pathomechanism was a compensatory hypertrophy for the deficient or absent hip abductors.

In comparison to the previously defined absolute measures for the iliocapsularis muscle hypertrophy (cross-sectional area, thickness, width, circumference [1]) this study shows also significantly different values in patients with dysplasia compared to patients with Pincer-type impingement. But our clinical experience revealed limited practicability of absolute measurements due to laborious obtaining of the values and because they might be driven more by the size and sex of the patient than by the pathology itself. Assessing the size of the

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iliocapsularis muscle compared with the anatomically adjacent rectus femoris muscle may increase the practicability of using this parameter in everyday clinical practice. A one-to-one iliocapsularis-to-rectus femoris ratio seems most practical in clinical routine use, ie, if the cross-sectional area of the iliocapsularis exceeds the cross-sectional area of the rectus femoris muscle, a DDH was present in 89% in our series (Table 3). A 100% PPV can be achieved when a threshold of 1.08 is chosen for the cross-sectional area ratio. Besides this newly described indirect sign for DDH, several other factors are suggestive of DDH such as hypertrophy of the labrum, presence of ganglia, decentration of the femoral head, decreased head sphericity and epiphyseal index, and an increased epiphyseal angle [9, 20]. In a selected patient group of dysplasia patients compared to Pincer patients, for hypertrophy of the labrum a PPV of 100% (95% CI 70-100%) with an accuracy of 93% (95% CI 83-100%) could be shown [9]. In the same study, the presence of ganglia showed a PPV of 77% (95% CI 46-94%) with an accuracy of 75% (95% CI 59-91%). For decentration of the femoral head on the radial MRI slices as well as morphology of the head and epiphysis no data on test preformence is available in the literature. A future approach is to use a test like our new ratio in concert with these other factors to get suggestive evidence about what the primary pathology is that might be causing the symptoms. This is particularly important in hips with questionable or mild dysplasia and a small cam-type deformity. Future studies should focus on the diagnostic performance of a combination of these criteria for different pathomorphologies.

A potential application of our new iliocapsularis-to-rectus femoris ratio is shown in Figure 5 where two patients with borderline hip dysplasia (Fig. 5A) and a subtle cam-type deformity (Fig. 5B) are shown. One patient (Figs. 5C, 5E) presented with a clearly larger iliocapsularis

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muscle in comparison to the rectus femoris muscle and was scheduled for acetabular reorientation. The other patient (Figs. 5D, 5F) presented with a similar size of the iliocapsularis and the rectus femoris muscle. He was scheduled for correction of the cam deformity only.

In conclusion, the iliocapsularis-to-rectus-femoris ratio may be a valuable secondary sign of DDH. This parameter can be used as an adjunct for clinical decision-making in cases with borderline hip dysplasia and an associated small cam-deformity where the underlying pathomechanism is unclear. Future studies will need to determine whether this finding can help clinicians determine whether the borderline dysplasia accounts for the hip symptoms with which the patient presents.

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Legends

Fig. 1 This figure illustrates the measurement of the two radiographic parameters on AP pelvic radiographs that were used as inclusion criteria for our two study groups and the control group. The LCE angle is measured between a line drawn through the femoral head center and the most lateral portion of the acetabular roof and a perpendicular line through the femoral head center. The acetabular index (AI) is the angle between a line connecting the most medial and the most lateral portion of the acetabular roof and a horizontal line drawn through the most medial portion of the acetabular roof. DDH was defined as a LCE angle of less than 25° and an AI greater 14°. Pincer hips were defined as LCE angle greater 39°. Hips in the control group had a LCE angle between 25° and 39° and an AI between 0° and 14°.

Fig. 2 The anatomical dimensions of the iliocapsularis and rectus femoris muscle were evaluated on an axial MRI slice on the height of the femoral head center. Reproduced with permission from Klaus Oberli.

Fig. 3 Four study parameters were assessed on the axial MRI slice at the height of the femoral head center (F): cross-sectional area, thickness, width, and circumference of the iliocapsularis (IC) and rectus femoris (RF) muscle. Thickness (a and b) was measured along a radial line passing through the femoral head center (F). Width (c and d) was measured perpendicular to the thickness.

Fig. 4 The boxplots represent the iliocapsularis-to-rectus-femoris ratio of the cross-sectional area of the two study groups and the control group.

Fig. 5A-F Radiographs of two hips (A-B) with comparable acetabular coverage and no clear predominant pathophysiological problem are shown. In the corresponding axial MRI slice, the ratio of iliocapsularis (IC) to rectus femoris (RF) for the cross-sectional area is increased in the left hip (C) and slightly decreased in the right one (D). This indicates that DDH is the predominant pathophysiology in the hip on the left (E), whereas acetabular coverage seems not to be insufficient in the other hip (F). F = femoral head; AC = acetabulum; L = labrum; LT = transversum ligament; MA = gluteus maximus; ME = gluteus medius; MI = gluteus minimus; T = tenor fasciae latae; S = sartorius; I = iliacus; PA = psoas major; PI = psoas minor; PE = pectineus; OI = obturatorius internus; A = femoral artery; V = femoral vein; N = femoral nerve; FS = superficial fascia; SC = subcutaneous fatty tissue.