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Hip morphology and its relationship with hip strength, mobility and lower limb biomechanics: a systematic review in adults

Relação da morfologia do quadril com força, mobilidade e biomecânica dos membros inferiores: uma revisão sistemática em adultos

Adriana Ferraz[1]
https://orcid.org/0000-0003-2795-9353
Heiliane de Brito Fontana[2]
https://orcid.org/0000-0002-5797-1233
Marcelo Peduzzi de Castro[3]
https://orcid.org/0000-0002-4416-853X
Caroline Ruschel[1]
https://orcid.org/0000-0002-4263-850X
Carlos Alberto Atherinos Pierri[4]
https://orcid.org/0000-0001-8693-6296
Helio Roesler[1]
https://orcid.org/0000-0002-1631-6961

Abstract –This systematic review (PROSPERO registration n.43640) aimed to summarise and determine the quality of evidence relating hip bone morphology to (i) hip strength, (ii) mobility and (iii) lower limb biomechanics during functional activities. A standardized search on MEDLINE/PubMed, Web of Science, ScienceDirect and Scopus resulted in 17 papers that met inclusion criteria: i) original investigations with a minimal sample of n=10, ii) studies on humans and iii) presence of at least one quantitative hip morphological parameter and one hip functional (i.e. strength and mobility) and/or one lower limb biomechanical parameter. Risk of bias was assessed using the Quality Assessment of Diagnostic Accuracy Studies tool with adaptations. Sixteen out of the 17 included studies showed high risk of bias. We observed that primary evidence pointed to the influence of hip morphology on hip mobility in the transverse plane. Specifically, positive correlations between femoral anteversion angle and range of internal hip rotation in physical examination were observed. Regarding biomechanical parameters, no clear evidence of association between hip morphology, and kinematic and kinetic parameters were found. Our results point to a field that is currently under explored and future studies with low risk of bias addressing these relationships are required.

Key words: Anatomy; Femur; Lower extremity; Movement; Pelvic bones

Resumo – *Essa revisão sistemática (PROSPERO registro nº 43640) tem por objetivo sintetizar e determinar a qualidade da evidência que relaciona morfologia do quadril à (i) força do quadril, (ii) mobilidade e (iii) biomecânica dos membros inferiores durante atividades funcionais. Uma busca padronizada no MEDLINE/PubMed, Web of Science, ScienceDirect e Scopus resultou em 17 artigos em acordo com os critérios de inclusão: i) estudos originais com amostra mínima de n=10; ii) estudos em humanos e iii) presença de no mínimo um parâmetro quantitativo da morfologia do quadril e um parâmetro funcional do quadril (ex.: mobilidade e força) e/ou um parâmetro biomecânico do membro inferior. A avaliação do risco de viés foi realizada através da ferramenta Quality Assessment of Diagnostic Accuracy Studies (QUADAS) com adaptações. Dezesseis dos 17 estudos incluídos apresentaram alto risco de viés. Observamos que a evidência primária aponta para influência da morfologia do quadril em sua mobilidade no plano transverso. Foram observadas, especificamente, correlações positivas entre o ângulo de anteversão femoral e a mobilidade de rotação interna do quadril durante o exame físico. Em relação aos parâmetros biomecânicos, não foram encontradas evidências claras sobre associação entre morfologia do quadril e parâmetros cinemáticos e cinéticos. Nossos resultados apontam para um campo atualmente subexplorado e investigações futuras com baixo risco de viés que avaliem essas relações são necessárias.*

Palavras-chave: *Anatomia; Extremidade inferior; Fêmur; Movimento; Ossos pélvicos*

1 University of the State of Santa Catarina. Centre of Health and Sports Sciences. Florianópolis, SC. Brazil

2 Federal University of Santa Catarina. Centre of Biological Sciences. Florianópolis, SC. Brazil

3 Labclin Neuromusculoskeletal Rehabilitation and Clinical Biomechanics Laboratory. Florianópolis, SC. Brazil

4 Centre of Orthopedics and Rehabilitation. Florianópolis, SC. Brazil

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INTRODUCTION

Over the last two decades, great attention has been directed to the hip in the assessment and investigation of lower limb injuries and disorders[1–3]. There has been an increasing body of literature suggesting that poor biomechanical performance within the hip joint, such as hip weakness and limited range of motion, is linked to the development of lower limb injuries, such as knee joint pain and osteoarthritis[2–5], and to traumatic injuries, such as knee and ankle sprains[1–6].

During weight bearing activities, increased hip internal rotation and adduction was shown to be a risk factor[1] and associated factor[7] for lower limb disorders. These findings have directed the focus of prevention and rehabilitation programs towards achieving control of hip internal rotation during functional gestures[8,9]. However, despite this fairly common practice, our understanding towards non-modifiable and modifiable factors related to abnormal hip biomechanics is incipient.

Among parameters that are not modifiable – not without surgery, the femur and hip bone morphology are likely strong determinants of the mechanical environment and behaviour of hip joints. Hip morphology varies depending on age, gender, ethnicity, activity level and developmental stage[10,11]. It is known that increased femoral anteversion influences lower extremity alignment during standing and also changes hip muscles' moment arms and hip range of motion[12,13]. Modifiable factors are those related to muscle strength, joint mobility and motor control[2].

In some studies, deviations in hip morphology have been associated to the development of lower limb disorders[14,15]. However, this relationship is often non-specific, with many individuals presenting radiographic alterations and not evolving to lower limb injury or pain[11–16]. While, for example, cam morphology seems to be associated with hip osteoarthritis, odds ratio varies between 2.2 and 20.6[14,16], with most people with cam morphology not developing hip osteoarthritis[11]. In the case of other morphological findings, such as pincer morphology, femoral and acetabular orientation, associations to injury and/or pain during functional daily activities seem to be even harder to draw from the literature[11,17,18].

Given the complex relationship between hip morphology and injury, investigations focusing on intermediate parameters may help on the identification of subgroups of higher risk of becoming symptomatic and/or developing lower limb injuries. Characteristics that are worth considering may include hip muscle strength, hip mobility, and lower limb biomechanical behaviour during functional activities such as gait, squatting, etc. Investigations on that matter may help to clarify the level of association between changes in hip morphology and the development of musculoskeletal disorders and to identify modifiable intermediate risk factors to prevent, stop, or slow down disease progression and/or to avoid overtreatment.

This systematic review was designed to summarise and investigate the quality of current available evidence relating hip bone morphology to hip strength, mobility and lower limb biomechanics in humans.

METHODS

We performed this systematic review according to the recommendations contained in *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA)[19,20]. The protocol was registered within the *International prospective register of systematic reviews* (PROPESRO) under the number 43640.

After a careful preliminary assessment of the literature related to hip morphology and clinical and biomechanical parameters, the three following sets of key words were elaborated: i) morphology set, ii) imaging findings set and iii) functional parameters set. For keywords within a set, the command OR was used in order to represent a given construct, while, between sets, the command "AND" was used to limit the search to the association between constructs (Box 1).

Box 1. Search strategy in MEDLINE (via Pubmed).

1#	hip OR femur OR femoral OR "iliac bone" OR acetabulum OR acetabular OR pelvis OR pelvic
2#	morphology OR morphological OR morphologic OR anatomy OR anatomical OR "caput-collum-diaphyseal angle" OR "neck-shaft angle" OR "coxa valga" OR "coxa vara" OR "femoral version" OR "femoral anteversion" OR "femoral neck anteversion" OR "femoral retroversion" OR "femoral neck retroversion" OR "femoral shape" OR "acetabular version" OR "acetabular anteversion" OR "acetabular retroversion" OR "center edge angle" OR "angle of Wiberg" OR "Wiberg angle" OR "Wiberg's angle" OR "angle of Lequesne" OR "vertical-center anterior angle" OR "cross-over sign" OR "alpha angle" OR "anterior offset" OR "X-ray" OR radiograph OR radiographic OR radiography OR radiographical OR "computed tomography" OR CT OR "magnetic resonance" OR MRI OR "Lyon's protocol" OR "tibial tubercle-trochlear groove distance" OR "tibial tuberosity-trochlear groove" OR TT-TG
3#	strength OR torque OR moment OR isokinetic OR mobility OR "range of motion" OR "range of movement" OR kinematics OR kinematical OR biomechanics OR biomechanical
Search	1# AND 2# AND 3#
Filters	1# title 2# title-abs 3# title-abs

Prior to the official search, these key words were used to verify in the Cochrane and PROSPERO database whether a similar systematic review had been published or registered. No relevant results were found. For the official search, four databases were screened from the date they were concepted to July 2016: MEDLINE/PubMed, Web of Science, ScienceDirect e Scopus. Last search was performed in July 2016. According to each database, filters were used (Figure 1). Inclusion criteria were: i) original investigations with a minimal sample of 10 participants per group comparison, ii) studies on humans, iii) presence of quantitative hip morphological parameters and quantitative hip functional parameters and/or lower limb biomechanical parameters.

Articles that were not available in full format or articles that contained morphological findings that solely represent the progression of joint diseases were excluded from the analysis. No language restrictions were imposed.

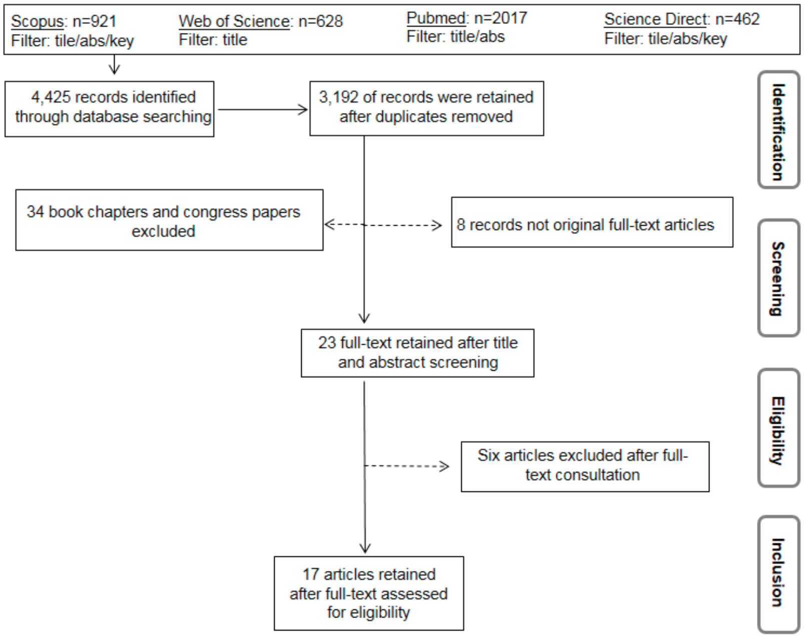

Figure 1. Systematic review diagram.

Three independent reviewers conducted the selection process. First, Reviewer #1 excluded duplicates, editorials, case studies, incomplete articles and non-original investigations. Second, Reviewers #1 and #2 analysed all titles and excluded unrelated titles. After reading all selected abstracts, articles that could potentially fit to the inclusion/exclusion criteria were evaluated in their full format and a final independent decision was made by reviewers. The list of references cited in each article was screened for potential inclusion in the review. Third, in case of disagreement between reviewers #1 and #2 that persisted after discussion, reviewer #3 was consulted.

Bias and quality analysis of the selected papers was performed using a set of questions that were adapted from the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool[21]. QUADAS contains 14 questions that are answered with "yes", "no" or "unclear". The instrument used in this systematic review was composed of 12 items (in contrast to 14 in the original QUADAS). Maximum score was 12 and meant that the paper met all requirements listed for a good quality. If the information was "unclear", the item was scored with 0 points, similarly to answer "no". As a cut point, articles that scored nine points or more, were considered of high quality, while articles that scored below nine were considered of poor methodological quality[22].

For the analysis of associations between morphology and functional parameters the following interpretation of correlation scores was adopted: r values between 0 and 0.20 were considered indicative of a very poor correlation; r values between 0.21 and 0.40, a poor correlation; between 0.41 e 0.60, moderate; 0.61 and 0.80, high and r values greater than 0.80 were considered indicative of an excellent correlation[23].

RESULTS

Up to the date this review was submitted (June, 2019), no systematic review addressing the relationship between hip morphological parameters and functional parameters of the lower limbs had been registered or published.

Our search returned 4425 titles, with 17 papers remaining eligible at the end of the selection process (Figure 1). Characteristics of individual studies are presented in Table II. The number of participants evaluated per study varied from 10[24] to 221[25]. Morphological parameters of interest were evaluated primarily with radiographs[25–34] followed by MRI[27–30,35–37] and computed tomography[24,25,27,38]. Only 1 study used bone densitometry[39].

The femoral version angle[24,25,27–29,31,35,37,38], the alpha angle[24,28–30,35,36,38,40] and the lateral centre-edge angle[25,29,31,32,34,35,38] were the most commonly evaluated morphological parameters. The neck-shaft angle[24,28,31,37–39], acetabular version angle[25,28,38], acetabular index[31,33,34], anterior centre-edge angle[31,33], acetabular depth[28], Idelberger and Frank angle[33] and Sharp angle[32] were also used. Some studies listed variables in the methods that were not presented in the results section[27,30]. An index relating the femoral and acetabular version angles was introduced by Chadayammuri et al.[25] (Box 2).

In the case of studies that focused on movement biomechanics[26,30,31,34,37–39], kinematic parameters were most often evaluated using infrared cameras[31,34,37,39], electromagnetic tracking[26] and inertial systems[30,38]. Ground reaction forces were assessed with force platforms[30,31,37], and plantar pressure distribution with insole systems and pressure platforms[30,36].

Muscle strength was assessed based on torque capacity or force against resistance. All contractions were isometric and the peak force achieved was the parameter estimated[34,37,39].

Thirteen studies verified hip mobility[24,27–35,38,40]. Functional questionnaires containing qualitative assessment of hip mobility were used in some studies[31–34]. Hip passive range of motion in the transverse plane was evaluated for hip internal and/or external rotation[24,27–30,32–35,38–40]. Positions for testing were supine with hip flexion[24] supine with hip extension[38] and prone[25]. Sagittal plane hip range of motion was evaluated for hip flexion[25,27,28,32–35,38] and extension[28,33], and frontal plane hip range of motion was evaluated for abduction and adduction[25,27,28,32,33,35].

Concerning the quality assessment of studies, raters independently agreed in 61.8% of the items (126) scored in the risk of bias scale, while, for the remaining 38.2%, agreement was met after discussion (Table 1). The study with the lowest score[40] received 4/12 points and the one with the highest score[37] received 10/12 points. A representative sample of the population of interest was present in only seven studies[28,30,36,38–40], with most studies based on samples that were not randomly selected. In addition, in most studies (9 out of 17), the selection criteria were not clear (Item 2)[25,28,30,31,33,36,38–40].

Box 2. Summary of studies included in this systematic review.

Studies	Aims	Participants	Instruments and Procedures	Outcomes, Unit
Asayama et al[26]	To define the necessary conditions between the femoral offset and reconstructed hip joint position to obtain a negative Trendelenburg sign after total hip arthroplasty.	30 patients; 34 limbs with total hip arthroplasty, 18 limbs symptomatic and 8 limbs with hip osteoarthritis.	Electromagnetic tracking instrument used to measure angle and standard anteroposterior hip radiographs. Trendelenburg test for 30s and retest after 30min rest. The angle formed by the line between the bilateral ASIS and the line between the ASIS and tibial tuberosity were measured on the stance limb side. The Trendelenburg test results were determined by the agreement of at least 3 of 4 orthopaedic surgeons. Standard anteroposterior hip radiographs measures.	The angle at 30 seconds after starting the Trendelenburg test was subtracted from the angle at 0 seconds to give the tilt angle of the pelvis by the Trendelenburg test (°). Femoral offset (FO), body-weight lever arm and the distance between the centers of rotation of the bilateral femoral heads (CC) were measured on each radiograph. The femoral offset ratio (%FO) was calculated (FO/CCx100).
Baggaley et al[39]	To investigate the relationship between hip anatomy, hip abductor muscular strength, and frontal plane hip kinematics during running in healthy active females.	25 female participants (18-40y) who ran for at least 30 min, three times per week.	Dynamometer, biomechanical analysis with cameras motion capture system (retro-reflective markers), dual femur DXA scan and a tape measure. Three 5s maximal voluntary isometric contractions. The mean torque of the three trials was calculated based on the subject's femur length and then divided by the body mass. The running speed on a treadmill was adjusted to a standardised speed of 2.7 m/s while kinematic data were collected for a period of 10s. Pelvis width was defined as the inter-ASIS distance, and femur length as the distance from the most prominent aspect of the greater trochanter to the knee joint line.	Femoral neck shaft angle (°); pelvis-width/femur length (PW–FL) ratio. Hip abduction strength (maximal voluntary isometric contractions) (Nm/Kg); isometric hip abduction strength % body weight. Hip adduction (peak and excursion) (°).
Bedi, et al[24]	To use computer-assisted 3D modeling to determine objective differences in hip flexion and internal rotation before and after in vivo arthroscopic surgical treatment of symptomatic FAI.	10 patients (mean age, 25.9 years; range, 19-31 years) with symptomatic FAI in the absence of significant chondral degeneration (Tönnis < 2) or previous surgery.	Preoperative and postoperative CT and goniometer. Preoperative and postoperative alpha angle, preoperative neck-shaft angle and preoperative femoral version. Preoperative and postoperative hip internal rotation (assessed at 90° of hip flexion).	Alpha angle (°), neck-shaft angle (°), femoral version (°). Hip internal rotation (°).
Botser, et al[27]	To evaluate the correlation between CT and MRI measurements of femoral anteversion, as well as to investigate the relationship between anteversion and physical examination (ROM).	123 patients, 129 hips, the mean age was 36 years (range, 14 to 74 years; 75 female and 54 male). Patients who had both preoperative CT and MRI scans with adequate knee and hip views for anteversion measurement. Patients with Tönnis arthritic grade 3 and those with any previous hip condition were excluded from the study.	Anteroposterior pelvic view and Dunn view x-rays, MRI and CT. Preoperative hip internal and external rotation were evaluated in a supine position with both the hip and knee joint flexed to 90°. Center-edge angle of Wiberg (AP view), alpha angle (MRI and the Dunn view), version of the femoral neck (CT and MRI).	Version of the femoral neck on CT and MRI (°). Abduction, flexion, internal rotation and external rotation hip range of motion (°).

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Chaday-ammuri et al[25]	To evaluate whether hip ROM was associated with femoral torsion and acetabular version	221 patients (64 males, 157 females) with a mean age of 32.5 ± 11.0 years undergoing hip arthroscopy.	Anteroposterior pelvic radiographs and CT. Measurements of hip passive flexion and rotational ROM (internal and external rotation) at 90° of hip flexion in the supine position. The abduction ROM was measured at a neutral hip position (0° of flexion/extension) with the patient in supine. Measurements of internal and external rotation ROM at a neutral hip position were performed with the patient lying prone.	Femoral torsion (°), central acetabular version (°), lateral center-edge angle (°). Femoral torsion-acetabular version (COTAV) index (the sum of femoral torsion and acetabular version components) (°). Passive hip flexion (°), abduction (°), IR (°) and ER (°) ROM (at 90° of hip flexion) with the patient placed in supine position. Hip IR (°) and ER (°) ROM with the patient in the prone position.
Crawford et al[38]	To compare passive and real-time active hip ROM in asymptomatic collegiate pitchers, to investigate whether differences in hip morphology and ROM exist between lead and trail hips, and to relate active hip ROM during the pitch to hip morphology and FAI.	11 baseball collegiate pitchers (mean age 20.4 years, SD 1.6 years) with no previous hip surgery and able to complete standard pitching practice.	Goniometer, full-body inertial-based motion-capture system suit (inertial-based motion-capture system) and CT. Passive ROM of each hip (supine position): flexion, internal rotation in extension, external rotation in extension, internal rotation in 90° of flexion, and external rotation in 90° of flexion (for rotational testing in extension, the knees were flexed over the end of the examination table and the pelvis remained secured to the table). The ROM data extracted from the kinematic testing included maximal hip flexion, extension, adduction, abduction, internal rotation, and external rotation during the pitching motion (wind-up to follow-through). Femoral neck version, femoral neck-shaft angle, alpha angle, acetabular version and lateral center-edge angle.	Hip passive ROM in flexion (°), IR in extension (°), ER in extension (°), IR in flexion (°), ER in flexion (°), total arc of rotation motion (IR + ER) in extension (°) and total arc of rotation motion (IR + ER) in flexion (°). Hip active ROM in flexion (°), extension (°), adduction (°), abduction (°), IR (°), ER (°) and total arc of rotation (IR + ER). Femoral version (°), femoral neck-shaft angle (°), alpha angle (°), acetabular anteversion (°) and lateral center-edge angle (°).
Duthon et al[28]	To clinically evaluate professional female dancers' hips with measurement of the passive ROM and to correlate clinical findings with magnetic resonance imaging (MRI) examination.	Twenty female ballet dancers (39 hips) (mean age, 26 years; age range, 18 to 39 years) and 14 active healthy female individuals as a control group (28 hips) (mean age, 27 years; age range, 20 to 34 years).	Handheld goniometer and MRI. Hip passive ROM for flexion/extension, abduction/adduction (back-lying with hip and knee in extension) and internal/external rotation (back-lying with hip and knee flexed at 90°). Acetabular depth, acetabular version, femoral alfa neck angle, femoral neck-shaft angle and femoral neck anteversion for dancers and control group.	Hip passive ROM in flexion (°), extension (°), abduction (°), adduction (°), IR (°) and ER (°). Femoral neck-shaft angle (°), femoral neck anteversion (°), acetabular depth (mm), acetabular version (°) and alpha neck angles (°).
Ejnisman et al[35]	(1) To describe values for femoral anteversion measured using MRI in patients undergoing hip arthroscopy for FAI; (2) to report the relationship between physical examination findings and femoral version in these patients; and (3) to report the relationship between the degree of femoral anteversion and intraoperative findings during hip arthroscopy.	188 patients (204 hips): 100 men and 88 women with a mean age of 35 years (range, 18 to 62 years).	Goniometer, radiographic views included an anteroposterior pelvic view, a cross-table lateral view, and a false-profile view, MRI. Range of motion was measured in all planes, including abduction, adduction, flexion, and internal and external rotation. Internal and external rotation measurements were performed with the patient lying in the prone position on the examination table. The alpha angle was measured in the cross-table lateral view, the lateral center-edge angle was measured on the anteroposterior view and the femoral anteversion was measured on MRI.	Hip ROM: abduction (°), adduction (°), flexion (°), ER (°) and IR (°). Femoral anteversion (°), lateral center-edge angle (°) and alpha angle (°).

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Ferro et al[29]	To determine whether outcomes after hip arthroscopy were different based on femoral version.	Patients who underwent a primary hip arthroscopy with a diagnosis of FAI who had preoperative measurement of femoral version by MRI were aged older than 18 years, and had a center-edge angle of more than 20º. 180 patients.	MRI, Radiographs included an anteroposterior pelvic view, a cross-table lateral view and a false-profile view. A standard clinical examination including hip ROM measurements. Alpha angle (measured on the cross-table lateral view), femoral version (MRI) and center-edge angle.	Alpha angle (º), center-edge angle (º) and femoral version (º). Hip ROM in IR (º) and ER (º).
Hagen et al[36]	To investigate plantar pressure distribution during walking in male soccer players with increased alpha angles and age-matched soccer players with normal alpha angles.	Male soccer players were recruited from teams from the fourth to the eighth German division. 10 soccer players with normal hip alpha angles <50º and 10 soccer players with bilaterally increased hip alpha angles >55º. All of them asymptomatic.	A capacitive pressure distribution platform embedded in a gangway was used to collect plantar pressure patterns during barefoot walking. MRI. Walking speed was prespecified at 1.6 m/s. Five parameters were investigated: contact area, peak pressure, pressure-time integral, force-time integral and relative loads, calculated as the percentage of the local force-time integral in relation to the total force-time integral in 10 areas of the foot (lateral and medial heel, lateral and medial midfoot, lateral, central and medial forefoot, hallux, second toe and third to fifth toes). Alpha angle.	Contact area (cm^2), peak pressure (kPa), pressure-time integral (kPa.s), force-time integral (N.s) and relative loads (%). Alpha angle (º).
Lahner et al[30]	To compare the foot rollover process during running between male semiprofessional soccer players with increased alpha angles and age-matched amateur soccer players.	14 male semiprofessional soccer players and 14 male amateur soccer players.	MRI, a piezoelectric force platform, an accelerometer, an electrogoniometer, regular running shoe and the same shoe with inserted valgus wedges. Alpha angle of the right hip (in all cases, the right leg was the kicking leg). In a biomechanical laboratory setting, each participant of both groups ran in two shoe conditions across a piezoelectric force platform. Running speed was controlled. Simultaneously, in-shoe pressure distribution (on seven anatomical locations of the foot: medial and lateral heel; lateral midfoot; first, third and fifth metatarsal heads; hallux), tibial acceleration and rearfoot motion measurements of the right foot were performed.	Alpha angle (º). Loading rate (bw/s), peak tibial acceleration (g), median power frequency (Hz), peak vertical force (bw), peak horizontal force (bw), horizontal impulse (bw.s), maximum rearfoot motion (°), peak pressure lateral heel (kPa), peak pressure medial heel (kPa), peak pressure lateral midfoot (kPa), peak pressure metatarsal head V (kPa), peak pressure metatarsal head III (kPa), peak pressure metatarsal head I (kPa), peak pressure hallux (kPa).
Lahner et al[40]	To investigate the technical aspect and accuracy of Kinect for the evaluation of the hip ROM compared to clinical and radiological findings.	24 hip joints of 24 patients (8 men and 16 women) with no previous hip surgery, inflammatory or metabolic rheumatic disease. The mean age was 46.8 ± 10.6 years (range 27–61 years).	Standing anteroposterior (AP) radiograph, goniometer, Kinect for Windows camera. Alpha angle. Flexion, extension, abduction, adduction, internal and external rotation hip passive ROM. Detection points for the joint position were provided and the actual position of the study participant was described as a vector. The Kinect system connects vectors as a triangle between the examined hip and both knee joints.	Alpha angle (º). Hip IR ROM (º). Kinect system values for motion (º).

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Romano et al[31]	To obtain an accurate description of the main variables characterizing locomotion of adult subjects affected by the residua of congenital dysplasia of the hip.	21 subjects (6 men and 15 women) who had residua of unilateral congenital dysplasia of the hip, with no previous operative or non-operative treatment for the hip, and no other disability related to a bone or a joint. The mean age was 48 years (range, 25 to 71 years). Control population of 40 subjects (14 men and 26 women who did not have any known abnormality of the locomotor apparatus. The mean age of the control subjects was 46 years (range, 31 to 71 years).	An anteroposterior radiograph of the pelvis and an axial radiograph (false-profile radiograph of Lequesne and de Seze) of both hips, kinematic data (4 video câmeras ELITE system) and a force platform. Clinical assessment of both hips from all of the subjects was performed with use of the Harris hip score. The Wiberg angle, the Tönnis angle, the neck shaft angle (anteroposterior radiograph of the pelvis), anterior center-edge angle (false-profile radiograph) and femoral anteversion (technique of Magilligan) of all subjects who had residua of congenital dysplasia of the hip were assessed. Kinematic and kinetics data evaluation. The measurements were made while the subjects walked barefoot on a ten-meter-long walkway. Natural cadence. Joint angles, moments, and powers were calculated. Spatiotemporal parameters, (the length of the stride, the length of the step, duration of stride, the mean velocity of progression, foot velocity).	Harris Hip Score (points). Drop of the pelvis (º), trajectory of the pelvis projected on a horizontal plane (º). Spatiotemporal parameters: gait velocity (% height/s), length of stride (% height), duration of stride cycle (s), duration of stance phase (% duration of stride), difference in stance phase (% duration of stride), duration of double support (% duration of stride), difference in double support (% duration of stride), length of step (% height), difference in length of step (% duration of stride), foot velocity (% height/s), difference in foot velocity (% height/s). The Wiberg angle (º), the Tönnis angle (º), the neck shaft angle (º), anterior center-edge angle (º) and femoral anteversion (º).
Siebenrock et al[33]	To evaluate the clinical course after acetabular reorientation and to describe the intra-articular findings related to the FAI.	22 patients (29 acetabula, 19 of male patients and 10 of female patients).	Merle d'Aubigné and Postel score, anteroposterior pelvic radiographs and a false-profile radiograph. The range of hip joint motion was measured and clinical evaluation with use of the score described by Merle d'Aubigné and Postel was performed preoperatively and at the last follow-up evaluation. Preoperative and postoperative radiographic measurements included the lateral center-edge angle, the acetabular index; the ACM angle according to Idelberger and Frank for evaluating the depth of the acetabulum, and the anterior center-edge angle on a false-profile radiograph.	Merle d'Aubigné score (points), Hip ROM: flexion, extension, ER, IR, adduction and abduction (º). The lateral center-edge angle, the anterior center-edge angle, the ACM angle, the acetabular index (º).
Siebenrock et al[32]	To report the ten-year results of a previously described patient cohort on corrective periacetabular osteotomy for the treatment of symptomatic acetabular retroversion.	22 patients, 13 men and 9 women; 29 hips, 19 male and 10 female, who had corrective periacetabular osteotomy for symptomatic acetabular retroversion.	Merle d'Aubigné and Postel score, goniometer, anteroposterior pelvic radiograph and a false-profile view. Full hip ROM. Thirteen radiographic parameters.	Merle d'Aubigné score (points). Hip ROM: flexion, IR in 90º of flexion, ER in 90º of flexion, abduction and adduction (º). The lateral center-edge angle, the Sharp angle (º).

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Souza et al[37]	To determine if hip-muscle performance and femoral structure differ between women with patellofemoral pain and pain-free controls, and to determine to what degree these measures predict average hip internal rotation during running.	19 women with patellofemoral pain (age 27 ± 6 years) and 19 pain-free women (control group) (age 26 ± 4 years).	Three-dimensional motion analysis was performed using a computer-aided video motion analysis system. Ground reaction forces were obtained using force plates. Strength testing was performed using a dynamometer. Femoral shape was quantified using MRI. Kinematic evaluation during running at a fixed velocity. The kinematic variable of interest was average hip internal rotation angle during the first 50% of the stance phase of running. Hip strength was performed in 4 different positions: standing pelvic drop (isometric, isokinetic, and isotonic endurance), seated hip external rotation (only isometric endurance), prone hip extension (isometric, isokinetic, and isotonic endurance) side-lying hip abduction (only isometric endurance). Femoral inclination and femoral anteversion hip.	The average hip internal rotation angle during the first 50% of the stance phase of running (º). Isometric pelvic drop, isometric hip ER, isometric hip extension isometric side-lying abduction (Nm/kg). Isokinetic pelvic drop concentric, isokinetic pelvic drop eccentric, isokinetic hip extension concentric, isokinetic hip extension eccentric (Nm/kg). Isotonic endurance pelvic drop, isotonic endurance hip extension (repetitions). Femoral structure (º): femoral anteversion and femoral inclination.
Tannast et al[34]	To present a selected series of symptomatic patients with total acetabular retroversion after reorientation for residual dysplasia. To investigate what is the clinical and radiographic presentation of these hips, what was their surgical management; and what is the clinical and radiographic outcome following corrective surgery.	26 patients, 26 hips.	Medical Research Council muscle strength grading system, the Merle d'Aubigné-Postel score and the anteroposterior pelvic radiograph. Hip ROM (flexion and internal/external rotation in 90° of flexion or in maximal flexion if less than 90°, limp, abduction force according to the Medical Research Council muscle strength grading system and clinical assessment were evaluated by the Merle d'Aubigné-Postel score. 13 radiographic results before and after corrective periacetabular osteotomy.	Limp (% positive), abduction force (M0-M5), ROM: flexion, IR and ER (º), Merle d'Aubigné-Postel score (points). Anteroposterior pelvic radiograph parameters: total Retroversion (%), crossover sign (% positive), retroversion index for hips with a positive cross over sign (%), ischial spine sign (% positive), sinal da posterior wall sign (% positive), absence of posterior wall (% positive), total anterior coverage (%), total posterior coverage (%), total cranio-caudal coverage (%), lateral center-edge angle (º), acetabular index (º), extrusion index (%), Shenton line (% intact).

Note. ASIS = anterior superior iliac spine. CT = computed tomography. ER = external rotation. FAI = femoroacetabular impingement. HHS = Harris Hip Score. IR = internal rotation. MRI = magnetic resonance imaging. ROM = range of motion. SD = standard deviation.

In 15 out of 17 studies, the imaging exam used was considered appropriate for the morphological parameter of interest (Item 3). However, in 1 study[39] the measurement of the neck-shaft angle was performed using densitometry; in another study[40], the alpha angle was measured using an anteroposterior incidence. Both imaging procedures may be considered inappropriate for the measurement of interest. In relation to the time between exams and the possibility of change in the parameters of interest, both reviewers agreed that the time was often irrelevant given the time required to modify a morphological measurement (Item 4). However, there were studies that involved participants with degenerative alterations, in which the time between exams could potentially influence results but was not mentioned[34]. In three studies[31,32,38], the exam of interest was not applied to the entire sample and the choice of which participants would or would not take the exam was not random (Item 5).

Table 1. Methodological quality of the included studies.

Studies	Item											
	1	2	3	4	5	6	7	8	9	10	11	12
Asayama et al[26]	N*	Y	Y	Y	Y	Y	Y	NC	NC	Y	NC*	NC*
Baggaley et al[39]	Y	NC*	N*	Y*	Y	Y	Y	NC	NC	Y	NC*	NC*
Bedi et al[24]	N*	Y	Y	Y	Y	Y	N*	NC	NC*	Y	NC*	NC*
Botser et al[27]	N*	Y	Y	Y*	Y	NC*	Y	NC*	NC*	Y	Y*	Y
Chadayammuri et al[25]	N*	NC*	Y	Y*	Y	NC*	N*	Y*	Y	Y	N	Y*
Crawford et al[38]	Y*	N*	Y	Y*	N*	Y	Y	NC	NC	Y	NC*	NC*
Duthon et al[28]	Y	NC*	Y	Y*	Y	NC*	Y	NC	NC	Y	N*	N
Ejnisman et al[35]	N*	Y	Y	Y*	Y	Y	Y	NC	NC	Y	NC*	N*
Ferro et al[29]	N*	Y	Y	Y*	Y	NC*	Y	NC	NC	Y	N	Y*
Hagen et al[36]	Y	N*	Y	Y*	Y	Y	N*	NC	NC*	Y	Y	NC*
Lahner et al[30]	Y	NC*	Y	Y*	Y	Y	Y	NC	NC	Y	NC*	N*
Lahner et al[40]	Y*	N	N*	Y*	Y	N	N	NC	NC	Y	N	N
Romanò et al[31]	N*	NC*	Y	Y*	N*	Y	Y	NC	NC	Y*	NC*	NC
Siebenrock et al[33]	N	N	Y	Y	Y	N	Y*	NC	NC	Y	Y	Y*
Siebenrock et al[32]	N*	Y	Y	Y	N*	N*	Y*	NC	NC	Y	N*	Y*
Souza et al[37]	Y	Y	Y	Y*	Y	Y	Y	NC	NC	Y	Y	Y
Tannast et al[34]	N	Y	Y	NC*	Y	NC*	NC*	NC*	NC*	N*	Y	Y*

Note. * symbol means agreement was met after discussion. N: no; Y: yes; NC: not clear. Item 1: Do participants' characteristics represent the population of interest? Item 2: Are the selection criteria clearly defined? Item 3: Does the imaging technique measure appropriately the morphological parameter proposed? Item 4: Is the time interval between measurements of morphology and biomechanical parameters short enough to assure that values have not changed between tests?
Item 5: Was all the sample or a randomized selection of sample analysed through the same imaging technique? Item 6: Is the biomechanical measuring parameter described in enough detail to allow replication? Item 7: Is the morphological measuring parameter described in enough detail to allow replication? Item 8: Were the biomechanical parameters measured and interpreted without previous knowledge of the results of the imaging exam? Item 9: Was the imaging exam interpreted without previous knowledge of the results of biomechanical parameters? Item 10: Is it clear what happened to all participants in the study? Item 11: Is the descriptive statistical procedure appropriate? Item 12: Is the inferential statistical procedure appropriate?

In relation to the biomechanical measurements, nine studies[24,26,30,31,35–39] described the procedures with enough detail to allow for replication (Item 6). The most commonly missing information in studies seemed to be the description of instruments[25,27,29] and patient positioning[29,33,39,40] used in the assessment of hip range of motion. With regards to the imaging exam procedure (Item 7), five studies did not seem to provide enough detail to allow for replication. Only one study clearly stated that measurements were blinded between the morphological and biomechanical tests (items 8 and 9)[25].

Considering the sample participation, one study did not clearly describe what happened to all participants that were initially included in the study (item 10)[34]. Five studies[27,33,34,36,37] presented a clear descriptive analysis of data, with mean/median and dispersion statistics (Item 11). With regards to the inferential statistics (Item 12), seven studies[25,27,29,32–34,37] introduced a correlation analysis.

Significant correlations between morphological and biomechanical parameters were found in some studies[25,27,29,30,35,36,37], while in some others descriptive statistics allowed for the exploration of possible associations between morphology and the parameters of interest in this review [24,25,29,30,35,36,38,40]. The significance, context and interpretation of these relationships are specified in the discussion section.

DISCUSSION

Based on the parameters evaluated, 16 out of the 17 studies performed poorly in the risk of bias and quality assessment with only one study reaching a score equal or above 9 in the scale and being considered of high quality[37]. We speculate the high risk of bias present in the literature regarding the relationship between morphological and biomechanical parameters is likely related to the difficulty in inspecting hip morphology in healthy control individuals and to the cost and ethical issues related to imaging tests. The results of our analysis emphasize the need of interpreting available evidence with caution.

Significant correlations between morphological and biomechanical parameters were found in some studies[25,29,30,36]. Patients with small femoral offset were associated to a greater pelvic drop in the Trendelenburg test (r=0.416; p=0.0137)[26]. In a study with female runners[39], a moderate correlation between neck-shaft angle and the strength of hip abductor muscles was found (r=-0.47; p=0.02) but not between neck-shaft angle and gait kinematic parameters.

Significant correlations were also observed in studies that focused in patients that had undergone hip video arthroscopy. In a study with 123 patients[27], the femoral anteversion angle was found to be related to the range of internal rotation in physical examination (r=0.36; p<0.001). Ejnisman et al.[35] evaluated 188 patients and also found a similar correlation (r=0.231; p=0.002) accompanied with a negative correlation between femoral anteversion and external rotation (r=-0.208; p=0.027). It is important to note however that despite reaching statistical significance, all observed correlations are poor, indicating that other parameters may contribute largely. Finally, Souza and Powers[37] investigated biomechanical and morphological factors related to hip internal rotation angle at the first 50% of stance phase during running in female runners with patellofemoral pain syndrome. No significant relationship was found between hip internal rotation and femoral version or neck-shaft angle (p=0.11 and p=0.10; respectively).

Some studies presented descriptive analysis that allow for the exploration of possible associations between morphology and the parameters of interest in this review. Chadayammuri et al.[25] grouped 221 patients in I) femoral version <10º; II) femoral version between 10 and 20º and III) femoral version >20º and found that internal rotation range of movement was significantly greater at group III, followed by II and I (40.7±14.8º, 30.9±11.8º and 24.8±12.5º respectively; p<0.001). An opposite effect was found for external rotation (28.6±11.7º; 26.4±10.4º; 22.7±11.8º for group I, II and III respectively; p<0.001). Ejnisman et al.[35] grouped patients in I) femoral version <5°; II) femoral version between 5 and 15°; and III) femoral version > 15°. Group I presented significantly greater range of movement towards external rotation (45±14°, 38±12° and 36±13° for group I II and III, respectively). No significant differences between groups were observed for internal rotation. Ferro et al,[29] using the same grouping criteria, also found that internal rotation increased, and external rotation decreased from group I to II and from group II to III.

We found only one study that focused on the potential effect of acetabular version angle on hip mobility. Chadayammuri et al.[25] grouped individuals in I) acetabular version >20º; II) acetabular version between 15 and 20º and III) acetabular <15º and identified that individuals in group I presented greater range of movement towards internal rotation than others. External rotation, however, did not seem to be affected by acetabular version. Besides the differences in the transverse plane, authors also found that hip flexion range of movement was significantly smaller for hips with the acetabulum retroverted – group III (104.6±17.6º) compared to normal hips or increased acetabular version (110.6±12.3º and 112.1±12.3º respectively) ($p<0.001$).

Chadayammuri et al.[25] also analysed the combination of acetabular (normal, anteversion and retroversion) and femoral version (normal, anteversion and retroversion), resulting in nine different groups. Overall, hips with femoral anteversion and acetabular anteversion exhibited the greatest internal rotation range of motion at a neutral hip position (44.2º), whereas hips with femoral retroversion and acetabular retroversion demonstrated the lowest corresponding value (20.1º; $p<0.001$). A combined femoral-acetabular version (COTAV) index was calculated as the sum of femoral and acetabular version angles. The COTAV was considered excessive if >45º, normal if between 20º and 45º, or reduced if <20º. A multiple linear regression analysis indicated that the COTAV index increased approximately 0.5º per degree increase in internal rotation range of movement and 0.26º per one year increase in age ($R^2=0.384$, $p<0.001$).

Bedi et al.[24] found that after an arthroscopic resection of cam deformity in patients with femoroacetabular impingement syndrome, the reduction in the alpha angle (59.8º to 36.4º; $p<0.001$) was accompanied by a significant increase in hip internal rotation range (17.5 ±11.4º to 31 ±8.43º). Lahner et al.[40] also found that individuals with hip alpha angles ≤55º presented a slightly greater range of hip internal rotation when compared to hip alpha angles >55º (27.6±5.1º versus 24.2±8.5º, respectively).

Investigations regarding morphological and biomechanical parameters in the sport context were found[30,36,38]. Hagen et al.[36] investigated differences in plantar pressure distribution during walking between male soccer players with alpha angle >55º or <50º and found that a greater alpha angle was accompanied with a smaller hallux contact area, smaller force and pressure integral on the rearfoot region and greater force integral on the medio-lateral region of the foot. Lahner et al.[30] compared amateur to professional soccer players with regards to hip alpha angle and plantar pressure distribution and rearfoot motion during running. Although plantar pressure parameters differed between them, no significant differences in alpha angle were observed. Crawford et al.[38] compared the alpha angle between the front and rear leg in baseball players and, despite the exposure to different kinematics during the throwing motion, no differences in hip morphology were found.

In general, there seems to be a significant relationship between femoral and acetabular version angles and hip mobility in the transverse plane. Most of the evidence available points to a small effect on range of motion with little being known about possible effects of morphology on movement biomechanics. Although there is a theoretical expectation of hip morphology to affect strength at a certain degree due to changes in moment arms, only one study was found supporting experimental evidence towards this hypothesis[39].

Some limitations should be considered in this systematic review. Although no restrictions in language were imposed to the search, the fact that only English keywords were entered may have restricted access to some non-English papers. With regards to the instrument used to access quality and risk of bias, although the original QUADAS scale from which the instrument was created has been extensively used, the adaptations made for the purpose of this review have not been validated. Finally, we used a cut point of 70% of affirmative responses to define a study of high quality[22], while there has been criticism on the use of scores to classify studies on quality[21].

CONCLUSION

This study assessed the quality and summarized the evidence available on the role of hip morphology in determining hip strength, mobility and the biomechanics of lower limb movement during functional and sport activities. Literature in the area is limited and the studies available are mostly accompanied by a high risk of bias. Primary evidence seems to be focused on the influence of hip morphology on the hip mobility in the transverse plane, primarily on changes in range of motion. With regards to biomechanical parameters that could provide insights into the association between hip morphology and kinematic and kinetic characteristics of movement, we were not able to draw a clear conclusion based on the available findings. Our results point to a field that is currently under explored and future studies addressing these relationships will be beneficial to our understanding of modifiable and non-modifiable parameters related to lower limb disorders.

COMPLIANCE WITH ETHICAL STANDARDS

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Ethical approval

This research is in accordance with the standards set by the Declaration of Helsinki.

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Conception and design of the experiment: MPC, AF, HBF and CAAP. Realization of the experiments: AF, HBF and MPC. Data analysis: AF and HBF. Contribution with reagents/research materials/analysis tools: AF, HBF and MPC. Article Writing: AF, HBF, MPC, CR and HR. All authors read and approved the final version of the manuscript.

REFERENCES

1. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes: A Prospective Study. Am J Sports Med 2005;33(4):492-501.
2. Powers CM. The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. J Orthop Sports Phys Ther 2010;40(2):42-51.
3. Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip Strength in Females With and Without Patellofemoral Pain. J Orthop Sport Phys Ther 2003;33(11):671-676.
4. Casartelli NC, Maffiuletti NA, Item-Glatthorn JF, Staehli S, Bizzini M, Impellizzeri FM, et al. Hip muscle weakness in patients with symptomatic femoroacetabular impingement. Osteoarthr Cartil 2011;19(7):816-821.
5. Magalhães E, Fukuda TY, Sacramento SN, Forgas A, Cohen M, Abdalla RJ. A Comparison of Hip Strength Between Sedentary Females With and Without Patellofemoral Pain Syndrome. J Orthop Sport Phys Ther 2010;40(10):641-647.
6. Friel K, McLean N, Myers C, Caceres M. Ipsilateral hip abductor weakness after inversion ankle sprain. J Athl Train 2006;41(1):74-78.
7. Souza RB, Powers CM. Differences in Hip Kinematics, Muscle Strength, and Muscle Activation Between Subjects With and Without Patellofemoral Pain. J Orthop Sport Phys Ther 2009;39(1):12-19.
8. Van Der Heijden RA, Lankhorst NE, Van Linschoten R, Bierma-Zeinstra SM, Van Middelkoop M. Exercise for treating patellofemoral pain syndrome: an abridged version of Cochrane systematic review. Eur J Phys Rehabil Med 2016;52(1):110-133.
9. Thomson C, Krouwel O, Kuisma R, Hebron C. The outcome of hip exercise in patellofemoral pain: A systematic review. Man Ther 2016;26:1-30.
10. Laborie LB, Engesæter IØ, Lehmann TG, Sera F, Dezateux C, Engesæter LB, et al. Radiographic measurements of hip dysplasia at skeletal maturity—new reference intervals based on 2,038 19-year-old Norwegians. Skeletal Radiol 2013;42(7):925-935.
11. van Klij P, Heerey J, Waarsing JH, Agricola R. The Prevalence of Cam and Pincer Morphology and Its Association With Development of Hip Osteoarthritis. J Orthop Sport Phys Ther 2018;48(4):230-238.
12. Arnold AS, Komattu AV, Delp SL. Internal rotation gait: a compensatory mechanism to restore abduction capacity decreased by bone deformity. Dev Med Child Neurol 1997;39(1):40-44.
13. Neumann DA. Kinesiology of the Hip: A Focus on Muscular Actions. J Orthop Sport Phys Ther 2010;40(2):82-94.
14. Gosvig KK, Jacobsen S, Sonne-Holm S, Palm H, Troelsen A. Prevalence of Malformations of the Hip Joint and Their Relationship to Sex, Groin Pain, and Risk of Osteoarthritis. J Bone Joint Surg Am 2010;92(5):1162-1169.
15. Doherty M, Courtney P, Doherty S, Jenkins W, Maciewicz RA, Muir K, et al. Nonspherical femoral head shape (pistol grip deformity), neck shaft angle, and risk of hip osteoarthritis: A case-control study. Arthritis Rheum 2008;58(10):3172-3182.

16. Bardakos NV, Villar RN. Predictors of progression of osteoarthritis in femoroacetabular impingement. J Bone Joint Surg Br 2009;91-B(2):162-169.
17. Frank JM, Harris JD, Erickson BJ, Slikker W 3rd, Bush-Joseph CA, Salata MJ, et al. Prevalence of Femoroacetabular Impingement Imaging Findings in Asymptomatic Volunteers: A Systematic Review. Arthrosc J Arthrosc Relat Surg 2015;31(6):1199-1204.
18. Mascarenhas VV, Rego P, Dantas P, Morais F, McWilliams J, Collado D, et al. Imaging prevalence of femoroacetabular impingement in symptomatic patients, athletes, and asymptomatic individuals: A systematic review. Eur J Radiol 2016;85(1):73-95.
19. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 2009;62(10):e1-34.
20. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Ann Intern Med 2009;151(4):264-269.
21. Whiting P, Rutjes AWS, Reitsma JB, Bossuyt PMM, Kleijnen J. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Med Res Methodol 2003;3:25.
22. Cook C, Mabry L, Reiman MP, Hegedus EJ. Best tests/clinical findings for screening and diagnosis of patellofemoral pain syndrome: a systematic review. Physiotherapy 2012;98(2):93-100.
23. Williams R, Binkley J, Bloch R, Goldsmith CH, Minuk T. Reliability of the modified-modified Schöber and double inclinometer methods for measuring lumbar flexion and extension. Phys Ther 1993;73(1):33-44.
24. Bedi A, Dolan M, Hetsroni I, Magennis E, Lipman J, Buly R, et al. Surgical Treatment of Femoroacetabular Impingement Improves Hip Kinematics: a computer-assisted model. Am J Sports Med 2011;39(Supplement 1):43S-49S.
25. Chadayammuri V, Garabekyan T, Bedi A, Pascual-Garrido C, Rhodes J, O'Hara J, et al. Passive Hip Range of Motion Predicts Femoral Torsion and Acetabular Version. J Bone Joint Surg Am 2016;98(2):127-134.
26. Asayama I, Naito M, Fujisawa M, Kambe T. Relationship between radiographic measurements of reconstructed hip joint position and the Trendelenburg sign. J Arthroplasty 2002;17(6):747-751.
27. Botser IB, Ozoude GC, Martin DE, Siddiqi AJ, Kuppuswami S, Domb BG. Femoral Anteversion in the Hip: Comparison of Measurement by Computed Tomography, Magnetic Resonance Imaging, and Physical Examination. Arthrosc J Arthrosc Relat Surg 2012;28(5):619-627.
28. Duthon VB, Charbonnier C, Kolo FC, Magnenat-Thalmann N, Becker CD, Bouvet C, et al. Correlation of Clinical and Magnetic Resonance Imaging Findings in Hips of Elite Female Ballet Dancers. Arthrosc J Arthrosc Relat Surg 2013;29(3):411-419.
29. Ferro FP, Ho CP, Briggs KK, Philippon MJ. Patient-centered outcomes after hip arthroscopy for femoroacetabular impingement and labral tears are not different in patients with normal, high, or low femoral version. Arthroscopy 2015;31(3):454-459.
30. Lahner M, von Schulze Pellengahr C, Walter PA, Lukas C, Falarzik A, Daniilidis K, et al. Biomechanical and functional indicators in male semiprofessional soccer players with increased hip alpha angles vs. amateur soccer players. BMC Musculoskelet Disord 2014;15(1):88.
31. Romano C, Frigo C, Randelli G, Pedotti A. Analysis of the Gait of Adults Who Had Residua of Congenital Dysplasia of the Hip. J Bone Joint Surg Am 1996;78(10):1468-1479.
32. Siebenrock KA, Schaller C, Tannast M, Keel M, Büchler L. Anteverting Periacetabular Osteotomy for Symptomatic Acetabular Retroversion. J Bone Joint Surg Am 2014;96(21):1785-1792.

33. Siebenrock KA, Schoeniger R, Ganz R. Anterior femoro-acetabular impingement due to acetabular retroversion. Treatment with periacetabular osteotomy. J Bone Joint Surg Am 2003;85-A(2):278-286.
34. Tannast M, Pfander G, Steppacher SD, Mast JW, Ganz R. Total acetabular retroversion following pelvic osteotomy: presentation, management, and outcome. Hip Int 2013;23 Suppl 9(Suppl 9):S14-26.
35. Ejnisman L, Philippon MJ, Lertwanich P, Pennock AT, Herzog MM, Briggs KK, et al. Relationship Between Femoral Anteversion and Findings in Hips With Femoroacetabular Impingement. Orthopedics 2013;36(3):e293-e300.
36. Hagen M, Abraham C, Ficklscherer A, Lahner M. Biomechanical study of plantar pressures during walking in male soccer players with increased vs. normal hip alpha angles. Technol Heal Care 2015;23(1):93-100.
37. Souza RB, Powers CM. Predictors of Hip Internal Rotation during Running. Am J Sports Med 2009;37(3):579-587.
38. Crawford EA, Whiteside D, Deneweth JM, Ross JR, Bedi A, Goulet GC. In Vivo Hip Morphology and Kinematics in Elite Baseball Pitchers. Arthroscopy 2016;32(5):798-805.
39. Baggaley M, Noehren B, Clasey JL, Shapiro R, Pohl MB. Frontal plane kinematics of the hip during running: Are they related to hip anatomy and strength? Gait Posture 2015;42(4):505-510.
40. Lahner M, Mußhoff D, Von Schulze Pellengahr C, Willburger R, Hagen M, Ficklscherer A, et al. Is the Kinect system suitable for evaluation of the hip joint range of motion and as a screening tool for femoroacetabular impingement (FAI)? Technol Heal Care 2015;23(1):75-82.

Corresponding author
Adriana Ferraz.
Laboratório de Pesquisas em Biomecânica
Aquática. Rua Pascoal Simone, 358 - Coqueiros,
Florianópolis - SC, 88080-350, Brazil.
E-mail: adriana15ferraz@gmail.com