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Hip joint mobility in relation to measurement position, gender and limb dominance

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Purpose: The purpose of this study was to determine whether three different measurement position yield divergent results in ROM using a goniometer, and how is it affected by anthropometrical factors. *Methods*: We measured the range of rotation in the hip joint in healthy participants aged 21.6 ± 1.88, seeking to determine how the distribution of internal vs. external rotation (RI) within the total range of mobility (TR) was influenced by the measurement position used, the gender of the participant, and the dominant lower limb. *Results*: We found that not only gender and limb dominance, but also the body position in which hip joint's range of motion is measured significantly affects the values of TR and RI. We found that TR achieves the highest values in the prone position – PrP (males: 95.35 ± 12.44 and 93.15 ± 12.49; females: 103.75 ± 14.87 and 106.25 ± 15.56) and the lowest values in supine position – SuP (male: 62.65 ± 8.51 and 57.85 ± 9.60; female: 59.5 ± 12.27 and 55.85 ± 8.54). The analysis shows that CERD occurs <0.42 RI in females (PrP) and <0.88 RI in men (PrP and sitting position – StP), and CIRD >1.72 RI in women (StP), and >2.08 RI in men (PrP). *Conclusions*: Due to the similarities between asymmetry of internal/external rotation in the hip joint and asymmetry in the rotation of the shoulder found in Glenohumeral Internal Rotation Deficit (GIRD), we propose the concepts of Coxal Internal Rotation Deficit (CIRD) and Coxal External Rotation Deficit (CERD) as tools to indicate the possibility for injury to the hip joint, and propose threshold rotation index values serving as indicators of these deficits.

Key words: *hip joint, rotation, GIRD, limb dominance, range of motion*

1. Introduction

A symmetrical and correct range of rotation (ROM) of the hip joint and the distribution of internal and external rotation in that joint are crucial for the movement of the pelvis in the gait cycle, and thus important for various activities of everyday life [19]. ROM of the hip joint in different maneuvers is determined by the morphology of the pelvis and femur, and their interaction with the soft tissues surrounding the joint, such as the labrum, joint capsule, ligaments, and muscles. Limited or asymmetrical ROM of the hip joint has been shown to predispose individuals for injuries such as tearing of the anterior cruciate ligament (ACL) [23], pain in the hip joint or in the lumbar spine [26], [30], and to be a sign of generalized joint hypermobility [7], arthroplasty or total hip replacement [18]. Taking measurements of the ROM – by means of a goniometer, inclinometer, or other method – is one of the most common and widely used methods of assessing the condition of the musculoskeletal system, including of the hip joint [24].

At the same time, values of the total range (TR) of motion of the hip joint and the distribution of internal rotation (IR) and external rotation (IR) of the hip joint are known to vary by sex [6], [9], level of physical activity [3], [4], sports discipline practiced, dominant limb [2] and by the body position in which the measurement was taken. Previous studies have shown strong positive correlations of hip rotation in static position with hip rotation during dynamic activities, whereby internally rotated hips in the static position are also internally rotated during dynamic activities (gait) [32].

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Moreover, rotation in the hip joint is a clinically important measurement that is used in planning femoral derotation osteotomies [33]. Measurements of the internal and external rotation of the hip can be performed in one of three positions: prone position (PrP – front lying/lying face down, with the knee joint flexed to a 90° and hip joint in neutral), seated position (StP – sitting at the end of the measurement table, with lower legs hanging freely, and the hip and knee joint flexed to a 90° angle) or in supine position (SuP – lying back, with one lower leg hanging freely from the table with a 90° angle in the knee joint and hip joint in neutral position and with the contralateral leg placed in flexion in both the hip and the knee joint with the heel resting on the table). However, there is no clear agreement between authors about what position of the hip joint during examination is the most effective from the diagnostic point of view. According to the American Academy of Orthopedic Surgeons, the StP position has become the reference for the measurement of hip rotation, and it should be 45° ER and 45° IR [29]. Kouyoumdjian et al. [19], on the other hand, reported that the highest values of TR and IR were measured in the sitting position, and found no statistically significant differences in the values of TR, IR and ER between the three measurement positions. Prather et al. [24] acknowledged sitting position as the most reliable for such measurements, whereas Gradoz et al. [9] recognized supine position as the most reliable position. In prone position (PrP), with the hip joint in the intermediate position, movement of external rotation will be mainly restricted by strong ligaments in front of the hip: iliofemoral ligament and pubofemoral ligament and, to a lesser extent, by muscles whose function is the internal rotation of the hip joint; m. gluteus minimus and tensor fasciae latae [5]. The gluteus medius and the tensor fasciae latae belong to the strongest pelvic and hip stabilizers. Lower tension in the aforementioned ligaments can be the result of increased antetorsion of the neck of the femur, which can result in limitation of rotation. Internal rotation may be limited by strong external rotators of the hip. In the StP position, as a result of the angle of the hip, there is decreased tension of the joint capsule and the ligaments of the hip, additionally the muscles of the front of the hip are in less tense position and, as a result, there is an increase in the total/global range of motion. The third position, SuP, causes increased tension in front of the hip joint and limitation of the range of external rotation of the hip joint [15], [22].

As has recently been noted in the literature, there are certain interesting similarities between the hip joint and the glenohumeral joint [31]. Although the functions of the two joints are different, given that the lower limbs are used for support and gait and the upper limbs for manipulation, they are of a similar type, with three degrees of freedom, movements take place in three planes of space (frontal, sagittal and transverse) and articular labrum [15]. Scher et al. [28] concluded that there is a complex relationship between hip and shoulder ROM during the throwing motion in baseball players. Moreover, limited IR of the glenohumeral joint, in turn, has been shown to correlate with increased risk of injury. Athletes who perform throws on a regular basis exhibit altered shoulder rotation distribution, with IR being reduced and ER greater in the dominant vs. non-dominant limb. This distribution might be the result of changes in the bone structure (retroversion angle of the head of the humerus), joint capsule (thickening of the posterior part) or muscles (passive rigidity, thixotropy) [17]. This syndrome has been called Glenohumeral Internal Rotation Deficit (GIRD) [16]. The aforementioned similarities of anatomy and function between the hip joint and the glenohumeral joint raise the possibility that there might be a syndrome similar to GIRD occurring in the hip joint. Our own observations and clinical practice suggest that this may indeed be the case.

Unfortunately, normative data for the range of motion of rotation of the hip joint (ROM) in the healthy population is scarce and the available data is not up to date [4]. Moreover, such statistics usually relate to multi-joint measurements or groups with different conditions.

The aim of the present study, therefore, was to assess the range of rotation in the hip joint in healthy participants and to determine how the distribution of internal vs. external rotation within the total range of mobility was influenced by the measurement position used, the sex of the participant and the dominant lower limb. We anticipated that such an assessment of rotation symmetry may provide some preliminary insight into potential GIRD-like rotation distributions within the hip joint.

2. Materials and methods

2.1. Patients

A total of 40 healthy university students majoring in physiotherapy (20 males and 20 females) were enrolled in the study. The inclusion criteria were as follows: no pain present in the musculoskeletal system,

Table 1. Participants' anthropometric values

	n	age [years]	BMI [kg/m^2]	body mass [kg]	body heigh [cm]	WC [cm]	HC [cm]
F	20	21.5 ± 1.82	22.76 ± 2.16	63.74 ± 7.82	167.15 ± 5.99	76.25 ± 7.37	97.38 ± 7.81
M	20	21.7 ± 1.98	24.01 ± 2.85	77.49 ± 11.80	179.45 ± 7.13	82.75 ± 9.55	97.3 ± 7.52
Total	40	21.6 ± 1.88	23.39 ± 2.57	70.62 ± 12.09	173.3 ± 9.00	79.5 ± 9.04	97.34 ± 7.57

F – females; M – males; WC – waist circumference; HC – hip circumference.

no restriction in activities of daily living as self-reported by the participants, age between 20 and 25 years old and moderate physical activity. Participants with past injuries to the lower limb, such as developmental issues (e.g., diagnosed hip dysplasia or acetabular impingement), fractures, surgeries or receiving treatment for sprains, were excluded from this study, as were participants reporting high physical activity. The study included 40 participants (20 female and 20 male). The age of the participants was 21.6 ± 1.88 years. Their anthropometric values are shown in Table 1. All subjects provided written informed consent prior to data collection. Ethical clearance for the study was granted from the local Ethics Committee (SKE 01-45/2021). This work was supported by the Ministry of Science and Higher Education in 2020–2022 under Research Group No. 3 at Józef Piłsudski University of Physical Education in Warsaw "Motor system diagnostics in selected dysfunctions as a basis for planning the rehabilitation process".

2.2. Methods

To ensure reliability and reproducibility, the same protocol was performed on all subjects by one physiotherapist with more than 20 years of clinical experience, with the assistant writing down results and adding stabilization. Measurements of internal and external rotation in hip joints were obtained with the participant in three positions: ventral decubitus (prone position – PrP), dorsal decubitus (supine position – SuP) and seated (seated position – StP) with the hip in flexion. A standard long-arm goniometer Saehan™ Grip 20 cm was used, having a reported accuracy within 1° and a range of 360°.

To determine the dominance of the lower extremity, each participant performed a kicking task. They were asked to kick a stationary soccer ball at a target using their preferred lower extremity. The participants completed three trials of this activity. The leg the participant chose to kick the ball at least two out of the three trials was defined as their dominant extremity, and other one as the support (non-dominant) extremity.

2.3. Procedures

To assure proper measurements of internal and external rotations, proper stabilization is essential. This was achieved by proper positioning of the participant. Additionally, participants were secured to the therapy table with straps to rule out any compensations or excessive movements.

In the prone position (PrP), the participant was positioned so as to avoid unbalanced positioning of the neck and the trunk. The participant's ipsilateral knee was flexed to a 90° angle and the pelvis was stabilized with a belt through the line of the superior posterior iliac spines and with manual pressure applied by an assistant, to prevent flexion of the hip joint and to remain in neutral position at 0°. The goniometer was placed so that the axis of the goniometer was placed at the apex of the patella, with the arms of the goniometer parallel to the anterior border of the tibia and pointing towards the ceiling. The value of rotation was the deviation from the zero starting position.

In the supine position (SuP), in turn, the participant was positioned with their knee bent to a 90° angle and hanging from the end of the table, with the femur lying parallel to the table allowing the hip joint to remain in neutral 0°. The contralateral knee was fully flexed to a 140° angle, in turn resulting in an around 60° (not measured) angle of the hip, permitting for the heel to be planted on the edge of the treatment table and as an added method of stabilization for the pelvis, and as means to allow for a clear rotation of the hip on the opposite side. The straps were placed across the pelvis of the participant through the line of the superior anterior iliac spines of the pelvis. The axis of the goniometer was placed at the apex of the patella, with one of the arms of the goniometer parallel to the shin and the other perpendicular to the floor (in the transverse plane of motion in relation to the participant lying on the therapy table). The moving arm of the goniometer followed the anterior border of the tibia in both internal and external rotation and the value of rotation was the deviation from the zero starting position.

Fig. 1. Three positions of hip rotation measurements: PrP, SuP, StP (from left side)

In the seated position (StP), the participant was positioned at the end of the therapy table with knees and hips flexed to a 90° angle, with the lower leg hanging from the table and the femurs fully supported on the table. The upper limbs were crossed on the chest and the participant was stabilized by an assistant sitting in back-to-back position. The goniometer was placed identically as in the supine position (SuP) and the value of rotation was the deviation from the zero starting position. All positions of the hip measurements are presented in Fig. 1.

2.4. Statistical analysis

Statistical analysis was performed using STATISTICA 13.0 (StatSoft). The Shapiro–Wilk test indicated that the distribution of variables did not differ from normal. To confirm the interaction between position of measurement, sex and side of measurement, a two-way analysis of variance (ANOVA) test was applied, followed by post-hoc Tukey's HSD test. Partial η^2 was used as a measure of effect size. The level of significance was set at $p \leq 0.05$.

3. Results

3.1. Total rotation (TR)

Our findings indicate that the total range of rotation within the hip joint (TR), being the summation of external (ER) and internal (IR) rotation, significantly depends on the position in which the measurement is performed ($F_{2,76} = 356.59$; $p < 0.0001$; $\eta^2 = 0.90$). Post-hoc tests revealed statistically significant differences in TR that occur between all measurement positions (PrP, SuP, StP) ($p < 0.0001$). The mean values of TR are presented in Table 2.

Table 2. Indicators of TR in relation to gender and measurement position

Position	Lower limb	TR $n = 20$	TR $n = 20$
		M	F
PrP	D	95.35 ± 12.44#	103.75 ± 14.87
	N	93.15 ±12.49	106.25 ± 15.56
SuP	D	62.65 ± 8.51	59.5 ± 12.27
	N	57.85 ± 9.60	55.85 ± 8.54
StP	D	68.65 ± 12.33	78.1 ± 11.87
	N	68.2 ± 10.10	79.3 ± 12.19

TR – total rotation; D – dominant lower limb; N – non--dominant lower limb; PrP – prone position; SuP – supine position; StP – seated position; M – males; F – females; # – differences between females and males.

In all the positions shown above, TR differentiates between male and female groups ($F_{2,76} = 12.01$; $p < 0.0001$; $\eta^2 = 0.24$). The only position in which the differences were found to be statistically significant is PrP ($p < 0.044$). In addition, we found an interaction between POSITION × SIDE ($F_{2,76} = 5.90$; $p = 0.041$; $\eta^2 = 0.13$). In the supine position, TR was significantly different between dominant (D) and non-dominant (N) lower limb ($p < 0.0024$). The results of the aforementioned analysis are presented in Fig. 2.

3.2. Rotation index (RI)

For statistical analysis, we calculated the ratio of ER to IR of the hip joint, which we call the rotation index (RI). Here, all passive ROM measurements of the hip joint were taken into account, in both the

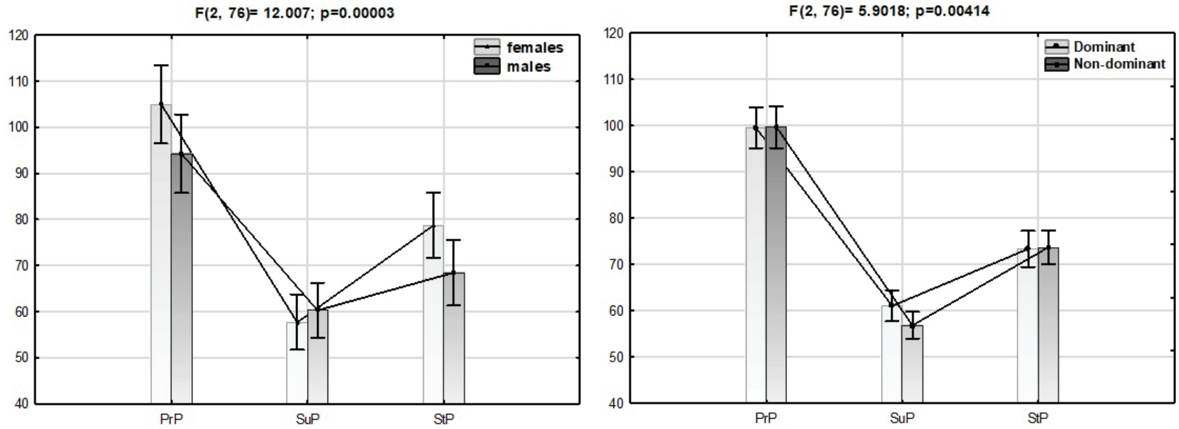

Fig. 2. Differences in TR in relation to measurement position, broken down by gender (left) and by dominant and non-dominant limb (right) PrP – prone position; SuP – supine position; StP – seated position

dominant (D) and non-dominant (N) lower limbs and in all three measurement positions: PrP, SuP, StP.

Table 3. Values of the RI parameter in three positions

Position	Lower limb	RI $n = 20$	RI $n = 20$
		M	F
PrP	D	1.42 ± 0.40*	0.91± 0.45
	N	1.36 ± 0.38*	0.81 ± 0.32
SuP	D	1.70 ± 0.59*#	0.97 ± 0.35
	N	1.97 ± 0.93*#	0.85 ± 0.33
StP	D	1.43 ± 0.42*	0.92 ± 0.22
	N	1.32 ± 0.44*	0.96 ± 0.23

RI – Rotation Index; PrP – prone position; SuP – supine position; StP – seated position; M – males; F – females; D – dominant limb; N – non-dominant limb; * – difference between body position in males; # – differences between females and males.

In the male group, the RI values were strongly affected by the measurement position. Statistically significant differences were observed at $p < 0.001$ between all positions – PrP and SuP; PrP and StP; SuP and StP. In the female group no such relationship was observed. However, there was a significant interaction between POSITION × SIDE × GENDER ($F_{2,76} = 4.40$; $p = 0.0155$; $\eta^2 = 0.104$). Post-hoc tests showed significant differences between the F and M groups in SuP position in both D and N limbs ($p = 0.0001$) (Table 3).

3.3. CIRD and CERD

Based on the literature, cut-off points were determined for the lowest and highest 10% values of the RI ratio. A logarithmic transformation of the RI indicators was performed in order to normalize their distribution. We defined the range of values of 0–10% of RI as the Coxal External Rotation Deficit (CERD), and the 10% of values as the Coxal Internal Rotation Deficit (CIRD). The precise results of the above analysis in different measurement positions in groups of men and women are shown in Table 4.

Table 4. CIRD and CERD values

Gender	Rotation deficit	PrP	SuP	StP
F	CERD	$x < 0.42$	$x < 0.57$	$x < 0.66$
	CIRD	$x > 1.55$	$x > 2.28$	$x > 1.72$
M	CERD	$x < 0.88$	$x < 0.97$	$x < 0.88$
	CIRD	$x > 2.08$	$x > 2.61$	$x > 2.12$

CERD – coxal external rotation deficit; CIRD – coxal internal rotation deficit.

4. Discussion

Range of motion (ROM) measurements belong to the most commonly used methods for joint diagnostics. Our results indicate that the position in which the ROM is assessed does indeed significantly affect the resulting measurements of total rotation (TR) of the hip joint. We found that TR achieves the highest values in the prone position (PrP), with the lower leg bent at the knee joint to a 90° (male: D – 95.35 ± 12.44 and N – 93.15 ± 12.49; female: D – 103.75 ± 14.87 and N – 106.25 ± 15.56), and the lowest values in supine position (SuP), with the lower leg outside the table and the unmeasured limb supported on the table (male: D – 62.65 ± 8.51 and N – 57.85 ± 9.60; female: D – 59.5 ± 12.27 and N – 55.85 ± 8.54).

Similar results were presented by Han et al. [11]. They reported that higher values of passive TR in prone position (PrP) may be the consequence of the force of gravity supporting the movement during the measurement, whereas in supine (SuP) or seated (StP) position the movement is conducted against the force of gravity. It is clinically significant that the difference in tension of the capsular, ligament and muscle structures is highly affected by the body position of the subject. In the seated position the structures that are located in the posterior part of the hip joint are more tensed than in PrP, whereas the anteriorly placed structures are more relaxed. Han et al. [11] did not assess TR of the hip joint in SuP. Moreover, Aefsky et al. [1] concluded that the rotation of the hip with external load may be measured in a clinical setting with moderate to good reliability, but it can be significantly reduced in relation to the movement with no external load.

Notably, Kouyoumdjian et al. [19] did not observe statistically significant differences in TR in terms of measurement position. However, they did report that the lowest range of rotation was obtained in the SuP. In our results presented above, the significant differences between the rotation values depending on measurement position may be the result of slight modifications to their starting positions. In the SuP, the lower limb was placed on the measuring table to increase stabilization. As a consequence, there was a slightly different position of the subject's pelvis: posterior pelvic tilt on the non-measured side and an increase in the tension of connective tissue structures in the anterior part of the joint on the measured side, which exerted a great impact on the range of rotation. Gradoz et al. [9] also reported that ranges of rotation of the hip are determined by the position in which the measurement is conducted. However, this phenomenon might also be the result of the evolutionary process of switching to an upright position, which, in turn, required a more vertical position of the femoral bones (a more extended position in the hip joint) and the formation of curvatures in the spine. The development of lumbar lordosis was paramount for gait and running stride, but, in turn, caused a tendency for injury and strain by overloading [13]. Switching to an upright position resulted in the loss of congruency in the hip joint. In the extended position of the hip joint, the femoral head is no longer covered by the joint socket on the front [15].

We found that women achieved a statistically significantly higher values of TR only in the PrP position. In the male group, higher TR was found in the SuP position, although this was not statistically significant. This may be associated with lower tension of the connective tissue structures in the anterior-lateral region of the hip joint in PrP and StP position in the male group, whereas increased tension of the area is more commonly associated with females [8], [27]. Moreover, we analyzed the relevance of dominant lower limb for differences in TR and found that TR differed significantly between dominant (D) and non-dominant (N) limb in the supine position (SuP).

However, instead of the total rotation (TR) of the hip joint, the ranges of external rotation (ER), internal rotation (IR) and their ratio seem to be much more important. According to the American Academy of Orthopedic Surgeons, the ranges of ER and IR of the hip joint should be similar, at 45° [18] whereas Zembaty et al. [34], state that the values should be in between the range of 35–40°. Many studies and clinical observations indicate that the distribution of the range of rotation in the hip joint is not symmetrical [12], [30]. Moreover, asymmetry in the distribution of rotation is often the component causing disorders in adjacent joints [23], [30].

Seeking to capture any partial lack of symmetry in the distribution of rotation of the hip joint, we also calculated the rotation index (RI), as the ratio of ER to IR. Kim et al. [18] used a similar indicator and found that RI strongly depends on the measurement position. We found significantly higher values of RI (indicating greater ER predominance) in men in each position studied. Women showed lower values of RI, indicating increased IR compared to ER. A similar predominance of IR in women and ER in men has been observed by other authors [11], [12], [14]. In specific, quite parallel results were observed by Han et al. [12], who reported a predominance of ER ($x > 10°$) in men (46.6%), and IR (>10°) in women (36.7%). Some authors explain these differences in terms of the gender-associated anatomical structures of the pelvis and hip joint, with the torsion (ante- or retroversion) of the femoral neck being particularly noteworthy. Increased levels of anteversion of the neck of the femur, more predominant in women, result in increased values of IR and a decreased value of ER in the hip joint. In men, the torsion of the femoral neck is more likely to be smaller [31]. It is noteworthy that Hallaçeli et al. [10] reported statistically significant differences in ROM of the lower limbs in favor of women in both passive and active IR and active ER of the hip. Their final conclusion was that gender does not have an effect on variability of ROM within the hip. Moreover, they found that culturally conditioned behaviors (kneeling, sitting cross-legged), also does not increase flexion ER of the hip and does not affect flexion of the shin in the knee joint or the extension in the talocrural joint.

Our statistical analysis showed that RI value depends not only on measurement position and gender but also on the dominance of the lower limb. We found statistically significant differences between men and woman in the SuP position between the dominant and mostly supportive non-dominant lower limb. However, contrary to these findings, Beddows et al. [2] and Hallaçeli et al. [10] reported no differences in ROM between the dominant and non-dominant limbs. The difference in results might be attributed to different stabilization methods used and measuring rotation only in supine position with the hip and knee bent to a 90° angle. Beddows et al. [2] and Halacelli et al. [10] did not clearly disclose their measurement methods, so, by assumption, the default position for measuring hip rotation in most of the handbooks is the same as the above. In our study, by adding patient stabilization by means of stabilization belts (PrP; SuP), the contralateral limb (SuP), or by manual pressure by an assistant (PrP; SuP; StP), our team may have restricted previously unnoticed compensations resulting in different results.

Intriguingly, a similar imbalance of rotation values in the hip as presented above is often observed in the glenohumeral joint. This syndrome, known as Glenohumeral Internal Rotation Deficit (GIRD), is characterized by significant limitations of IR in the dominant vs. non-dominant upper limb [20] or a decrease in total rotation of the glenohumeral joint in the dominant vs. non-dominant upper limb [21], [25]. GIRD is a predisposition for many injuries, most commonly in sports involving throws. Athletes in such disciplines show altered ranges of motion in the rotation of the shoulder. This distribution may be the result of changes in bone structure (humerus retroversion), joint capsule (thickening of the posterior part) or muscle stiffness (passive thickness, known as thixotropy). Certain similarities in structure and function of hip and shoulder joint suggest that it may be expedient to define similar syndromes for cases involving asymmetric distribution of rotation of the hip. A predominance of ER over IR regarding the hip joint may be defined as Coxal Internal Rotation Deficit (CIRD) and a predominance of IR over ER – as Coxal External Rotation Deficit (CERD). However, the threshold value of the difference between external and internal rotation, taken to indicate the occurrence of CIRD or CERD, remains debatable.

Somewhat similar observations have been made by Uding et al. [31]. They established as the boundary value of the difference between IR and ER in the hip joint an angle equal to 20°. In their approach, asymmetry greater than 20° points to abnormal femoral version (FV) in MRI imaging. An ER value greater than 20° in relation to IR suggests excessive femoral retroversion of the hip joint. On the other hand, a difference of 10° in favor of IR indicates greater anteversion.

In our study, we used the rotational index (RI) to identify whether a participant shows a deficit of ER (potentially classifiable as CERD), or of IR (potentially classifiable as CIRD). After analyzing the RI indicators for different measurement positions, we found that for women with a deficit of ER, IR is on average twice the value of the ER. A similar tendency occurs in the male group exhibiting a deficit of IR, where the ER of the hip is on average twice as high as IR. Using these results as a basis, we preliminarily propose to adopt, as threshold values for determining whether we are dealing with CIRD or CERD, when the IR value is below half of the ER value (for CIRD), or analogously, when the ER value is below half of the IR value (for CERD).

We anticipate that such an assessment of rotation symmetry and a better understanding of the potentially GIRD-like rotation distribution within the hip joint may open up an innovative avenue of research and contribute to the improving the quality of hip injury prevention and screening programs.

5. Conclusions

Not only gender and limb dominance, but also the body position in which the hip joint's range of motion was measured and were found to significantly affect the values of total range of rotation (TR) and the rotation index (RI).

TR measurements showed the highest values in the prone position and the lowest values in supine position.

Based on the results for the rotation index (RI), we propose the concepts of Coxal Internal Rotation Deficit (CIRD) and Coxal External Rotation Deficit (CERD) – by analogy to the shoulder joint asymmetry found in Glenohumeral Internal Rotation Deficit (GIRD) – as tools to indicate the possibility for injury to the hip joint.

As threshold values of asymmetry for determining CIRD or CERD, we propose to take when either external rotation (ER) or internal rotation (IR) range value exceeds twice the other value.

Limitations of the study

Further research needs to be conducted on the distribution of the range of rotation in the hip joints for both sexes, as it depends on the measurement position, including larger and more representative study groups. Additionally, more functional measurement positions should also be introduced and assessed, e.g., ROM measurement with loads. Moreover, the possible clinical relevance of, and threshold values for, the CIRD and CERD concepts posited herein, as related to hip-related dysfunctions, including of the lower limbs, pelvis and lumbar spine, need to be examined more closely.

References

[1] AEFSKY B., FLEET N., MYERS H., BUTLER R.J., *Reliability and Validity of a Novel Approach to Measure Hip Rotation*, J. Sport Rehabil., 2016, 25 (4), 330–337.

[2] BEDDOWS T.P.A., VAN KLIJ P., AGRICOLA R., TAK I.J.R., PISCAER T., VERHAAR J.A.N., WEIR A., *Normal values for hip muscle strength and range of motion in elite, sub-elite and amateur male field hockey players*, Phys. Ther. Sport, 2020, 46, 169–176.

[3] BELLO A.I., ABABIO E., ANTWI-BAFFOE S., SEIDU M.A., ADJEI D.N., *Pain, range of motion and activity level as correlates of dynamic balance among elderly people with musculoskeletal disorder*, Ghana Med. J., 2014, 48 (4), 214–218.

[4] BRADLEY P.S., PORTAS M.D., *The relationship between preseason range of motion and muscle strain injury in elite soccer players*, J. Strength Cond. Res., 2007, 21 (4), 1155–1159.

[5] BUGALSKA A., HADAMUS A., WÓJTOWICZ S., DANILUK A., WIADERNA K., GRABOWICZ M., *Influence of force-time parameters of hip abductors on maintaining balance in frontal plane in young healthy females*, Acta Bioeng. Biomech., 2022, 24 (1), 1–13.

[6] CHIACCHIERO M., DRESELY B., SILVA U., DELOSREYES R., VORIK B., *The Relationship Between Range of Movement, Flexibility, and Balance in the Elderly*, Top Geriatr. Rehabil., 2010, 26 (2), 148–155.

[7] EWERTOWSKA P., KLENIEWSKA A., WASILEWSKI J., WASILEWSKA A., ZIELIŃSKA A., HAPONIUK I., CZAPROWSKI D., *Assessment of lower limbs in people with Generalized Joint Hypermobility (GJH) – preliminary report*, Adv. Rehab., 2021, 35 (4), 25–32.

[8] FERREIRA A.S., DE OLIVEIRA SILVA D., BRIANI R.V., FERRARI D., ARAGÃO F.A., PAZZINATTO M.F., DE AZEVEDO F.M., *Which is the best predictor of excessive hip internal rotation in women with patellofemoral pain: Rearfoot eversion or hip muscle strength*? Exploring subgroups, Gait Posture, 2018, 62, 366–371.

[9] GRADOZ M.C., BAUER L.E., GRINDSTAFF T.L., BAGWELL J.J., *Reliability of Hip Rotation Range of Motion in Supine and Seated Positions*, J. Sport Rehabil., 2018, 27 (4), 1–4.

[10] HALLAÇELI H., URUÇ V., UYSAL H.H., OZDEN R., HALLAÇELI C., SOYUER F., INCE PARPUCU T., YENGIL E., CAVLAK U., *Normal hip, knee and ankle range of motion in the Turkish population*, Acta Orthop. Traumatol. Turc., 2014, 48 (1), 37–42, DOI: 10.3944/AOTT.2014.3113.

[11] HAN H., KUBO A., KUROSAWA K., MARUICHI S., MARUYAMA H., *Hip rotation range of motion in sitting and prone positions in healthy Japanese adults*, J. Phys. Ther. Sci., 2015, 27 (2), 441–445.

[12] HAN H., KUBO A., KUROSAWA K, MARUICHI S., ISHIZAKA M., SADAKIYO K., NOMURA T., HONZAWA K., *Ipsilateral patterns of the rotational range of motion of the hip in healthy Japanese adults*, J. Phys. Ther. Sci., 2016, 28 (9), 2550–2555.

[13] HOGERVORST T., VEREECKE E.E., *Evolution of the human hip*. Part 1: *The osseous framework*, J. Hip. Preserv. Surg., 2014, 28, 1 (2), 39–45.

[14] HOGG J.A., SCHMITZ R.J., NGUYEN A., SHULTZ S.J., *Passive Hip Range-of-Motion Values Across Sex and Sport*, J. Athl. Train., 2018, 53 (6), 560–567.

[15] KAPANDJI A.I., *The Physiology of the Joints*. Vol. 2: *The Lower Limb*, Handspring Publishing Limited, 2019.

[16] KELLER R.A., DE GIACOMO A.F., NEUMANN J.A., LIMPISVASTI O., TIBONE J.E., *Glenohumeral Internal Rotation Deficit and Risk of Upper Extremity Injury in Overhead Athletes: A Meta--Analysis and Systematic Review*, Sports Health, 2018, 10 (2), 125–132.

[17] KIBLER W.B., SCIASCIA A., THOMAS S.J., *Glenohumeral internal rotation deficit: pathogenesis and response to acute throwing*, Sports Med. Arthrosc. Rev., 2012, 20 (1), 34–38.

[18] KIM Y., KANG S., *The relationship of hip rotation range, hip rotator strength and balance in healthy individuals*, J. Back Musculoskelet. Rehabil., 2020, 33 (5), 761–767.

[19] KOUYOUMDJIAN P., COULOMB R., SANCHEZ T., ASENCIO G., *Clinical evaluation of hip joint rotation range of motion in adults*, Orthop. Traumatol. Surg. Res., 2012, 98 (1), 17–23.

[20] LUBIS A.M., WISNUBAROTO R.P., ILYAS E.I., IFRAN N.N., *Glenohumeral internal rotation deficit in non-pitcher overhead athletic athletes: case series analysis of ten athletes*, Ann. Med. Surg. (Lond.), 2020, 58, 138–142.

[21] MANSKE R., WILK K.E., DAVIES G., ELLENBECKER T., REINOLD M., *Glenohumeral motion deficits: friend or foe*?, Int. J. Sports Phys. Ther., 2013, (5), 537–553.

[22] MEYERS T.W., *Anatomy Trains – Myofascial Meridians for Manual Therapists and Movement Professionals*, Elsevier, 2020.

[23] NAKANO N., BARTLETT J., KHANDUJA V., *Is restricted hip movement a risk factor for anterior cruciate ligament injury*?, J. Orthop. Surg. (Hong Kong), 2018, 26 (3), 2309499018799520.

[24] PRATHER H., HARRIS-HAYES M., HUNT D.M., STEGER-MAY K., MATHEW V., CLOHISY J.C., *Reliability and agreement of hip range of motion and provocative physical examination tests in asymptomatic volunteers*, PMR, 2010, 2 (10), 888–895.

[25] SACCOL M.F., ALMEIDA G.P., DE SOUZA V.L., *Anatomical glenohumeral internal rotation deficit and symmetric rotational strength in male and female young beach volleyball players*, J. Electromyogr. Kinesiol., 2016, 29, 121–125.

[26] SADEGHISANI M., MANSHADI F.D., KALANTARI K.K., RAHIMI A., NAMNIK N., KARIMI M.T., OSKOUEI A.E., *Correlation between Hip Rotation Range-of-Motion Impairment and Low Back Pain. A Literature Review*, Ortop. Traumatol. Rehab., 2015, 17 (5), 455–462.

[27] SAHRMANN S., AZEVEDO D.C., DILLEN L.V., *Diagnosis and treatment of movement system impairment syndromes*, Braz. J. Phys. Ther., 2017, 21 (6), 391–399.

[28] SCHER S., ANDERSON K., WEBER N., BAJOREK J., RAND K., BEY M.J., *Associations among hip and shoulder range of motion and shoulder injury in professional baseball players*, J. Athl. Train, 2010, 45 (2), 191–197.

[29] Surgeons AAOO., *Joint motion: method of measuring and recording*, American Academy Orthopaedic Surgeon, 1965.

[30] TAK I., ENGELAAR L., GOUTTEBARGE V., BARENDRECHT M., VAN DEN HEUVEL S., KERKHOFFS G., WEIR A., *Is lower hip range of motion a risk factor for groin pain in athletes? A systematic review with clinical applications*, Br. J. Sports Med., 2017, 51 (22), 1611–1621.

[31] UDING A., BLOOM N.J., COMMEAN P.K., HILLEN T.J., PATTERSON J.D., CLOHISY J.C., HARRIS-HAYES M., *Clinical Tests to Determine Femoral Version Category in People with Chronic Hip Joint Pain and Asymptomatic Controls*, Musculoskelet. Sci. Pract., 2019, 39, 115–122.

[32] UEMURA K., ATKINS P.R., FIORENTINO N.M., ANDERSON A.E., *Hip rotation during standing and dynamic activities and the compensatory effect of femoral anteversion: An in-vivo analysis of asymptomatic young adults using three-dimensional computed tomography models and dual fluoroscopy*, Gait Posture, 2018, 61, 276–281.

[33] WREN T.A., DO K.P., HARA R., RETHLEFSEN S.A., *Use of a patella marker to improve tracking of dynamic hip rotation range of motion*, Gait Posture, 2008, 3, 530–534.

[34] ZEMBATY A., *Kinesiotherapy*. Tom I, Kasper, 2017.