

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

Running title: Iliocapsularis-to-rectus Ratio

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1 **Abstract**

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

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

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

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

30 *Results* The iliocapsularis-to-rectus-femoris ratio for cross-sectional area, thickness, width,
31 and circumference was increased in hips with radiographic evidence of DDH (ratios ranging
32 from 1.31 to 1.35) compared with pincer (ratios ranging from 0.71 to 0.90; $p < 0.001$) and
33 compared with the control group, the ratio of cross-sectional area, thickness, width, and
34 circumference was increased (ratios ranging from 1.10 to 1.15; p ranging from 0.002 to
35 0.039). The area under the ROC curve ranged from 0.781 to 0.852. For a one-to-one
36 iliocapsularis-to-rectus-femoris ratio, the PPV was 89% (95% confidence interval [CI], 73%-
37 96%) for cross-sectional area, 77% (95% CI, 61%-88%) for thickness, 83% (95% CI, 67%-
38 92%) for width, and 82% (95% CI, 67%-91%) for circumference.

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

45 **Level of Evidence:** Level III, prognostic study.

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46 **Introduction**

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

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

64 A diagnostic test based on the size of the iliocapsularis would be an additional adjunct for
65 decision-making in these challenging hips. However, previously defined absolute measures
66 for the iliocapsularis muscle hypertrophy (cross-sectional area, thickness, width,
67 circumference [1]) are of little use in everyday clinical practice, because these may be driven

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68 more by the size and sex of the patient than by the pathology itself. Assessing the size of the
69 iliocapsularis muscle compared with adjacent anatomical structures--that is, calculating the
70 ratio of the size of this muscle to nearby, easily measured structures on MRI--would be more
71 beneficial. We have observed that the rectus femoris muscle could potentially serve as such a
72 reference, because the size of the rectus femoris remains relatively unchanged in patients with
73 various hip pathologies [4, 8, 11], in particular in its proximal aspect [5].

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

79 **Patients and Methods**

80 We retrospectively compared the anatomical dimensions of the iliocapsularis and rectus
81 femoris muscles between two study groups with different acetabular coverage with a control
82 group of asymptomatic patients. The local institutional review board approved this study. The
83 first study group consisted of 45 patients with 45 symptomatic hips resulting from deficient
84 acetabular coverage (dysplasia group). The second study group consisted of 37 patients with
85 40 symptomatic hips with as a result of excessive coverage (pincer group). The groups were
86 selected from a series of 421 patients (480 hips) with DDH or pincer-type femoroacetabular
87 impingement (FAI), who were seen at our outpatient clinic from November 1997 to October
88 2006. We excluded 42 patients (48 hips) with a history of known hip disorders (eg, Legg-
89 Calvé-Perthes disease), two patients (two hips) with muscle disorders (eg, muscle dystrophy),
90 79 patients (90 hips) with previous hip surgery, six patients (six hips) with skeletally

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91 immature hips (Stage 4 or less, according to Risser [16]), 12 patients (14 hips) with advanced
92 osteoarthritis (Stage 2 or greater, according to Tönnis [27]), and 51 patients (58 hips) with
93 incomplete or nondigital radiographic documentation [1]. This left 229 patients (262 hips).
94 The allocation to one of the two study groups was then based on the conventional radiography
95 only. The dysplasia group was defined by a LCE angle less than 25° [12] with a minimum
96 acetabular index of 14° measured on an AP pelvic radiograph [28] (Fig. 1). The pincer group
97 was defined as hips with a LCE angle exceeding 39° on the AP pelvic radiograph [22, 28]
98 (Fig. 1). One hundred forty-seven patients (177 hips) did not meet these radiographic criteria,
99 leaving 82 patients (85 hips) for evaluation, 45 patients (45 hips) for the dysplasia group and
100 37 patients (40 hips) for the pincer group. Among the 45 hips with hip dysplasia, there were
101 43 hips with Grade 1 and two hips with Grade 2 according to Crowe [2]. The demography of
102 these patients is comparable to other series available from the literature [18, 19]. Based on
103 chart review, none of the involved patients had an underlying neurological or muscular
104 disease.

105 As a control group of asymptomatic patients, we added 26 patients (30 hips) who had been
106 selected from a series of 117 patients (150 hips) with MRI involving the hip from our
107 institutional picture archiving and communication system between July 2010 and March
108 2013. Most of these MRIs were taken for nonorthopaedic reasons. The following exclusion
109 criteria were applied: known hip disease or pain or previous hip trauma (33 patients, 38 hips),
110 age younger than 16 years (20 patients, 35 hips), THA (10 patients, 11 hips), previous surgery
111 (six patients, eight hips), and incomplete data (22 patients, 28 hips). The demographic factors
112 of all three groups did not differ for sex, side, height, weight, or body mass index (Table 1).
113 The control group was older ($p < 0.001$).

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114 AP pelvic radiographs were performed according to a previously described standardized
115 technique [25] for both study groups. The patient was placed in a supine position with
116 internally rotated legs to compensate for femoral antetorsion. The film-focus distance was 1.2
117 m and the central beam was directed to the midpoint between the symphysis and a line
118 connecting the anterosuperior iliac spines [25]. One observer (DB) assessed the acetabular
119 morphology on AP pelvic radiographs using previously developed and validated software,
120 Hip²Norm (University of Bern, Bern, Switzerland) [23, 26, 30].

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

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

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137 The width was measured perpendicular to the thickness (Fig. 3). Prior investigation has shown
138 both excellent reproducibility with an intraclass correlation coefficient (ICC) ranging from
139 0.90 to 0.95 and a good reliability with an ICC ranging from 0.80 to 0.88 [1]. We then
140 compared the iliocapsularis-to-rectus-femoris ratio for each variable between the two study
141 groups. Commercially available software, Osirix (Version 6.0; Geneva, Switzerland), was
142 used for analysis [17].

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

151 Normal distribution was confirmed with the Kolmogorov-Smirnov test. We used analysis of
152 variance to compare demographic, radiographic, and the anatomical parameters among the
153 three groups. To compare binominal demographic data of the three groups, the Kruskal-
154 Wallis test was used. Results were expressed as mean with SD and range. We calculated the
155 95% confidence interval for the 2 x 2 tables. The power analysis was performed using
156 G*Power [6] (Version 3.1.9.2; University of Düsseldorf, Düsseldorf, Germany) based on the
157 primary research question (differences in the iliocapsularis-to-rectus-femoris ratio for the
158 cross-sectional area) and with the following parameters: α error 0.05, β error 0.80, a reported

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159 cross-sectional area of 2.5 cm² for the iliocapsularis muscle, an assumed cross-sectional area
160 of 1.8 cm² for the rectus femoris muscle, and a SD of 0.6 cm² [1]. This resulted in a minimal
161 sample size of 78 hips (39 hips for each group). Statistical analysis was performed using
162 MedCalc® (Version 14.12.0; MedCalc Software bvba, Ostend, Belgium).

163 **Results**

164 The iliocapsularis muscle showed an increased thickness, width, and circumference in the
165 dysplasia group compared with both pincer and control groups (p ranging from < 0.001 to
166 0.026; Table 2). The cross-sectional area of the iliocapsularis muscle was increased in the
167 dysplasia group compared with pincer (p < 0.001) but did not differ compared with the
168 control group (p = 0.464; Table 2). The rectus femoris muscle showed a decreased cross-
169 sectional area, thickness, width, and circumference in the dysplasia group compared with the
170 pincer group (p ranging from 0.001 to 0.045) but showed no difference compared with the
171 control group (p ranging from 0.330 to 0.967; Table 2). The iliocapsularis-to-rectus-femoris
172 ratio for cross-sectional area (Fig. 4), thickness, width, and circumference differed among the
173 three study groups (p ranging from < 0.001 to 0.039; Table 2). The highest ratios were found
174 in the dysplasia group ranging from 1.31 to 1.35 for the four study parameters (Table 2). The
175 lowest ratios were found in the pincer group with ratios ranging from 0.71 to 0.90 (Table 2).
176 With the sample numbers available, we could not determine the best parameter (cross-
177 sectional area, thickness, width, and circumference) for differentiating between the dysplastic
178 and the pincer group based on a standard 2 x 2 table where we evaluated sensitivity,
179 specificity, PPV, NPV, and overall accuracy. Similarly, area under the curve (AUC) values
180 for ROC curves were fair to good, but were similar for all four parameters. Using our chosen
181 one-to-one iliocapsularis-to-rectus ratio, we found sensitivities ranging from 71% to 80%.

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182 specificities ranging from 75% to 90%, and NPVs ranging from 71% to 78%. We found a
183 PPV of 89% (95% confidence interval [CI], 73%-96%) for cross-sectional area (indicating
184 that hip dysplasia was present in 89% of symptomatic hips), 77% (95% CI, 61%-88%) for
185 thickness, 83% (95% CI, 67%-92%) for width, and 82% (95% CI, 67%-91%) for
186 circumference (Table 3). Overall accuracy ranged from 74% to 80%. When we adjusted the
187 iliocapsularis-to-rectus ratio to achieve a PPV of 100% for each test parameter, we found a
188 ratio of > 1.08 for cross-sectional area, > 1.49 for thickness, > 1.26 for width, and > 1.28 for
189 circumference. The greatest area under the ROC curve was found for width (AUC 0.852)
190 followed by circumference (AUC 0.849), cross-sectional area (AUC 0.844), and thickness
191 (AUC 0.781; values between 0.80 and 0.90 are considered to reflect good accuracy, whereas
192 values between 0.70 and 0.80 are considered fair.

193 **Discussion**

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

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

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

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228 time-related correlation between the duration of the symptoms of the patients and the relative
229 size of the iliocapsularis muscle.

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

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

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251 iliocapsularis muscle compared with the anatomically adjacent rectus femoris muscle may
252 increase the practicability of using this parameter in everyday clinical practice. A one-to-one
253 iliocapsularis-to-rectus femoris ratio seems most practical in clinical routine use, ie, if the
254 cross-sectional area of the iliocapsularis exceeds the cross-sectional area of the rectus femoris
255 muscle, a DDH was present in 89% in our series (Table 3). A 100% PPV can be achieved
256 when a threshold of 1.08 is chosen for the cross-sectional area ratio. Besides this newly
257 described indirect sign for DDH, several other factors are suggestive of DDH such as
258 hypertrophy of the labrum, presence of ganglia, decentration of the femoral head, decreased
259 head sphericity and epiphyseal index, and an increased epiphyseal angle [9, 20]. In a selected
260 patient group of dysplasia patients compared to Pincer patients, for hypertrophy of the labrum
261 a PPV of 100% (95% CI 70-100%) with an accuracy of 93% (95% CI 83-100%) could be
262 shown [9]. In the same study, the presence of ganglia showed a PPV of 77% (95% CI 46-
263 94%) with an accuracy of 75% (95% CI 59-91%). For decentration of the femoral head on the
264 radial MRI slices as well as morphology of the head and epiphysis no data on test
265 performance is available in the literature. A future approach is to use a test like our new ratio
266 in concert with these other factors to get suggestive evidence about what the primary
267 pathology is that might be causing the symptoms. This is particularly important in hips with
268 questionable or mild dysplasia and a small cam-type deformity. Future studies should focus
269 on the diagnostic performance of a combination of these criteria for different
270 pathomorphologies.

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

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

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

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References

1. Babst D, Steppacher SD, Ganz R, Siebenrock KA, Tannast M. The iliocapsularis muscle: an important stabilizer in the dysplastic hip. *Clin Orthop Relat Res.* 2011;469:1728-1734.
2. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. *J Bone Joint Surg Am.* 1979;61:15-23.
3. Domb BG, Stake CE, Lindner D, El-Bitar Y, Jackson TJ. Arthroscopic capsular plication and labral preservation in borderline hip dysplasia: two-year clinical outcomes of a surgical approach to a challenging problem. *Am J Sports Med.* 2013;41:2591-2598.
4. Ema R, Wakahara T, Kanehisa H, Kawakami Y. Inferior muscularity of the rectus femoris to vasti in varsity oarsmen. *Int J Sports Med.* 2014;35:293-297.
5. Ema R, Wakahara T, Miyamoto N, Kanehisa H, Kawakami Y. Inhomogeneous architectural changes of the quadriceps femoris induced by resistance training. *Eur J Appl Physiol.* 2013;113:2691-2703.
6. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods.* 2007;39:175-191.
7. Grimaldi A, Richardson C, Stanton W, Durbridge G, Donnelly W, Hides J. The association between degenerative hip joint pathology and size of the gluteus medius, gluteus minimus and piriformis muscles. *Man Ther.* 2009;14:605-610.

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8. Ladjeroud S, Touraine S, Laouenan C, Parlier-Cuau C, Bousson V, Laredo JD. Impact of osteoid osteomas of the hip on the size and fatty infiltration of the thigh muscles. *Clin Imaging*. 2015;39:128-132.
9. Leunig M, Podeszwa D, Beck M, Werlen S, Ganz R. Magnetic resonance arthrography of labral disorders in hips with dysplasia and impingement. *Clin Orthop Relat Res*. 2004;418:74-80.
10. Leunig M, Werlen S, Ungersbock A, Ito K, Ganz R. Evaluation of the acetabular labrum by MR arthrography. *J Bone Joint Surg Br*. 1997;79:230-234.
11. Mendis MD, Wilson SJ, Hayes DA, Watts MC, Hides JA. Hip flexor muscle size, strength and recruitment pattern in patients with acetabular labral tears compared to healthy controls. *Man Ther*. 2014;19:405-410.
12. Murphy SB, Ganz R, Muller ME. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. *J Bone Joint Surg Am*. 1995;77:985-989.
13. Rasch A, Bystrom AH, Dalen N, Berg HE. Reduced muscle radiological density, cross-sectional area, and strength of major hip and knee muscles in 22 patients with hip osteoarthritis. *Acta Orthop*. 2007;78:505-510.
14. Rasch A, Bystrom AH, Dalen N, Martinez-Carranza N, Berg HE. Persisting muscle atrophy two years after replacement of the hip. *J Bone Joint Surg Br*. 2009;91:583-588.
15. Retchford TH, Crossley KM, Grimaldi A, Kemp JL, Cowan SM. Can local muscles augment stability in the hip? A narrative literature review. *J Musculoskelet Neuronal Interact*. 2013;13:1-12.

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16. Risser JC. The iliac apophysis; an invaluable sign in the management of scoliosis. *Clin Orthop Relat Res.* 1958;11:111-119.
17. Rosset A, Spadola L, Ratib O. OsiriX: an open-source software for navigating in multidimensional DICOM images. *J Digit Imaging.* 2004;17:205-216.
18. Steppacher SD, Anwander H, Zurmuhle CA, Tannast M, Siebenrock KA. Eighty percent of patients with surgical hip dislocation for femoroacetabular impingement have a good clinical result without osteoarthritis progression at 10 years. *Clin Orthop Relat Res.* 2015;473:1333-1341.
19. Steppacher SD, Tannast M, Ganz R, Siebenrock KA. Mean 20-year followup of Bernese periacetabular osteotomy. *Clin Orthop Relat Res.* 2008;466:1633-1644.
20. Steppacher SD, Tannast M, Werlen S, Siebenrock KA. Femoral morphology differs between deficient and excessive acetabular coverage. *Clin Orthop Relat Res.* 2008;466:782-790.
21. Sutter R, Kalberer F, Binkert CA, Graf N, Pfirrmann CW, Gutzeit A. Abductor tendon tears are associated with hypertrophy of the tensor fasciae latae muscle. *Skeletal Radiol.* 2013;42:627-633.
22. Tannast M, Hanke MS, Zheng G, Steppacher SD, Siebenrock KA. What are the radiographic reference values for acetabular under- and overcoverage? *Clin Orthop Relat Res.* 2015;473:1234-1246.
23. Tannast M, Mistry S, Steppacher SD, Reichenbach S, Langlotz F, Siebenrock KA, Zheng G. Radiographic analysis of femoroacetabular impingement with Hip2Norm-reliable and validated. *J Orthop Res.* 2008;26:1199-1205.

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24. Tannast M, Siebenrock KA. Imaging: Plain Radiographs. In: Sekiya JK, Safran MR, Leunig M, Ranawat AS, eds. *Techniques in Hip Arthroscopy and Joint Preservation Surgery*. Philadelphia, PA, USA: Saunders, Elsevier Inc; 2011:333.
25. Tannast M, Siebenrock KA, Anderson SE. Femoroacetabular impingement: radiographic diagnosis--what the radiologist should know. *AJR Am J Roentgenol*. 2007;188:1540-1552.
26. Tannast M, Zheng G, Anderegg C, Burckhardt K, Langlotz F, Ganz R, Siebenrock KA. Tilt and rotation correction of acetabular version on pelvic radiographs. *Clin Orthop Relat Res*. 2005;438:182-190.
27. Tönnis D. General radiography of the hip joint. In: Tönnis D, ed. *Congenital Dysplasia and Dislocation of the Hip in Children and Adults*. New York, NY: Springer; 1987:100-142.
28. Tönnis D, Heinecke A. Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. *J Bone Joint Surg Am*. 1999;81:1747-1770.
29. Ward WT, Fleisch ID, Ganz R. Anatomy of the iliocapsularis muscle. Relevance to surgery of the hip. *Clin Orthop Relat Res*. 2000;374:278-285.
30. Zheng G, Tannast M, Anderegg C, Siebenrock KA, Langlotz F. Hip2Norm: an object-oriented cross-platform program for 3D analysis of hip joint morphology using 2D pelvic radiographs. *Comput Methods Programs Biomed*. 2007;87:36-45.

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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

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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.

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