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Muscle Strength Differences of Hamstring-to-Quadriceps Ratio in Para-Footballers with Cerebral Palsy

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Abstract: The aims of this study were 1) to examine differences in knee flexor and knee extensor muscle strength between lower limbs and 2) to compare the hamstring to quadriceps (H/Q) muscle strength ratio and asymmetries, considering more and less affected legs in para-footballers with cerebral palsy (CP) and unilateral spasticity impairment profile. This cross-sectional design study included nine male para-footballers with CP who participated in this study. Participants performed an isometric knee extension and flexion for 5 seconds, and the force was registered with a load cell. The maximum peak force for the hamstring and quadriceps was registered for the more and less affected leg. The difference between legs, between muscle groups, and the hamstring and quadriceps ratio (H/Q ratio) was calculated. The knee extension of the less affected leg showed significantly greater strength than the more affected leg ($p = 0.014$, $d = 0.63$), but there no differences between knee flexors ($p = 0.35$, $d = 0.13$). The H/Q ratio was significantly lower in the less affected leg than in the more affected leg ($p = 0.03$, $d = -0.75$). The majority of participants (77%) showed asymmetry in lower limb strength levels by more than 10%. Para-footballers with CP showed asymmetries and strength deficits which could be related to a higher prevalence of injury risk factors. The characteristics of this population should be taken into account, and this type of test should be implemented in order to design appropriate training programs to counteract the neuromuscular consequences of CP and improve physical performance.

Keywords: Para-athletes; para-sport; Paralympic; spasticity; neurological impairments.

1. Introduction

Cerebral palsy (CP) is a group of conditions affecting movement, posture, and generating activity limitations commonly related to a motor disability (Graham et al., 2016). CP is a non-progressive neurological disorder produced by a brain lesion early in maturation that causes motor impairments such as abnormal muscle activity, altered strength, coordination problems, contractures, and spasticity (Tisha et al., 2019). Spasticity is a part of hypertonia (i.e., muscle tone alteration) and is one of the clinical phenomena most frequently presented in people living with CP, where a significant percentage present either unilateral or bilateral body problems (Dayanidhi & Lieber, 2018). Along with the aforementioned disorders, people with CP can exhibit abnormal motor development which may cause retained immature motor strategies, including developmental co-contraction and poor selective movement control which impact running and the performance of sports activities (Graham et al., 2016).

According to Böhm & Döderlein (2012), people with CP and motor problems in one side of the body (i.e., hemiplegic or unilateral spasticity profile) suffer an increase in asymmetries while running due to the associated impairments uncovering compensation mechanisms with musculature in the less affected side. Muscle asymmetries result from a primary injury in the central nervous system that could negatively impact performance during motor activities affecting balance control and posture (Rodby-Bousquet et al., 2013), increasing the risk of overuse of the less affected side (Böhm & Döderlein, 2012), and potentially, increasing injury risk factors due to imbalances as was described in the non-impaired population (Ruas et al., 2019). Previous studies reported higher asymmetries in kinematic running parameters and jumping capacities possible due to the impact of neural and non-neural components of CP (i.e., spasticity, joint stiffness, tissue properties) which alters the efficacy of the stretch-shortening cycle use and muscle power production (Chappell et al., 2019; Eek et al., 2023). Furthermore, Runciman et al. (2016) suggest that highly trained athletes with CP may reach maximal muscular adaptations towards a considerable performance compared to able-bodied athletes while maintaining the asymmetry constant.

Football is a popular discipline among people with CP, which presents some technical adaptations that bring the possibility of being played by participants with motor impairments. Like the regular version, CP football is characterized by high-intensity intermittent activities involving rapid turns, sprinting, acceleration, jumping and kicking the ball in an unpredictable competitive environment where players present specific activity limitations according to the impact of the impairment (Henríquez et al., 2020; Reina et al., 2017; Roldan et al., 2022; Yanci et al., 2018). Previous research described that people with spastic hemiplegic have muscle weakness in the affected limb compared to non-paretic limbs (Hussain et al., 2014), impaired torque production of knee flexors and extensors (Antunes et al., 2017; dos Santos Andrade et al., 2005), and limited knee muscle strength compared to non-impaired participants (de Groot et al., 2012), affecting motor performance.

In sports that require acceleration and deceleration, such as football, injuries to the lower limbs are the most common and are localized principally in the knee joint areas (e.g., anterior cruciate ligament injury, or hamstring rupture/strain) (Ekstrand et al., 2011; Timmins et al., 2016). Strength deficits in quadriceps or hamstring muscle groups have been identified as a risk factor that may result in a musculoskeletal injury (Kaeding & Borchers, 2014). In order to detect risk factors and identify procedures to prevent them, different studies have analyzed indicators such as hamstring to quadriceps ratio (H/Q ratio), which compare the force that can be produced by the mentioned muscles using isokinetic (Baroni et al., 2020; Croisier et al., 2008; Dedinsky et al., 2017; Fousekis et al., 2010; Moreno-Perez et al., 2013; Ramos et al., 2022) or isometric protocols in dynamometers (Ishøi et al., 2021; Peek et al., 2018; Pellicer-Chenoll, Serra-Añó, et al., 2017; Pietraszewska et al., 2020). In general, several studies reported that there is a common imbalance of the H/Q ratio based on weaker hamstrings, along with asymmetries between limbs which have been associated with an increased risk of injury (Alarcón et al., 2021; Croisier et al., 2008; dos Santos Andrade et al., 2005; Peek et al., 2018; Ramos et al., 2022). Given the importance of the H/Q ratio, the imbalances and asymmetries produced between limbs in football players, and taking into account the conditions of coordination and motor control of players with CP which affects actions such as accelerations, changes of direction or jumps (Reina et al., 2017, 2018; Roldan et al., 2022), it is possible to assume that performance is affected and these risk factors are incremented due to these characteristics. Thus, in light of the few studies on football players with CP that explored interlimb asymmetries and muscle imbalances (Alarcón et al., 2021; dos Santos Andrade et al., 2005), and considering the relevance of these parameters in performance, further analysis is required to provide a more profound understanding of risk factors that interact in a complex sports activity such as football. Therefore, this study aimed 1) to examine differences in knee flexor and knee extensor muscle strength between lower limbs and 2) to compare the hamstring to quadriceps (H/Q) muscle strength ratio and asymmetries, considering more affected and less affected legs in para-footballers with CP and unilateral spasticity impairment profile.

2. Materials and Methods

Subjects — A convenience sample of nine male para-footballers (24.9 ± 7.0 yr; 168.8 ± 7.0 cm; 70.8 ± 8.9 kg; 24.9 ± 3.5 kg·m^{-2}) with CP and unilateral spasticity participated in this study (Cans, 2000). All the participants were recruited from the national team and were classified according to the International Federation of Cerebral Palsy Football (IFCPF), presenting the following categorization: FT1 (n = 1), FT2 (n = 6), and FT3 (n = 2) (i.e., FT1 and FT3 sports classes contain para-athletes with higher and lower levels of impairment, respectively). At the time of data collection, all the players had at least one year of experience at their specific competitive level and performed between 2–5 training sessions per week. The participants were not injured or rehabilitated from a skeletal muscle injury or medical treatment that could influence their physical performance in the three months prior to assessment. This investigation was performed following the Declaration of Helsinki (2013). Before data collection, participants agreed to participate and gave their informed consent after being informed with a detailed written and oral explanation of the research design. The Scientific Ethical Committee approved the protocol of this study at Los Andes University (Reference no. k6008.SCEC201809).

Methodology —A cross-sectional design was performed to examine differences in knee flexor and knee extensor muscle strength and compare the H/Q ratio and asymmetries in para-footballers with CP. Data were collected in a single-day session during the preseason in preparation for an international CP competition (i.e., IFCPF America Cup). The participants were evaluated for their anthropometrics, considering body weight, height, and strength performance. All the players were instructed to report to the laboratory in the morning (10:00 am), avoid intense exercise for 24 h, and perform their maximum effort. Prior to measures, each participant carried out a familiarization process with the strength testing for isometric knee flexion and extension. The dominant leg, or less affected leg, was considered by the level of lower limb impairment (i.e., less spasticity) and by which the player referred as their preferred leg for kicking and passing during the game (Reina et al., 2020, 2021). Before the isometric strength assessment, a standardized warm-up was performed, including 6-min on a regular cycle ergometer at 50-60 Watts, followed by dynamic stretching exercises in the lower limbs.

Measures —Isometric Muscle Strength: Isometric knee extension and knee flexion muscle strength were assessed in a Leg Extension/Curl Rehab exercise machine with pneumatic resistance (pressure resistance 10 bar) (5530, HUR Ltd, Kokkola, Finland) connected to a performance recorder unit (HUR ®, Kokkola, Finland) using a tension and compression load cell (HMD1005B; Yuyao Tongyong Meter Co., Ltd, China). The manufacturer software of the exercise machine provided results in kilograms (kg) and Newton meter (Nm) (Neil et al., 2013) (Figure 1). The participants were placed in a seated position and stabilized with straps at the hip and thighs to prevent possible involuntary movements during the assessment. In addition, the lumbar support saddle was adjusted to provide full support, and the participants were instructed to use the handles located on the side of the machine to provide greater stability and safety during the test. The instrumentation was calibrated according to the manufacturer's recommendations, and the position of the participants, considering the axis rotation of the swing arm of the exercise machine, was adjusted using a standard protocol as used in previous studies (Neil et al., 2013; Uehara et al., 2020). The trunk position of the participants was between 110° to 120° of flexion. Previously, Neil et al., 2013 reported an excellent intra-class correlation (ICC > 0.90) using a muscle strength isometric protocol at the same exercise machine.

Figure 1. Leg Extension/Curl Rehab exercise machine with pneumatic resistance (HUR® 5530) used for the isometric muscle strength measurements.

Before taking measurements, each participant performed two trials of isometric strength of knee extension and knee flexion at 50% of the maximum subjective intensity. Following this, participants performed three measurements of maximum voluntary isometric contractions unilaterally in each lower limb (i.e., flexion and extension movement) each repetition lasting 5 s with a 1-min rest-pause between each contraction (Worrell et al., 2001). For the quadriceps muscle strength measurement, the test started with approximately 60° of knee flexion with the pad over the malleoli, asking the participant to activate the knee extensor musculature, lift the lever arm, and maintain the resistance. On the other hand, for the measurement of hamstring strength, the test started from an initial position of 30° of knee flexion with the pad behind the ankle, asking the participant to activate the knee flexor muscles, lower the lever arm, and maintain the resistance. The measurements started with the less affected lower limb, followed by the more affected lower limb with 3 min rests between each leg (Flansbjer & Lexell, 2010). The participants were verbally encouraged to generate a maximum effort for the entire duration of the contraction, and the highest peak isometric torque production during the maximal voluntary contractions in each leg was considered for statistical analyses.

Hamstring to Quadriceps Ratio and Strength Asymmetry: The peak isometric strength from hamstrings and quadriceps was used to calculate the isometric ratio (H/Q). As a reference in isometric parameters, the general population presented an average H/Q ratio of 0.66 (Steindler, 1955). In turn, in isokinetic parameters, a lower chance of developing muscle injuries was described in range values between 0.55 to 0.64 and when the peak torque for knee extensors or flexors is smaller than 10% in the comparison of bilateral legs (Liporaci et al., 2019). Furthermore, the strength asymmetry was analyzed by calculating the differences in the less affected leg versus the more affected leg in each muscular group and it was shown as the percentage difference between legs (%) (Alarcón et al., 2021).

Statistical Analysis — This study presents the data as means ± standard deviations (SD). The normality of the data distribution and homogeneity of variance were assessed using Shapiro-Wilk and Levene's tests. A student's paired *t*-test was used to determine the differences in H/Q muscle strength ratio and muscle imbalance between more affected and less affected legs. Practical significance was assessed by Cohen’s effect size (Cohen, 1998), using the Hedges correction *(d)* for the comparison between groups including a subsample lower than 20 participants (Hedges & Olkin, 1985). The 95% confidence intervals (CI) of the effect size were calculated with their respective upper and lower boundaries. The effect size above 0.8, between 0.8 and 0.5, between 0.5 and 0.2, and lower than 0.2 were considered large, moderate, small, and trivial, respectively. The statistical analysis was conducted utilizing the GraphPad Prism package (version 8.2; GraphPad Software, San Diego, CA, USA). The level of significance was set at $p < 0.05$.

3. Results

Overall, the less affected leg coincided with the reported dominant side in all the participants, with a left lower limb prevailing

(87.5%). The peak muscle strength torque of the knee flexor and knee extensor in each leg are described in Table 1. Differences between knee flexor and extensor musculature are reported in the more affected leg ($p < 0.001$, $d = -1.23$, CI = -2.23 to -0.22, large) and the less affected leg ($p < 0.001$, $d = -1.89$, CI = -3.00 to -0.78, large).

Table 1. Descriptive values for peak isometric strength from knee flexors and knee extensors for more affected and less affected legs.

	Less Affected Leg			More Affected Leg		
Variable	Min	Max	Mean (SD)	Min	Max	Mean (SD)
Knee Flexors (Nm)	69.26	185.15	122.70 (32.79)*	61.83	195.03	117.65 (39.55)#
Knee Extensors (Nm)	125.21	286.05	213.87 (55.98)	119.99	283.94	178.00 (53.12)

**Indicates a significant difference (p < 0.01) compared to the knee extensors of the less affected leg. # Indicates a significant difference (p < 0.01) compared to the knee extensors of the more affected leg.*

Regarding the comparison between legs, knee flexion musculature showed no significant differences when comparing both legs ($p = 0.35$, $d = 0.13$, CI = -0.79 to 1.06, trivial). Although, significant differences were demonstrated for the imbalance of knee extension muscle strength ($p = 0.014$, $d = 0.63$, CI = -0.32 to 1.57, moderate) between less affected and more affected legs (Figure 2).

The overall mean results of H/Q were 0.58 ± 0.09 for the less affected leg and 0.66 ± 0.12 for the more affected leg. Figure 3 shows the significant differences in the H/Q ratio between the less affected leg and the more affected leg of the nine footballers with CP ($p = 0.03$, $d = -0.75$, CI = -1.70 to 0.21, moderate).

Regarding strength asymmetries between the less affected leg and the more affected leg, 77.7% of participants present imbalance values higher than 10% in at least one muscular group. Moreover, the mean values for the comparison of muscular imbalance between knee flexors and knee extensors presented significant differences ($p = 0.010$, $d = -0.91$, CI = -1.88 to 0.06, large). Individual imbalance/asymmetry data for knee flexors and knee extensors are described in Figure 4.

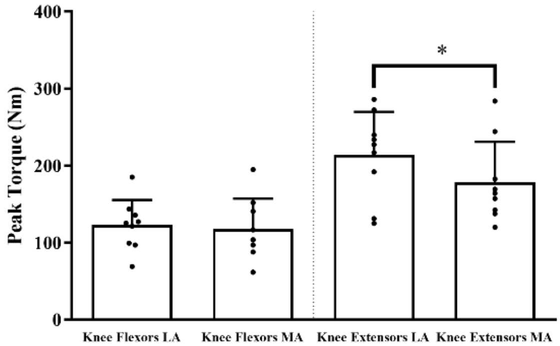

Figure 2. Strength peak torque results of knee flexors and knee extensors considering less affected leg and more affected leg. LA = less affected leg; MA = more affected leg. * $p < 0.05$.

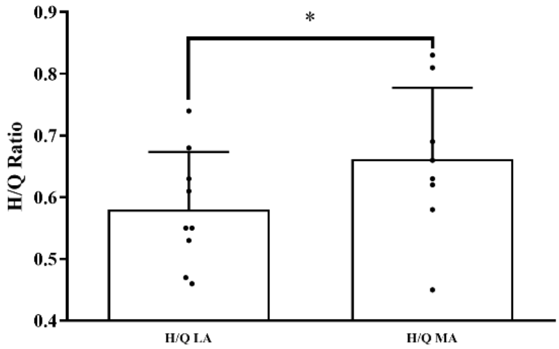

Figure 3. Hamstring/quadriceps muscle strength ratio between the less affected leg and the more affected leg. H/Q = hamstring to quadriceps strength ratio; LA = less affected leg; MA = more affected leg. * $p < 0.05$.

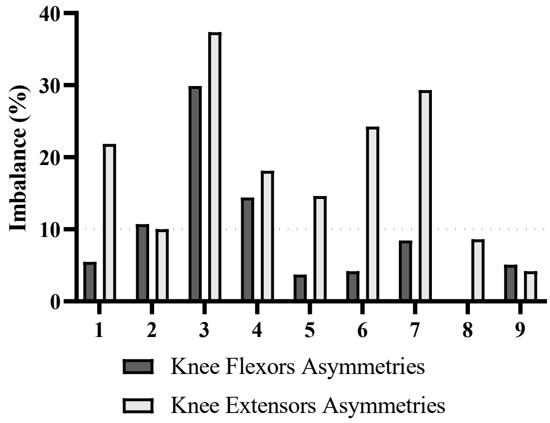

Figure 4. Individual asymmetry data for comparison between more-affected and less-affected knee flexors and knee extensors imbalance. Above the line indicates a score higher than 10%.

4. Discussion

This study investigated the differences in knee flexor and knee extensor strength considering more affected and less affected legs, the H/Q ratio between lower limbs, and strength asymmetries in para-footballers with CP and unilateral spasticity impairment profiles. In general, our data show that para-footballers with CP exhibited lower values than those reported in non-impaired footballers assessed for hamstring and quadriceps musculature strength in isometric contraction (Ishøi et al., 2021; van Melick et al., 2022). de Groot et al. (2012) found a reduced isokinetic and isometric knee extension strength in a group of para-athletes with CP compared to a non-impaired group, suggesting that the muscle strength in addition to coordination impairments, could be a limiting factor in performing motor activities. The muscle strength and torque production capacity of lower limbs were identified as fundamental factors contributing to running performance and have been differentiated according to the severity of the impairments in para-athletes with CP (Antunes et al., 2017; Beckman et al., 2016), affecting motor performance.

When comparing the muscle strength of the hamstring and quadriceps of the more and less affected leg in the participants of this study, significant differences were obtained for the results of knee extension assessment; in contrast, no differences were found for knee flexion. These results are contrary to those observed by Śliwowski et al. (2017) in non-impaired football players, where only the peak torque of the knee flexors was higher for the dominant leg than for the non-dominant leg. On the other hand, other studies showed no significant differences in peak torque assessment of quadriceps or hamstrings in comparing lower extremities (Denadai et al., 2016; Zabka et al., 2011). In this sense, the obtained differences in the comparison between legs on knee extensor muscle strength might be explained by the unilateral impairment profile of the participants, presenting the influence of muscle weakness, lack of muscle control, spasticity, involuntary coactivation, and compensatory strategies that affect neuromuscular performance (Bar-On et al., 2015; Graham et al., 2016; Stackhouse et al., 2005). Additionally, due to the requirements of football, it is likely that the involvement of the quadriceps has a greater weight in this population, thus showing a significant difference between the less affected limb and the more affected limb in this musculature alone. Football tasks require multidirectional activities that involve some actions in which only the dominant leg is needed, or both legs perform different movements, generating demands of quadriceps and hamstring musculature that play a determinant role as contributors and stabilizers of joint movements (Pellicer-Chenoll, Pardo, et al., 2017; Śliwowski et al., 2017). Taking into account that hamstring muscle action balance quadriceps contraction for knee protection (Baroni et al., 2020), it is plausible to think that the non-differences between less and more affected legs in knee flexors peak torque could be due to low levels of neuromuscular strength related to the impairments caused by the upper motoneuron injury characterized in CP (Antunes et al., 2017).

Considering the H/Q muscle strength ratio, 88.9% of para-footballers presented values outside the range established as lower possibilities of developing muscle injuries in at least one of their lower limbs (range = 0.55 to 0.64, in isokinetic measures) (Liporaci et al., 2019). However, the overall mean results of H/Q are inside this range of values in the less affected leg (0.58 ± 0.09, range 0.46 – 0.74) and outside this range in the more affected leg (0.66 ± 0.12, range 0.45 – 0.83). The main findings were that a significantly higher H/Q ratio is described in the more affected leg than the less affected leg, and a significant muscle strength imbalance was found only in the comparison of values obtained in knee extension assessment in both legs. Furthermore, the H/Q muscle strength ratio in the less affected leg showed that the results are similar to those reported by dos Santos Andrade et al. (2005) in Brazilian para-footballers with CP evaluated with an isokinetic dynamometer (i.e., 0.57 ± 0.18) and as in early studies performed in non-impaired footballers describing close values to those presented in the dominant leg (Denadai et al., 2016; Śliwowski et al., 2017). These findings are contrary to the reported in previous studies, where non-impaired football players presented a higher H/Q ratio in the dominant leg than the non-dominant leg, possibly indicating better knee joint stability than in this specific population (Pellicer-Chenoll, Pardo, et al., 2017; Śliwowski et al., 2017). The H/Q ratio strength imbalance reported between both legs could be expected due to the presence of impaired force production and weakness as a consequence of the central nervous system lesion affecting quadriceps activation and hamstring coactivation during voluntary efforts (Stackhouse et al., 2005). However, based on our data, we suggest that the higher ratio on the more affected leg is produced by an inherent weakness and muscle imbalances related to the CP health condition of the players. Therefore, the less affected leg has a greater workload than the more affected leg, probably due to this, the force in muscle extension is greater and consequently, there may be a higher risk factor of injury. However, it is important to note that further investigation is needed to fully understand this aspect and the possible relationship between muscle asymmetries or imbalances with musculoskeletal injury prevalence.

Although the physical and technical requirements of football influence the presence of asymmetrical loading patterns where lower limb strength is fundamental for the performance, it is plausible to think that para-footballers with unilateral spasticity compensate with motor strategies or incorporate lower-body musculoskeletal adaptations in response to the mechanical demands of the sport (Hart et al., 2016; Maly et al., 2014). According to Liporaci et al. (2019), the values obtained in the H/Q ratio for the more affected leg are outside a safe range, where a possible greater chance of developing non-contact muscle injuries could occur. In this regard, Webborn et al. (2016) have reported a significantly higher rate of injuries, specifically on the ankle or knee joints in para-footballers with CP, which may have a greater risk of strain and musculoskeletal injury considering the presence of deficient neural control mechanisms which contribute to hypertonia, muscular imbalances, and maladaptation of movement patterns (Dietz & Sinkjaer, 2007). Moreover, these results suggest that the more affected leg presents considerable muscle imbalance reflected in the isometric H/Q ratio, possibly influenced by neuromuscular and musculoskeletal impairments, accentuating the unequal development of players with unilateral involvement affecting motor and sport skills (e.g., strength differences between kicking limb and support limb) (Hart et al., 2016; Reina et al., 2020).

Previous studies demonstrated the presence of asymmetries in para-footballers with CP in biomechanical parameters during running (Kloyiam et al., 2011), vertical jump performance (Reina et al., 2019; Runciman et al., 2016), horizontal jump performance (Reina et al., 2018), and balance (Reina et al., 2020), showing the neuromuscular particularities faced by this group. In this line, Alarcón et al. (2021) reported that a six-week eccentric strength training protocol in a group of para-footballers with CP improved the strength asymmetry assessed on knee extensor musculature showing the feasibility of this type of intervention as a countermeasure to muscle imbalance. The present results showed that the percentage of peak torque asymmetry was significantly higher on knee extension than on knee flexion. Muscle strength asymmetry index and imbalance assessment between legs have demonstrated association with injury risk and are valuable practices for monitoring readiness to return to sport in able-bodied individuals (Risberg et al., 2018; Ruas et al., 2019). However, coaches and the medical support team should keep in mind that using these parameters to assess muscle strength function could be influenced by the diverse nature of impairments, characteristics and functional profiles presented in para-footballers with CP. To counteract the negative impact of the impairments, the use of strength training could be a feasible option for para-athletes with CP to improve muscle function and physical performance, where several studies reported positive benefits (Fleeton et al., 2020, 2022).

The limitations of this study include the assessment of lower limbs through isometric contractions at a specific joint angle and the recruitment of a convenience sample of trained CP football players limiting the statistical power results. This makes it difficult to compare with other studies as some have been conducted at different angles or with other types of contractions. In addition, suggested optimal values of H/Q ratio and inter-limb imbalance were exclusively investigated in able-bodied athletes. Comparing these findings to reference values can provide insights into the neuromuscular characteristics that may increase susceptibility to musculoskeletal injuries in individuals with CP (Runciman & Derman, 2018). Thus, although the conclusions provide valuable information, they should be taken with caution. Further studies should consider the evaluation of concentric or eccentric muscle contractions in an isokinetic dynamometer as done in early studies with non-impaired footballers, which possibly could provide a deeper understanding of the impaired muscle function in trained athletes with CP (Denadai et al., 2016; Maly et al., 2014). In addition, an extended sample size including participants with other impairment profiles (i.e., bilateral spasticity, athetosis, or ataxia) could show differences in the H/Q ratio according to the player's impairment-specific characteristics.

5. Practical Applications.

Using the H/Q ratio and identifying muscle strength asymmetries could help identify possible risk factors of injuries and establish individualized programs considering the player's impairment profile. Further research is needed to determine the appropriate way to use the H/Q ratio as a tool to prevent injuries in this population with CP. Different ways of assessment using multiple methodologies should be investigated, for example conducting studies of muscle strength assessment at different joint angles or analyzing variables such as rate of force development that can assist coaches in optimizing the physical performance of para-athletes with CP.

6. Conclusions

These results suggest that para-footballers with unilateral spasticity presented differences in comparing the level of muscle strength between the hamstring and quadriceps of the more affected and less affected leg. This imbalance appears to be due to the presence of a greater quadriceps strength in the less affected leg. For this reason, it may be interesting to implement conditioning and strength training programs focused on decreasing these imbalances in this population. Additionally, a higher H/Q ratio was obtained in the more affected leg considering significant levels of muscle imbalance for the quadriceps on the same side.

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Conflicts of Interest: The authors declare no conflict of interest.

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