KNEE ISOKINETIC TORQUE IMBALANCE IN FEMALE FUTSAL PLAYERS

DESEQUILÍBRIO DO TORQUE ISOCINÉTICO DO JOELHO EM JOGADORAS DE FUTSAL FEMININO

DESEQUILIBRIO DEL TORQUE ISOCINÉTICO DE LA RODILLA EN JUGADORAS DE FUTSAL FEMENINO

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ABSTRACT

Introduction: The specificity of sports training can lead to muscle specialization with a possible change in the natural hamstring/quadriceps torque ratio (HQ ratio), constituting a risk factor for muscle injury at the joint angles in which muscle imbalance may impair dynamic stability. Objective: The aim was to evaluate the torque distribution of the hamstrings and quadriceps and the HQ ratio throughout the range of motion in order to identify possible muscle imbalances at the knee of female futsal athletes. Methods: Nineteen amateur female futsal athletes had their dominant limb HQ ratio evaluated in a series of five maximum repetitions of flexion/extension of the knee at 180°/second in the total joint range of motion (30° to 80°). The peak flexor and extensor torque and the HQ ratio (%) were compared each 5° of knee motion using one-way repeated measures ANOVA and Tukey's post hoc test (p<0.05) to determine the joint angles that present muscular imbalance. Results: Quadriceps torque was higher than 50° to 60° of knee flexion, while hamstrings torque was higher than 55° to 65°. The HQ ratio presented lower values than 30° to 45° of knee flexion and four athletes presented values lower than 60%, which may represent a risk of injury. However, the HQ ratio calculated by the peak torque showed only one athlete with less than 60%. Conclusion: The HQ ratio analyzed throughout the knee range of motion allowed identifying muscle imbalance at specific joint angles in female futsal players.

Keywords: torque; soccer; knee joint; muscle, skeletal/physiopathology.

RESUMO

Introdução: A especificidade do treinamento esportivo pode levar à especialização muscular, com possível alteração da razão do torque isquiotibiais/quadríceps (razão IQ) natural, constituindo um fator de risco de lesão muscular nos ângulos articulares em que o desequilíbrio muscular pode prejudicar a estabilidade dinâmica. Objetivo: O objetivo foi avaliar a distribuição do torque dos músculos isquiotibiais e quadríceps e da razão IQ ao longo de toda a amplitude de movimento, de modo a identificar possíveis desequilíbrios musculares no joelho de atletas de futsal feminino. Métodos: Dezenove atletas amadoras de futsal feminino tiveram a razão IQ do membro dominante avaliada em uma série de cinco repetições máximas de flexão/extensão do joelho a 180°/ segundo na amplitude de movimento total (30° a 80°). O pico de torque flexor e extensor e a razão IQ (%) foram comparados a cada 5° de movimento do joelho pela one-way ANOVA de medidas repetidas e do teste post hoc de Tukey (p < 0,05) para determinar os ângulos articulares que apresentam desequilíbrio muscular. Resultados: O torque do quadríceps foi maior que 50° a 60° de flexão do joelho, enquanto o torque dos isquiotibiais foi maior que 55° a 65°. A razão IQ apresentou menores valores que 30° a 45° de flexão do joelho e quatro atletas apresentaram valores abaixo de 60%, o que pode representar risco de lesão. No entanto, a razão IQ calculada pelo pico de torque mostrou apenas uma atleta com menos de 60%. Conclusão: A razão IQ analisada ao longo de toda a amplitude de movimento permitiu identificar desequilíbrio muscular em ângulos articulares específicos em atletas de futsal feminino.

Descritores: *torque; futebol; articulação do joelho; músculo esquelético/fisiopatologia.*

RESUMEN

Introducción: La especificidad del entrenamiento deportivo puede llevar a la especialización muscular, con posible cambio de la razón de torque entre isquiotibiales/cuádriceps (razón IC) natural, constituyendo un factor de riesgo de lesión muscular en los ángulos de las articulaciones, en el que el desequilibrio muscular puede perjudicar la estabilidad dinámica. Objetivo; El objetivo fue evaluar la distribución del torque de los músculos isquiotibiales y cuádriceps y la razón IC a lo largo de todo el rango de movimiento para identificar posibles desequilibrios musculares en la rodilla en atletas de futsal femenino. Métodos: Diecinueve atletas amateurs de futsal femenino tuvieron la razón IC de la extremidad dominante evaluada en una serie de cinco repeticiones máximas de flexión/extensión de la rodilla a 180°/segundo en el rango de movimiento total (30° a 80°). El pico de torque flexor y extensor y la razón IC (%) fueron comparados a cada 5° de movimiento de la rodilla por el ANOVA one-way de medidas repetidas y de la prueba post hoc de Tukey (p < 0,05) para determinar los ángulos articulares que presentan desequilibrio muscular. Resultados: El torque del cuádriceps fue mayor que

50° a 60° de flexión de la rodilla, mientras que el torque de los isquiotibiales fue mayor que 55° a 65°. La razón IC presentó los valores más bajos que 30° a 45° de flexión de la rodilla y cuatro atletas presentaron valores inferiores al 60%, lo que puede representar riesgo de lesión. Sin embargo, la razón IC calculada por el pico de torque máximo, mostró sólo una atleta con menos del 60%. Conclusión. La razón IC analizada a lo largo de todo el rango de movimiento permitió identificar desequilibrio muscular en ángulos articulares específicos en atletas de futsal femenino.

INTRODUCTION

In team sports[1,2] as futsal, muscle force imbalance is a common phenomenon due to the specific demands associated with sports practice because of knee extensors predominant use compared to knee flexors[3,4]. In females, there is a greater quadriceps activation and decreased hamstrings co-activation due to hormonal factors, along with specific demands of the extensor of the dominant limb, which can increase muscle imbalance between opposing (agonists and antagonists) muscles[5-8]. The hamstrings/quadriceps peak torque ratio (HQ ratio) is an index used to evaluate the stabilizing efficiency of the knee joint muscles[9,10]. Specifically, it measures the ability of the hamstrings to neutralize tibial anterior translational forces produced by the knee extensors, providing dynamic joint stability during knee extension[9-11]. It is well established that the HQ physiological peak torque ratio is 60% on average, representing the level of muscular balance. This value is an overall average based on many different studies using different dynamometers[1,2], different genders[1,2], specific populations such as athletes[12,13], physically active subjects[1,2], and patients pre-post anterior cruciate ligament (ACL) reconstruction[1,2]. Because of this, the use of this conventional ratio as a normative value has gained general acceptance[14-17].

However, knee dynamic stability may be compromised even within this 60% ratio[18,19]. Although the HQ ratio provides means to evaluate the likelihood of injuries, this ratio is often calculated using the peak torque achieved by the hamstrings and quadriceps during isokinetic tests, independent of angle and time. Consequently, torque production changes throughout the entire joint range of motion are not taken into consideration. Hiemstra et al.[20] analyzed the work produced by the knee flexors and extensors in a joint range of motion from 5° to 95° of knee flexion in 10 different sagittal angular velocities. Although both muscular groups can present a similar area under the torque-angle curve displaying a similar work, the amplitude and instant at which the peak torque occurs differs between the hamstrings and quadriceps muscles, and muscle imbalances can occur at specific joint angles that might overload some joint structures.

The force produced by skeletal muscles depends on their length, and is influenced by anatomical parameters such as muscle architecture, tissue elasticity and joint geometry. In other words, muscle force production is muscle-length dependent and therefore different torques are produce at different joint angles[21,22]. In addition, muscle architecture changes depending on the training specificity of different sports modalities and activities, thereby changing the normal HQ ratio and the joint angle where peak torque occurs.

Therefore, to better understand the HQ ratio it is important to analyze this parameter throughout the total joint range of motion. Using this rationale, the HQ ratio should be evaluated at the same joint angles at which hamstrings and quadriceps torque values are obtained in order to assess possible adaptations in this ratio due to sports training. This is essential to assess the thigh muscles' force production capacity to control the dynamic stability during motion in the sagittal plane. Thus,

the aim of this study was to evaluate the HQ ratio in female futsal athletes in order to identify possible muscle imbalances throughout the knee flexion/extension range of motion. Our hypothesis is that female futsal athletes have higher muscle imbalance when compared to male athletes imbalance described in the literature due to a combination of functional demands of these muscle groups and decreasing hamstrings co-activation due to hormonal factors.

METHODS

Nineteen amateur female futsal athletes aged 21 ± 2.8 years (mean ± SD), with no reported pathology on lower-limb muscles, with no contra-indication to perform maximal effort, and at least five years of futsal practice participated in the study. All participants were informed about the procedures, requirements, risks and benefits before signing a consent form to participate in the study, which was approved by University's local ethics committee (n°1201/2010-CEP).

An isokinetic dynamometer (Biodex Medical Systems 3, New York, USA), with a sampling frequency of 100 Hz, was used to obtain torque data during the maximal voluntary contractions of the athletes' dominant limb, established as the lower-limb mostly used to kick the ball. Subjects were seated on the dynamometer chair and had the dominant hip, thigh, and tibia stabilized by straps. The knee joint axis of rotation was aligned with the dynamometer's axis of rotation. Quadriceps and hamstrings muscle torques were evaluated concentrically, with the knee range of motion established from 90° to 0° of knee flexion (0° = full knee extension). Gravity effect was corrected automatically by the dynamometer software.

Participants went through a familiarization procedure aimed at providing the athletes with a previous experience of the maximal effort test. Before the test, athletes had a five-minute warm-up trial on a cycle ergometer, cycling at their preferred cadence. Evaluation was performed through one set of five knee flexion and extension repetitions at an angular velocity of 180°/s, which was chosen based on a study that showed a relationship between torque produced at this velocity and jump performance[18,23]. The repetition with the highest torque value over the five repetitions of knee flexion and extension was considered for analysis.

The data obtained were analyzed through specific routines developed in Matlab®, which was also used for all statistical procedures. All data were filtered by 4th order Butterworth low-pass filter with a cutoff frequency of 2Hz, determined by spectral analysis performed previously.

The acceleration and deceleration phases (beginning and end of the motion amplitude) were excluded to eliminate the torque that was not generated in an isokinetic condition[24,25]. Thus, the corrected isokinetic joint range of motion ranged from 30° to 80° and was normalized in order to facilitate the results interpretation. This range of motion has been reported as the optimal range for quadriceps and hamstrings peak torque production (71.3° and 30.1°, respectively)[26].

The normalized HQ ratio (%) was determined based on the torque values of torque-angle curves (30° to 80°) from each muscle group. The ratio was calculated by dividing the hamstrings torque values by the quadriceps torque values throughout the range of motion. The specific ratio measures were obtained every five degrees of the total range of motion (from 30° to 80° of knee flexion), so that the pattern of the HQ ratio distribution could be better characterized and specific angles in which the ratio was under 60% could be determined. HQ ratio values below this threshold indicated that the natural balance between hamstrings and quadriceps was disrupted[14-17].

Data normality was tested using the Lilliefors test. To compare the HQ torque ratio among the different knee angles at each 10% of the motion cycle, a one-way repeated measures ANOVA was used. A pairwise comparison was done using the Tukey *post hoc* test. Data are presented in mean ± standard deviation values (P<0.05).

RESULTS

Mean quadriceps torque values were higher from 50° to 60° of knee flexion compared to the other joint angles of the total range of motion, whereas the mean hamstrings torque was higher from 55° to 65° of knee flexion (Figure 1).

On average, HQ ratio presented a pattern in its distribution with lower values at 30° to 45° and higher values at 65° to 80° of knee flexion, respectively (Figure 2). The obtained mean HQ ratio values were above 60% for the entire range of motion, which reflected the presence of muscle imbalance, with values between 70% to 90%.
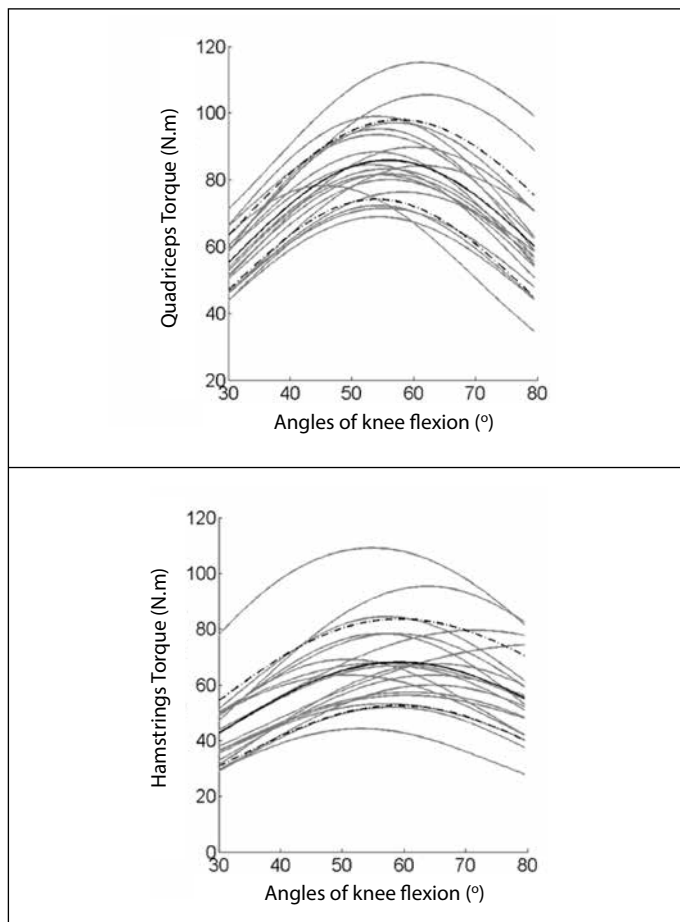
When the HQ ratio obtained for each 5° of knee flexion was compared among the different joint angles throughout the entire range of motion, significantly higher values were found at the highest degrees of knee flexion (70° to 80°, p<0.001) compared to the 30-35° of knee flexion (Figure 3).

Interestingly, when the mean HQ ratio produced by the athletes was examined at each 5° angle (from 30° to 80° of knee flexion), four athletes presented HQ ratios below the 60% threshold, although on average the HQ ratio was above this percentage level. When looking at the conventional HQ ratio that uses just the peak torque values, only one athlete was under the 60% ratio threshold, as can be verified at the underlined data of Table 1. As the angle of peak torque differs between the hamstrings and the quadriceps muscles, the conventional peak torque HQ ratio was obtained using peak torque values from the optimal muscle lengths.

DISCUSSION

The main outcome of the present study is that the HQ ratio showed imbalance in force production throughout the entire knee flexion/extension range of motion. This imbalance is apparently due to some kind of neuromuscular adaptation due to sports practice in female futsal players. Although futsal players prioritize the quadriceps while kicking a ball during training[5-8], an HQ ratio close to 100% (or higher than 60%, the normal ratio value that is said to represent muscle balance) can be due to a decrease in knee extensor torque production, to an increase in knee flexor torque production or to a combination of these two. The
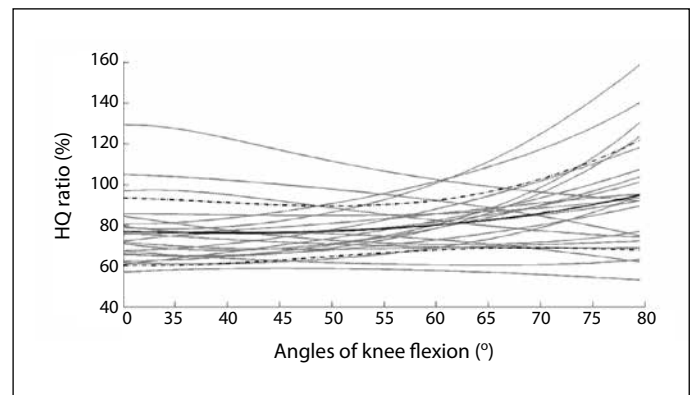

Figure 1. Quadriceps and hamstrings torque of the dominant limb of amateur female futsal players measured from 30° to 80° of knee flexion. Torque was measured during isokinetic test at the angular velocity of 180°/s. Gray solid lines represent individual torque measures of the 19 players in each situation. Solid and dotted black lines represent group mean and standard deviation, respectively.

Figure 2. Hamstrings/quadriceps torque ratio (HQ ratio) of the dominant limb of amateur female futsal players measured from 30° to 80° of knee flexion (angular velocity = 180°/s). Gray solid lines represent individual HQ ratio measures of the 19 athletes in each situation. Solid and dotted black lines represent group mean and standard deviation, respectively. The horizontal dotted line at 60% of HQ represents the threshold ratio below which the injury risk is increased.
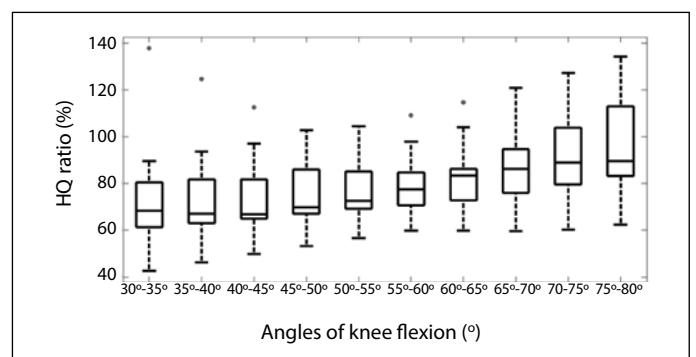

Figure 3. Boxplot of the hamstrings/quadriceps torque ratio (HQ torque ratio) calculated each 5° of the joint motion (35°, 40°, 45°., 50°, 55°, 60°, 65°, 70°, 75° and 80° of knee flexion) at 180°/s. + denotes outliers. Boxplots were used for presenting the group values at each joint angle.

	Mean HQ ratio (%)										HQ Peak torque (%)
	30-35°	35-40°	40-45°	45-50°	50-55°	55-60°	60-65°	65-70°	70-75°	75-80°	
S1	67.77	70.05	72.85	76.14	80.01	84.58	90.04	96.63	104.61	114.26	86.93
S2	71.14	76.86	82.43	87.73	92.77	97.58	102.20	106.59	110.52	113.46	92.93
S3	42.66	46.26	49.82	53.29	56.68	59.99	63.27	66.50	69.64	72.51	57.84
S4	80.62	82.54	85.29	88.73	92.89	97.89	103.98	111.54	121.24	134.20	99.94
S5	68.38	66.78	66.83	68.21	70.87	74.88	80.47	87.98	97.87	110.66	80.33
S6	60.99	61.86	63.30	65.14	67.30	69.78	72.59	75.76	79.34	83.31	68.76
S7	65.85	65.22	66.16	68.45	72.14	77.47	84.91	95.14	109.15	128.32	89.44
S8	137.87	124.59	112.66	102.87	95.25	89.58	85.68	83.48	83.15	85.22	86.58
S9	61.23	62.98	64.79	66.71	68.82	71.20	73.96	77.16	80.84	84.93	69.63
S10	57.80	61.48	65.53	69.94	74.81	80.26	86.47	93.65	101.94	111.40	82.56
S11	69.88	67.13	65.61	65.05	65.31	66.34	68.15	70.84	74.53	79.28	66.56
S12	87.97	82.79	78.44	74.97	72.34	70.49	69.38	68.99	69.42	70.84	71.84
S13	75.47	74.62	74.81	75.81	77.56	80.10	83.56	88.12	94.04	101.56	80.16
S14	89.58	93.65	97.14	100.65	104.58	109.19	114.61	120.76	127.29	133.37	103.43
S15	79.72	79.48	79.93	80.90	82.23	83.83	85.61	87.40	88.91	89.69	83.72
S16	66.06	65.23	64.07	62.80	61.59	60.56	59.84	59.64	60.33	62.53	61.16
S17	87.21	89.02	88.88	87.75	86.25	84.77	83.53	82.73	82.56	83.27	86.28
S18	54.05	59.16	64.02	68.54	72.72	76.56	80.07	83.10	85.38	86.39	73.26
S19	61.48	63.44	65.87	68.71	72.02	75.91	80.56	86.22	93.22	102.01	77.90
X	72.93	73.32	74.13	75.39	77.16	79.52	82.57	86.43	91.26	97.22	79.96
SD	±19.87	±16.91	±14.55	±13.04	±12.46	±12.75	±13.80	±15.54	±18.03	±21.48	±12.32

Note: X=mean; SD=standard deviation;

way this ratio was calculated in the present study provides important information about knee flexor/extensor imbalance along the entire joint range of motion in female futsal players, and might allow for the identification of possible injury risks during this range of motion.

The HQ ratio is frequently used as an index to evaluate the stabilizing efficiency of the knee joint muscles[9-11]. In this study, HQ ratios varied throughout the joint range of motion, with lower values at 30° to 45° of knee flexion, and higher values at 65° to 80°. The low values close to knee extension are associated with two factors: the low quadriceps torque production, in that the mean peak of torque production occurred at 54° of knee flexion and the decreases in force production capacity of this muscle as a result of the force-length relationship and the mechanical disadvantage of this muscle at full knee extension[17]. That is, the quadriceps muscle is lengthened at the beginning of the motion when the knee is fully flexed and is much shorter with the knee extended to generate power. The other factor is the increased hamstring torque production around 67° of knee flexion in some athletes. Hamstrings are used around this joint angle in futsal practice, which might explain the need for a higher torque production of this muscle group.

The HQ ratio values can be affected by specific sports demands; therefore, varying values have been reported for different sports modalities (judo, handball and soccer). Apparently, different hormone characteristics also produce sex-specific changes among these athletes on the HQ ratio[7,18]. Andrade et al.[18] compared male and female HQ ratio of handball, football and judo athletes, and found lower values at 60°/s for female athletes (judo: 53±10, handball: 56±6, soccer: 54±11) compared to male athletes (judo: 57±14, handball: 63±12, soccer: 66±12). However higher values were observed at the angular velocity of 180°/s for female (judo: 72±10, handball: 65±6, soccer: 72±11) compared to male (judo: 69±8, handball: 63±9, soccer: 68±12) athletes. These findings are similar to those seen in this study, as the observed values were above 60% in female futsal players.

Apparently, this higher knee joint muscle strength imbalance has been correlated with a higher injury incidence in females. This lower hamstrings torque in relation to quadriceps torque decreases the female players' ability to control the knee motion at the coronal and sagittal planes, predisposing them to greater lower-limb injury incidence[12,18]. This higher injury risk reinforces the importance of evaluating female athletes maximal torque production throughout the entire joint range of motion between antagonistic muscle groups, as well as the HQ ratio, in order to better understand muscle function and muscle imbalance in these athletes.

Some studies[21,27] analyzed the HQ ratio in isometric and isokinetic conditions through mathematical models and specific angles. All studies showed that the HQ ratio values were highly dependent on the tested angle. Nevertheless, the analysis of the HQ ratio using peak torque values similarly showed the existence of muscle imbalances in professional and amateur athletes of different sports[7,9,12,13,15,19]. However, it is not possible to determine if the muscle imbalance was caused by the increase of hamstrings torque or decreased quadriceps torque for these athletes, as the torque production was not evaluated throughout the total knee range of motion in these studies.

Our findings indicate that the analytical approach, based on a single measure of peak torque, may underestimate the real muscle imbalances frequency in athletes. For example, in this study the HQ ratio using the peak torque revealed that only one athlete was above the 60% ratio threshold at the angular velocity of 180°/s. However, the HQ ratio obtained throughout the entire range of motion showed that four athletes had HQ ratios above this threshold. Therefore, assessing muscle imbalance by the HQ peak torque ratio neglects the force-length relationship, in which different torque values are produced at different joint angles[21,22,28]. The method here presented detects specific angles of imbalance that can be used to design training programs aimed at decreasing these imbalances in female futsal players.

Hiemstra et al.[20,29] found similar work (area under the torque-angle curve) results by the knee flexors and extensors from 5° to 95° of knee flexion and different angular velocities. However, the amplitude and instant at which the peak torque occurred differs between muscle groups, and they did not identify how the torque was distributed throughout the range of motion between both muscle groups. The present study goes a step beyond in the analysis of knee torque production, detailing and identifying the different ratios along the range of motion, with the angles that have muscle imbalance. This procedure may contribute to improving training sessions and rehabilitation procedures, avoiding possible injury risks and possibly removing athletes from sports practice before these injuries are established.

The angle-specific HQ ratio demonstrated a strong relationship with sports practice that might be related to injury risks. It also allows for a better understanding of dynamic force production and dynamic stability around the knee, as both muscle groups produce torque in the same range of motion to ensure dynamic stability.

This study had some limitations. First, we did not included athletes with lower-limb injuries history, which would add interesting information if their HQ ratio was compared with healthy athletes. We also did not calculate the functional HQ ratio. The functional HQ ratio is widely used in assessing knee muscles imbalance, and differs from the conventional ratio used in this study as it is calculated as the ratio between eccentric hamstrings torque divided by concentric quadriceps torque. This information could give an idea about the torques produced during the kicking motion, where there is concentric quadriceps contraction followed by eccentric hamstrings contraction at the phase where the knee is extending towards the ball contact.

CONCLUSION

Female futsal players produced mean HQ ratio values above 60% for the entire knee joint range of motion, reflecting the presence of muscle imbalance. The analysis of quadriceps and hamstrings torque values and HQ ratio throughout the total knee range of motion enables the identification of muscle balance distribution, as well as determining specific angles with lower values of torque production and muscle imbalance in female futsal players. This new methodology may contribute to preventing lower limb injury. Future studies in other settings and populations may prove useful to enhance training and rehabilitation programs, as well as injury prevention.

AUTHORS' CONTRIBUTIONS: Each author made significant individual contributions to this manuscript. ACMAR (0000-0002-1722-1737)* conceived the study, acquired and interpreted data, and drafted and reviewed the manuscript. NAV (0000-0002-8245-4844)* ALM (0000-0001-7344-4647)* and JES (0000-0003-4409-7329)* analysed data, and reviewed the manuscript. MAV (0000-0001-6741-3502)* interpreted data, and drafted and reviewed the manuscript. SAC (0000-0003-1927-0142)* conceived the study, acquired and interpreted data, and drafted and reviewed the manuscript. *ORCID (Open Researcher and Contributor ID).

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