Normative hamstring-to-quadriceps strength value in elite female basketball, handball and volleyball athletes

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Abstract

Introduction: A low H/Q ratio is considered a relevant risk factor for ACL injury due to the reduced capacity for dynamic knee-joint stabilisation. The decline of this value after menarche in contrast to the rise in males makes adolescent girls more susceptible to ACL injuries. The main objective of the study is to determine a normative H/Q ratio value and hamstring and quadriceps strength values in healthy elite youth female basketball, handball and volleyball athletes.

Participants: A total of 55 basketball (n=19), handball (n=21) and volleyball (n=15) female athletes were included in the study, all those belonging to the Catalan Technification Centre.

Methods: The maximal isometric voluntary muscle contraction (IVMCmax) of quadriceps and hamstring were assessed using a fixed hand-held dynamometer (HHD). (Mark-10 series 3 Digital Force Gauge, Copiague, NY).

Results: The H/Q ratio values fluctuates between 0.35 and 0.42, therefore, in accordance with other studies we observe that the pre-established ratio value of 0.6 as an injury risk cut-off point does not reflect all sports, sexes and ages . No statistically significant strength differences were observed by sport or dominance. Furthermore, a significant age effect was observed in relation to the quadriceps normalised strength peak torque (p = 0.02).

Keywords: Isometric strength; Hand-held dynamometry; adolescence; female; sport

Introduction

Adolescent sports injuries appear to be very frequent – the highest prevalence is observed in athletes between 16 and 19, and mainly in handball, football and basketball players. 19.3% of them reported having had one or more injuries in a year[1].

In adolescent athletes, circulating androgens cause the development of greater mass and speed and therefore power, moreover during puberty there is a temporary decline in coordination and balance. All this may make the adolescent athlete more susceptible to injury[2].

The knee was the most commonly injured body part, the anterior cruciate ligament (ACL) injury being the one that receives the most attention due to the long practice-off period from practice and considering that two-thirds of ACL patients do not return to their pre-injury competition level[1,3,4]. Besides, sex differences in ACL injury rate have been observed. Female athletes were statistically more susceptible to injury than male athletes (0.29 vs 0.07)[5,6].

The ligament laxity, dynamic stability and inter-limb asymmetry may be the biomechanical factors that contribute as an injury risk[7]. The dynamic stability and the inter-limb asymmetries are intrinsic modifiable variables on which we can focus in order to reduce injury risk and improve performance[8-10].

Dynamic stability may be related to an imbalance in hamstring and quadriceps strength[1,4]. The balance of muscle function around the knee joint is often described using the hamstrings-to-quadriceps (H/Q) ratio. The H/Q ratio has conventionally been calculated as the maximum knee flexion strength divided by the maximum knee extension strength obtained at a given knee angular velocity and contraction mode (isometric, concentric, eccentric). These values can be based on peak- or angle-specific moments[11].

Due to the co-activation and simultaneous function of these muscles around the knee, the imbalance at a given angle would be pertinent to an injury. Therefore, the angle-specific H/Q torque would seem to be a greater risk indicator value[12,13].

A low H/Q ratio is considered a relevant risk factor for ACL injury due to the reduced capacity for dynamic knee-joint stabilisation. This may be because of the significant anterior tibial translation or shear by the quadriceps muscle contraction and the lack of hamstring muscle co-activation to counterbalance this tibial shear. Furthermore, the quadriceps may also produce substantial internal rotation of the tibia in relation to the femur, which would be compensated by the hamstring[4,11].

After menarche, female athletes increase quadriceps activation without a boost in hamstrings activation, observing a rise of 27% according to hamstring strength in girls compared to 179% in boys. This may indicate morphological or neural differences between sexes primarily regarding to the hamstrings. The activation differ comes with a lower H/Q ratio in females than in males[14].

The decline of this value after menarche in contrast to the rise in males makes adolescent girls more susceptible to ACL injuries[14-16].

There seems to be some degree of consensus on 0.6 as a normative cut-off for a conventional H/Q ratio (60°.s-1) measured with the isokinetic dynamometer to determine people at risk[9,12]. In healthy basketball and handball players, the mean ratio value observed fluctuates from 0.54 to 0.58, under the aforementioned value[17]. However, the same subjects may exhibit a H/Q of 0.27 to 1.05 depending on the contraction mode[11]. Additionally, the normative value tends to differ depending on the joint angular velocity, gravity correction and contraction mode, besides sex and maturation level[16,18].

For an objective measurement of muscle strength we can use a isokinetic dynamometer or a hand-held dynamometer (HHD). When considering the extensive data that isokinetic testing can provide, it may be easy to conclude that the HHD will not completely replace the isokinetic testing device in the clinical setting[19].

Furthermore, the isokinetic dynamometer presents several disadvantages from a clinical point of view, including the high cost of equipment and time-consuming testing sessions, which entail impractical daily or routine clinical testing[19].

In contrast, the HHD provides several clinical advantages. It is portable thanks to its small size, easy-to-use, inexpensive, and requires minimal space for a testing session. In addition, it is considered to have moderate-to-good reliability and validity when compared with the gold standard [Knee extensors: ICC 0.8; r=0.43-0.99] [Knee flexors: ICC=0.83-0.85; r=0.77][19]. The reliability of the HHD is enhanced with the stabilisation device, providing excellent reliability for the lower-limb isometric strength [ICC:0.93]20.

However, the H/Q ratio is focused to the intra-limb disbalance without taking into account the inter-limb interaction. The inter-limb asymmetries are defined as a performance comparation between legs. The performance task as a change of direction (COD), jumping and sport-specific skills seem to be negatively affected by the strength inter-limb asymmetries[10]. Furthermore, previous studies point out an inter-limb asymmetries up to 15% as a risk factor to take into account[8].

There is just one study in elite youth athletes that describes normative isometric H/Q ratio values measured with the HHD. These values are established for football players between the ages of 8 and 15. Relative to the age, they observe a decline of 0.3 in the ratio, monitoring how the ratio gets worse as the age increases . Furthermore, 18% of the players demonstrated less than a normative 0.6 H/Q ratio. However, when this was categorised by age group, only 5% of all players aged 8-11 years were under the cut-off value, while for the players aged 12-15 years it represent 38%[18].

The isometric H/Q ratio decline observed in male youth athletes and the muscle activation differences between sex may suggest that a pre-established cut-off value does not reflect the reality in adolescent girl athletes[14,18]. Due to the variability of the values achieved, it may be important to define normative values in specific age, gender and sport groups, especially in population with injury risk. These normative values can be used to set rehabilitation goals and as a return-to-play criterion after injury[17].

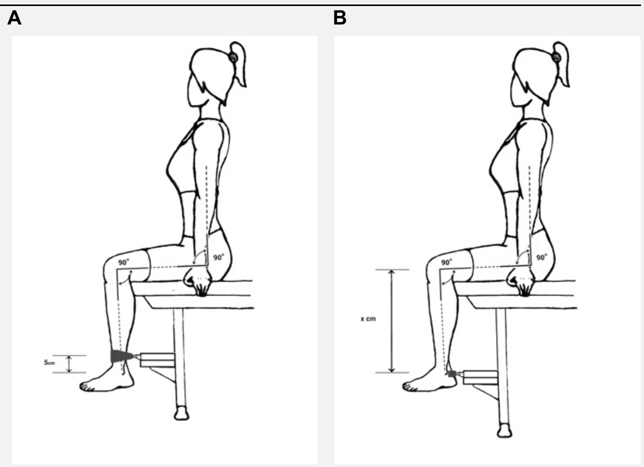
The main objective of the study is to determine a normative H/Q ratio value and hamstring and quadriceps strength values in healthy elite youth female basketball, handball and volleyball athletes. The secondary aims of the study are, (1) to define the differences in these values among sports and age and (2) to describe neuromuscular imbalances between legs in sports by inter-limb asymmetry magnitude.

Methods

Study design and setting

A cross-sectional descriptive study reported in line with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (STROBE)[21]. All the basketball, handball and volleyball female athletes belonging to the Catalan Technification Centre and residing in Blume student housing of Esplugues de Llobregat were included in the study. The athletes have a grant that includes school attendance, residence, medical services and sport practice in the installations. The program is aimed at 14- to 19-year-olds. It takes place 40 weeks a year across four years. All of them train five days a week, constituting 14 to 18 hours of practice, and they play one match per week.

FIGURE I. *The muscle strength assessment position for quadriceps (A) and hamstring (B).*



x: fibula length

Participants

A total of 55 basketball (n=19), handball (n=21) and volleyball (n=15) athletes were included in the study (table 1). All those athletes currently experiencing any lower-limb injury that leads to time-loss or training modification at the time of testing or have mentioned having pain during the testing were excluded. Written consent was obtained prior to data collection from their parent/ legal guardian. Approval for the research was granted by the Facultat de les ciencies de salut blanquerna, Barcelona. The study was conducted following the national and international guidelines for medical human researches according to the regulation of the 2013 Helsinki Declaration.

Data collection

All data were collected in the first period of the season by the centre's physiotherapist. All of the players were assessed by the same professional to avoid the inter-rater bias. The first limb tested and the test sequence were randomly pre-established for each athlete.

TABLE I. *Study sample characteristics (n = 52). Mean (SD)*

	Age	Weight	Height	IMC
Basketball (n = 19)	15.9 (1.16)	71.9 (11.32)**	181.11 (8.56)***	21.84 (2.38)*
Handball (n = 19)	15.88 (1.14)	63.02 (5.06)**	172.68 (4.91)***	21.12 (1.19)
Volleyball (n = 14)	15.93 (1.41)	63.55 (7.19)	177.09 (4.46)	20.23 (1.76)*
Total (n = 52)	15.9 (1.2)	66.41 (9.23)	176.94 (7.26)	21.14 (1.92)

Age:

The date of birth was asked.

Anthropometric measures:

Anthropometry data of height, weight (seca 703s, Hamburg) and fibula length were collected. The fibula length was measured with the direct clinical technique using a supine tape measuring method, taking the lateral joint space and lateral malleoli as body landmarks[22,23].

Leg dominance:

Three tests were used to determine the functional leg: ball kick, step-up and balance recovery. In the ball-kick test, the athlete was instructed to kick the ball with moderate intensity and to score in a 1m goal located 5m away from the athlete. The leg used to kick the ball was considered the

dominant leg for that specific test. In the step-up test, the athlete has to step onto a 20cm-high step. The leg used to perform the test was identified as a dominant leg for the test. The balance recovery test entails applying a perturbation to the athlete and observing the leg used in the step to balance recovery. The perturbation consists of a nudge applied in the athlete's back. The leg used for most trials was defined as the functional dominant limb[24].

Muscle strength assessment:

The maximal isometric voluntary muscle contraction (IVMCmax) of quadriceps and hamstring were assessed using a fixed hand-held dynamometer (HHD). (Mark-10 series 3 Digital Force Gauge, Copiague, NY). The tested muscle was assigned at random in order to minimise bias. The muscle strength assessment was performed using a standardised protocol[23] (Figure I).

The quadriceps and hamstring IVMCmax were tested with the athlete in the sitting position with the hips and knees flexed at 90 degrees. The legs were fixed to the stretcher as proximal as possible to the hip. The arms were placed next to the body with the hands holding the stretcher at the height of the trochanter. They were instructed to keep the body in a vertical position.

In order to test the hamstrings strength, the push technique was used. The HHD was placed most distal on the posterior surface of the leg. For the quadriceps strength, the pull technique was used[25]. The band was placed 5 cm above the lateral malleolus, perpendicular to the leg. The dynamometer was fixed to the stretcher with screws [Figure I].

For warm-up and test familiarisation, two sub-maximal contraction were carried out. A five-second progressive contraction was done in which the player is instructed to achieve the maximal contraction[26]. Three maximal contractions were done with 10 seconds of rest between the assessments. The highest value was recorded as a peak force unless it is the last contraction. In this case one more test was done.

Statistical analysis

The data was analysed using RStudio Version 1.2.5001 (South Bend, Indiana, U.S). The descriptive data of strength, ratio and asymmetries were set forth with mean and Standard Deviation (SD) for each sport. The normalised quadriceps and hamstring peak torque will be provided by multiplying the muscle strength in Newtons with the distance between the knee and the dynamometer in meters, divided by the body mass in

TABLE II. *Mean and SD for normalized isometric peak torque (N·m·kg-1)muscle strength with the hand-held dynamometer for dominant (D) and non-dominant (ND) legs of youth basketball, handball and volleyball female athletes.*

	Normalized hamstring peak torque, N·m·kg-1(SD)				Normalized quadriceps peak torque N·m·kg-1 (SD)				H/Q Ratio †			
	D	ND	Cohen's f^2	% θ	D	ND	Cohen's f^2	% θ	D	ND	Cohen's f^2	% θ
Basketball (n=19)	1.26 (0.24)	1.21 (0.26)	0.2	14.31 (9.91)	2.98 (0.41)	2.88 (0.38)	0.25	10.39 (6.15)	0.42 (0.08)	0.42 (0.09)	0.	15.54 (7.5)
Handball (n=19)	1.06 (0.38)	1.12 (0.33)	0.17	14.81 (10.58)	3.01 (0.62)	2.85 (0.53)	0.28	8.83 (8.03)	0.35 (0.09)	0.39 (0.09)	0.44	15.33 (12.3)
Volleyball (n=14)	1.14 (0.24)	1.16 (0.22)	0.09	6.68 (4.21) *	3.08 (0.47)	3.11 (0.52)	0.06	8.19 (5.31)	0.38 (0.09)	0.38 (0.1)	0.	11.36 (6.48)
Total (n=52)	1.15 (0.3)	1.16 (0.3)	0.03	12.44 (9.55)	3.02 (0.5)	2.93 (0.48)	0.18	9.23 (6.65)	0.38 (0.09)	0.4 (0.09)	0.22	14.34 (9.34)
Cohen's f^2	$ 0.63	0.3		0.05	0.06	0.07		0.22	0.82	0.33		0.02
	# 0.25	0.14		1.01	0.13	0.5		0.09	0.33	0.11		0.4
	† 0.5	0.21		1	0.23	0.51		0.38	0.47	0.42		0.6

† H/Q-ratio: hamstring strength [N·m]/quadriceps strength [N·m].

θ Bilateral Strength Asymmetry [(Strong-Weak)/Strong x 100].

**p<0.05*

$ basquet vs handball

 # handball vs volley

† basket vs volley

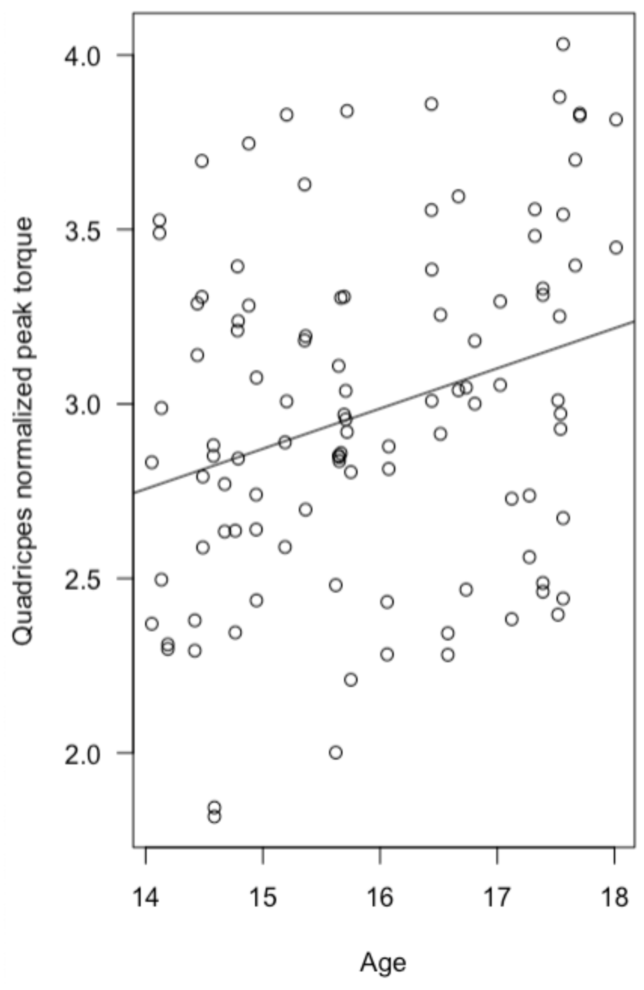
kilograms [N·m·kg-1]. The strength ratio is the result of the division between normalised hamstring peak torque and normalised quadriceps peak torque [H/Q].The asymmetry was assessed by Symmetry Index[27] [(Strong-Weak)/Strong x 100]. Taking into account that the Shapiro-Wilk test had set the normality of the data, a linear regression was used to observe the evolution of the ratio by age. The effect size will be determined by Cohen's f^2 considering $f^2 \geq 0.02$, $f2 \geq 0.15$, and $f2 \geq 0.35$, as small, medium and large effect sizes respectively[28]. The Analysis of Variance (ANOVA) was used to determine the differences between sports. The level of significance was set at 0.05.

Results

Of the 55 athletes, 3 players were excluded due to previous lower-limb injury. A total of 52 basketball (n=19), handball (n=19) and volleyball (n=14) athletes were assessed in the study (table I).

Table II shows mean ratio and strength values and the inter-limb asymmetries by sport. Due to the height and weight differences between sports, the peak torque values were normalised using body mass (Nm·kg-1) to eliminate the effects of subject heterogeneity in their body

FIGURE II: Age effect in normalized quadriceps peak toque plot.



build. No statistically significant strength differences were observed by sport or dominance.

Furthermore, a significant age effect was observed in relation to the quadriceps normalised strength peak torque (p = 0.02) (figure II).

The ANOVA tests demonstrated statistically significant (F = 3.889, $p < 0.027$) difference in hamstring strength asymmetry in handball ($\bar{x}$ = 14.84; SD = 10.77) and volleyball ($\bar{x}$ = 9.36; SD = 10.4) (figure III). The percentage of players across all sports and ages with an inter-limb strength hamstring asymmetry up to 15% was 34,62 (n=17), this imbalance being evident in basketball (42.11%) and handball (47.37%), in contrast to 7.14% in volleyball.

Discussion

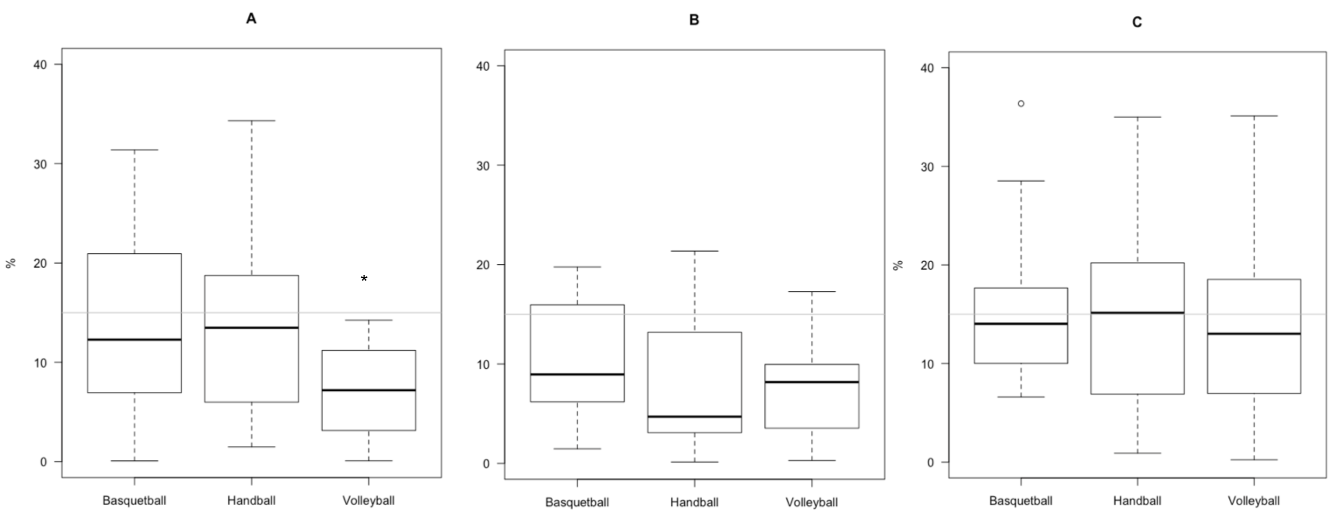
The purpose of this research was to determine a reference isometric H/Q ratio value and hamstring and quadriceps isometric strength values in healthy elite youth female basketball, handball and volleyball athletes. The HHD with the stabilisation device seems to provide excellent reliability in the lower-limb isometric strength [ICC:0.93][20].

As we can observe in previous studies, the pre-established ratio value of 0.6 as an injury risk cut-off point does not reflect all sports, sexes and ages. Andrade MDS et al[29] presented healthy football and handball players ratio values, in which they observe a significant ratio difference in favour of football players. Risberg MA et al[17], come to the same conclusion, finding that the ratio mean in handball was 0.58 and 0.57 for dominant and non-dominant legs, both under the aforementioned cut-off value. Even so, these values are much higher than our results of 0.35 and 0.39 observed in handball, in which no player was over 0.6.

Several studies analysing normative H/Q ratio with the isokinetic dynamometer in basketball and handball players between 9 and 26 years old have observed that the mean ratio fluctuates between 0.49 and 0.58[17,30,31].

Considering the three assessed sports, the ratio mean of our sample fluctuates between 0.37 to 0.42, with the athletes with ratios above the aforementioned value constituting only 3.77% (n=2) of the sample. The stark difference with the previous studies may be due to the measure instrument. Peek K et al[18] carried out the only study providing normative ratio value with the HHD in athletes in which the sample was male football players between 8 and 15 years old. As with our observation, it was suggested that the 0.6 value measured with isokinetic value should be interpreted with caution when you compare with HHD data. They observe that the percentage of athletes with the H/Q ratio below 0.6 increases with age, making up 38% (n = 18; 95% CI: 25–54%) of male football players between 12 and 15 years old.

Figure III. Strength asymmetries in basketball, handball and volleyball players [(Strong-Weak)/Strong x 100]; A) normalised hamstring peak torque asymmetries by sport; B) normalised quadriceps peak torque asymmetries by sport; C) H/Q ratio asymmetries by sport



*p<0.05

With regard to the quadriceps and hamstring normalized peak torques, in accordance with the Risberg et al[17] study, there was no significant difference between D and ND legs. No statistically significant sport differences were obtained but apparent differences are observed, noticing greater normalised hamstring peak torque and lower normalised quadriceps peak torque in basketball players compared to volleyball and handball players. The highest ratio values are therefore observed in basketball players ($\bar{x}$ = 0.42; SD = 0.08-0.09).

Hannah et al[14] indicates that strength difference between sex is evident. After menarche the increase of hamstring activation was not at the same level as quadriceps activation in female athletes. This observation concurs with the results of our study. The age effect was only significant with regard to the normalized quadriceps peak torque ($p = 0.02$). The quadriceps peak torque increase without the hamstring strength development entail that the ratio may decrease. Adding the sex difference to the previously observed age effect in the ratio in the Peek et al. study may suggest that the decline slope in female athletes would be greater. Hence, the low ratio values of 0.37 to 0.42 observed in our study would be expected. Even so, no statistically significant age effect was observed in the ratio.

The inter-limb strength asymmetry is a highly studied parameter due to the evidence related to performance and injury risk[8,10]. There is a consensus of 15% of asymmetry as a suitable imbalance, so any value over this is considered an injury risk factor. As for the ratio asymmetry mean values obtained in the study can be said to be close to 15%, being over it in basketball ($\bar{x}$ = 15.54; SD = 7.5) and handball ($\bar{x}$ = 15.33; SD = 12.3) athletes.

The percentage of athletes over 15% of normalised peak torque asymmetry is high: 23.08% in quadriceps and 34.62% in hamstring strength. With regard to the normalised hamstring peak toque asymmetry there is a statistically significant sport difference ($F = 3.889$, $p < 0.027$). 42.11% and 47.37% of handball and basketball athletes respectively present a higher imbalance, while in volleyball only 7.14% has more than 15% of asymmetry. The sport difference may be due to the degree of asymmetry of each sport, accordingly observing more imbalanced athletes in handball and basketball compared to volleyball. This imbalance appears to negatively affect sport performance like COD and sport-specific skills and also increase the injury risk[8,10], therefore external compensatory work may be interesting to reduce the imbalance generated due to the specific sport practice.

A limitation of the research is that only girls are included in the study and no sex differences will be provided. Furthermore, the age influence will not be assessed prospectively.

This study provide healthy youth female basketball, handball and volleyball strength values measured with the HHD. Due to the economical and functional practicality of this instrument, other clubs with this population may be encouraged to measure their athletes now that the reference values make it easier to interpret their results and compare with them. The ratio value of 0.6 is far from the reality of the values achieved with the HHD, so our results should also be compared carefully with other isokinetic studies. Hence further studies will provide a cut-off H/Q ratio value calculated with IVMCmax measured with the HHD to identify at-risk athletes. Focus on hamstring strength in youth female athletes may be the key to increase the ratio and therefore protect the ACL and to balance the high asymmetry observed in basketball and handball athletes.

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