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Increased Tone and Stiffness of the Teres Major Muscle in Elite Handball Athletes: A Cross-Sectional Study

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Abstract: Background: The aim of this study was to determine whether the elite handball (HB) athletes with glenohumeral internal rotation deficit (GIRD) present differences in the mechanical properties in the teres major muscle, and strength and extensibility of the posterior shoulder tissues of the throwing shoulder (TS) compared to the non-throwing (non-TS) and non-HB athletes. Methods: A cross-sectional study was carried out, with sixty male participants: 30 HB athletes with GIRD and 30 age-matched healthy non-HB athletes. Mechanical properties of the teres major muscle were measured with MyotonPRO; also, extensibility of the posterior shoulder tissues and maximum isometric internal rotation (IR) and external rotation (ER) strength were recorded. Results: The teres major muscle of the TS in the HB group achieved a higher tone (Δ 0.34; 95% CI: 0.15, 0.53) and stiffness (Δ 30.86; 95% CI: 23.04,38.68), and a lower relaxation time compared to the non-TS of the same group (Δ −0.69; 95% CI: −1.15, −0.24;) and to the TS of the control group for the tone (Δ 0.36; 95% CI: 0.02, 0.70) and for the stiffness (Δ 27.03; 95% CI: 15.24, 38.83). The extensibility of the TS of the HB group presented a statistically significant decrease compared to the control group (Δ −7.83; 95% CI: −12.42, 3.23). A between-groups ER/IR ratio imbalance was found for the TS (Δ −12.18; 95% CI: −25.59, −1.23) and the non-TS (Δ −13.01; 95% CI: −25.79, −0.25). Conclusions: HB athletes with GIRD present a higher tone and stiffness of the teres major muscle and lack of extensibility of the tissues of the posterior part of the shoulder compared to the non-TS and to healthy non-HB athletes.

Keywords: handball; myotonometry; GIRD; cross-sectional

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Citation: Jiménez-del-Barrio, S.; Jiménez-Rejano, J.J.; Rebollo-Salas, M.; Mingo-Gómez, M.T.; Lorenzo-Muñoz, A.; Ceballos-Laita, L. Increased Tone and Stiffness of the Teres Major Muscle in Elite Handball Athletes: A Cross-Sectional Study. *Appl. Sci.* **2023**, *13*, 8457. https://doi.org/10.3390/app13148457

Academic Editor: Mark King

Received: 5 July 2023
Revised: 18 July 2023
Accepted: 19 July 2023
Published: 21 July 2023

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1. Introduction

Shoulder injuries are the most frequent in throwing sports such as handball (HB). The elite HB athletes make around 48.000 throwing actions in over 16.000 different shoulder positions during a season [1–3] which overloads the shoulder complex and may provoke several injuries such as impingement, labral and rotator cuff tears, and anterior instability, among others [4–8]. Studies in elite HB athletes have reported 3.7 injuries per 1000 h of training and 20.3 injuries per 1000 matches [9], and the prevalence of acute shoulder pain has been stated to be between 36% to 44.2% [10–12].

The repetitive throwing actions have shown several adaptations in the shoulder complex. The most frequent adaptation is the reduction of the glenohumeral internal rotation (IR) range of motion (ROM) commonly known as glenohumeral internal rotation deficit (GIRD), and the decrease of the total rotation ROM (tROM) [8,13–16]. Athletes with GIRD have shown a two- to four-fold increased risk of suffering injuries in the shoulder complex [5].

Adaptations in the soft tissues have been also described, such as external rotation (ER) weakness [17], strength imbalance between the ER and IR muscles [18], and shortening or lack of extensibility of the posterior muscles [8,13,14,19].

GIRD is currently considered the primary risk factor for shoulder pain [4,20] and has been associated with the stiffness and weakness of the posterior shoulder muscles by several authors [6–8,13,14,19]. The stiffness of the posterior muscles seems to shift the humeral head upward during the shoulder flexion, increasing the compression forces in the joint and the stress in the anterior part of the capsule and ligaments [6,7,21,22]. Previous clinical trials have applied different interventions to the posterior shoulder muscles (upper trapezius, infraespinatus [23], or shoulder external rotator muscles [24]) to decrease the posterior stiffness in overhead athletes, but the teres major muscle has never been taken into consideration.

A cadaveric study hypothesized that the teres major muscle may play an important role in the glenohumeral stability and function [25]. The teres major muscle is a monoarticular scapulohumeral muscle that is inserted in the same plane as the subscapularis muscle but is not part of the conjoined tendon of the rotator cuff. When the arm is elevated, the inferior surface of the humeral head rests against the teres major muscle. This direct support of the humeral head may contribute to maintaining glenohumeral joint stability [25]. This muscle has been described to be more active in instable shoulders [26]. Therefore, in this way, an increment in the mechanical properties of tone and stiffness in this muscle may be related to GIRD. However, to the best of our knowledge, no study has assessed the mechanical properties of the teres major muscle in elite HB athletes.

Thus, the assessment of the mechanical properties of the teres major muscle such as tone and stiffness, the internal and external rotators muscle strength, and extensibility of the posterior soft tissues could be relevant in elite HB athletes with GIRD. We hypothesize that the TS of the elite HB athletes with GIRD present a higher tone and stiffness in the teres major muscle, a muscle imbalance between internal and external rotators, and a decreased extensibility compared to the non-TS and non-HB athletes. Therefore, the aim of the study was to determine whether the elite HB athletes with GIRD present differences in the mechanical properties in the teres major muscle of the throwing shoulder (TS) compared to the non-throwing (non-TS) and non-HB athletes, and to verify if HB athletes present asymmetry in muscle strength and extensibility compared to the non-TS shoulder and differences compared to non-HB athletes.

2. Materials and Methods

A cross-sectional study was carried out between October and December 2021. This study was approved by the Research Ethics Committee of Valladolid Este (CASVE-NM-21-538), and followed the STROBE Statement Guide [27]. The study was performed according to the Declaration of Helsinki (2013) and the Taipei criteria (2016). All the participants were informed about the objective of the study, agreed to participate, and signed the informed consent form.

The recruitment was performed by contacting professional handball clubs. Sixty male volunteers participated in the study (30 elite HB athletes and 30 healthy non-HB athletes). The inclusion criteria in the HB group were: male aged between 18–30 years with a GIRD value > 15° [8,19], a minimum of 2 years' experience practicing HB at professional level, and practice routine of a minimum 2 h/d and 3 d/w. The inclusion criteria in the control group were: male aged between 18–30 years, practice any type of sport in which throwing actions were not involved, and practice routine of a minimum 2 h/d and 3 d/w. Exclusion criteria for both groups were: pain or symptoms in the neck or shoulder region; previous fracture, luxation, subluxation or surgery in any joint of the upper limb, cervical spine or thoracic spine, neurological or systemic pathologies, use of analgesics, muscle relaxants, corticoid injections or other pharmacological treatment, or previous physiotherapy treatment in the last month.

The aim of our study was to compare teres major muscle mechanical properties, shoulder rotator strength, and extensibility between the TS and non-TS of HB athletes with GIRD and non-HB athletes. Thus, shoulder IR and ER ROM, tROM, and GIRD were registered in the HB group to ensure that all the patients met this criterion. The ROM variables were assessed by a physiotherapist who knew the group assignment. The dependent variables were measured by a second physiotherapist blinded to the group allocation.

2.1. Shoulder Assessment

Demographic and sport-related variables, and shoulder ROM of the HB group were measured for descriptive purposes. The clinical variables were mechanical properties of teres major muscle measured by myotonometry, IR and ER isometric strength, and extensibility. All the variables were assessed in the TS and the non-TS by two examiners who were experts in the field with more than 8 years of clinical practice treating patients with musculoskeletal disorders. The examiners were blinded to the group allocation and to the dominant side of each subject. The order of the shoulder was selected randomly. All assessments were performed prior to the sporting activity.

2.2. Reliability of the Measures

Test–retest reliability was assessed for all the variables before the study. The measurements were performed by a professional physiotherapist with more than ten years of clinical experience. Ten healthy non-HB athletes were assessed on the same day with 10 min between evaluations. Maximum isometric IR and ER strength, extensibility of the tissues of the posterior part, and myotonometry evaluation of the teres major muscle were assessed similarly to the assessments conducted in this study. These measures were used to calculate the intraclass correlation coefficient (ICC), mean-based error measures (SEM), and minimum detectable changes (MDC) (Table 1).

Table 1. Test–retest reliability of the study variables.

	ICC (95% CI)	SEM	MDC
ER strength (Kg)	0.97 (0.96, 0.98)	0.52	1.44
IR strength (Kg)	0.98 (0.97, 0.99)	0.64	1.79
Extensibility (°)	0.92 (0.9, 0.94)	2.23	6.19
Tone (Hz)	0.98 (0.96, 0.99)	0.29	0.80
Stiffness (N/m)	0.97 (0.95, 0.98)	8.99	24.91
Elasticity	0.95 (0.9, 0.97)	0.08	0.23
Relaxation time (ms)	0.98 (0.97, 0.99)	0.67	1.88
Creep (D)	0.97 (0.94, 0.98)	0.04	0.12

ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error of measurement; MDC: minimal detectable change; ER: external rotation; IR: internal rotation.

2.3. ROM Assessment

IR and ER were measured using a digital inclinometer (ACUR001 Lafayette Instrument, Lafayette, IN, USA). Three measurements of each shoulder joint were recorded, and the average of the three trials was calculated.

The tROM (sum of IR and ER), and the GIRD (difference between IR RS and IR non-TS as a comparable reduction in ROM described in negative value) were calculated after the measurements [13,14].

IR and ER ROM were measured with the patient in supine position with the arm at 90° of abduction and the elbow at 90° of flexion with a towel under the arm to ensure the correct alignment of the upper limb in the frontal plane. The examiner manually stabilized the scapula in the anterior part of the shoulder applying pressure with one hand. The other hand was used to perform passive IR and ER. The inclinometer was placed by the second examiner on the dorsal part of the distal part of the forearm [13,14].

2.4. Maximum Isometric Strength Assessment

The maximum isometric IR and ER strength was recorded using a hand-held dynamometer (Lafayette Instrument 01165). All the patients perform a first trial to familiarize with the procedure. Then, two measurements of each shoulder movement were recorded with 30 s break between them to avoid fatigue, and the maximum of the two trials was used for statistical purposes.

Maximum isometric strength was initially measured in Kg. Then, strength was normalized by the body weight and multiplied by 100 and expressed as percentage of body weight (%BW) [28]. In addition, the strength ratio between ER and IR muscles was calculated by dividing the average maximal strength of each muscle group and multiplying it by 100 to express the result as percentage [28].

Patients were in supine position with the shoulder at 90° of abduction and the elbow at 90° of flexion with a towel under the upper limb to ensure the correct alignment. The hand-held dynamometer was placed on the ventral part of the forearm or on the dorsal part of the forearm to assess IR or ER strength, respectively. The patients were verbally encouraged to apply the maximum force against the dynamometer [29].

2.5. Extensibility Assessment

The extensibility was measured using a digital inclinometer (ACUR001 Lafayette Instrument). Three measurements of each shoulder joint were recorded, and the average of the three trials was calculated.

The patient was placed in side-lying position with the shoulder at 90° of abduction. The examiner manually stabilized the scapula and allowed the humerus to drop. If the humerus was horizontal, it was considered 0°; if the humerus was below (adducted), it was recorded as a positive value, and if was above (abducted), it was recorded as a negative value [30,31].

2.6. Mechanical Properties Assessment

Mechanical properties of the teres major muscle were measured with MyotonPRO (Mumeetria Ltd., Tallinn, Estonia). The device measures mechanical oscillations by a short duration mechanical impulse (15 ms) and constant mechanical force (up to 0.6 N). The variables obtained from this procedure are frequency or tone (Hz), stiffness (N/m), logarithmic decrement or elasticity, mechanical stress relaxation time (ms), and creep (D) [32]. Three measurements were performed in each teres major muscle with 10 min of rest between trials. The average of all the trials were used for statistical analysis.

The participant was positioned in prone lying with 90° of shoulder abduction, neutral internal and external shoulder rotation, 90° elbow extension, and wrist in neutral position. A rest time for 10 min prior to measurements was performed. During this time, the site for measurement on the teres major muscle was identified by manual palpation following the direction of muscle fibers in the middle of the muscle belly, according to previous protocol studies [33,34]. After 10 min, the testing end of MyotonPRO was placed on the skin perpendicular to the surface of the muscle belly over the site located. The device was applied into the measurement position and automatically performed the predefine measurement series.

2.7. Sample Size and Statistical Analysis

The revised sample size of 60 participants including a 95% confidence interval was calculated on the bases of the estimate of what this would provide the percentage of power for each outcome variable. The power is the ability to detect if there is an effect present and is important for reducing the chances of a type II error. A 95% power for strength ratio, 89% for IR isometric strength, 99% for extensibility, 97% for tone, 100% for stiffness, 100% for relaxation, and 70% for creep were found. Only less than 50% power were obtained for ER isometric strength and elasticity. The statistical power was calculated using G*Power 3.1.

SPSS version 20.0 for Windows was used for statistical analysis. The test–retest reliability was calculated for all the variables. The reliability was considered excellent when the values of ICC exceeded 0.75. When the ICC ranged from 0.4 to 0.74, the reliability was considered good to fair, and when the value was less than 0.4, it was considered poor. The SEM was calculated with this formula: SEM = SD $\times \sqrt{(1 - \text{ICC})}$; and the MDC was calculated with the next formula: MDC = 1.96 $\times$ sem $\times \sqrt{2}$ [35].

Quantitative variables were presented as mean (M) and standard deviation (SD). The Shapiro–Wilk test was used to evaluate the normal or non-normal distribution of the variables. Between-groups comparisons of clinical and demographic variables were analyzed using the Student's *t*-test or the Mann–Whitney U test, for normally distributed data or non-normally distributed data. Between-shoulders comparison was analyzed using the paired *t*-test or the Wilcoxon test, for normally distributed data or non-normally distributed data. A *p*-value < 0.05 was considered statistically significant.

3. Results

Sixty-five participants were recruited for the study. Five were excluded for different reasons: two of them presented shoulder pain, two were under physical therapy treatment, and one received a surgery in the shoulder complex. Finally, 60 participants met all the eligibility criteria and were included in the study (HB group n = 30; control group n = 30). No dropouts during the study were reported. This process is shown in Figure 1. No differences between the HB group and the control group were found in the demographic and sport-related variables (Table 2).

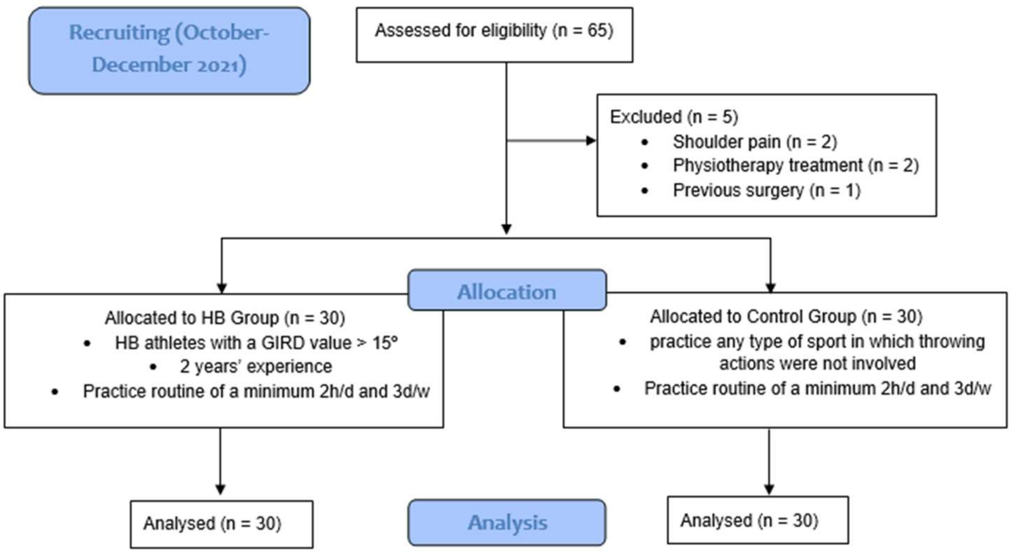

Figure 1. Flowchart of the study.

Table 2. Demographic and sport-related variables.

	HB Group M (SD)	Control Group M (SD)	*p*-Value
Age (years)	25.83 (5.39)	24.47 (4.37)	0.577
Weight (kg)	87.33 (12.22)	85.25 (12.51)	0.605
Height (cm)	183.67 (6.11)	182.80 (6.99)	0.894
Weekly practice (hours)	3.41 (2.45)	3.01 (2.84)	0.794
Frequency (days/week)	4.20 (0.81)	3.80 (1.27)	0.637

HB: handball; M: mean; SD: standard deviation.

The ROM assessment showed in the HB group an IR ROM of 17.57° (5.42) and 41.30° (6.97) in the TS and non-TS, respectively. The difference between both shoulders was statistically significant ($p < 0.001$) and represented a mean GIRD of 23.58° (95% CI: −27.49; −19.97). The tROM was 93.77° (16.68) in the TS and 123.77° (11.86) in the non-TS, with a mean difference of 30.00° (95% CI: −37.96; −22.03; $p < 0.001$).

Table 3 shows strength and extensibility results. No differences were found in isometric strength between the TS and non-TS in any group or between shoulders of both groups ($p > 0.05$). The ER/IR ratio showed no differences between shoulders in any group ($p > 0.05$), but a between-groups ER/IR ratio imbalance was found for the TS (Δ −12.18; 95% CI: −25.59, −1.23; $p = 0.009$) and the non-TS (Δ −13.01; 95% CI: −25.79, −0.25; $p = 0.025$). The extensibility was significantly lower in the TS of both groups compared to the non-TS ($p < 0.001$). The TS of the HB group presented a statistically significant decrease compared to the control group (Δ −7.83; 95% CI: −12.42, 3.23; $p = 0.006$).

Table 3. Analysis of isometric strength and extensibility.

	HB Group		Control Group		
Outcomes		**Differences (*p*-Value)**		**Differences (*p*-Value)**	**Between-Groups Differences *p*-Value**
IR Strength (%BW)					
TS	14.60 (3.66)	0.77 (−0.30; 1.84); 0.152	12.61 (5.28)	0.16 (−0.75; 1.08); 0.716	1.99 (−0.40; 4.40) $p = 0.102$
Non-TS	13.83 (2.80)		12.44 (6.07)		1.39 (−1.10; 3.88) $p = 0.269$
ER Strength (%BW)					
TS	13.09 (3.18)	−0.94 (−1.93; 0.04); 0.061	12.85 (5.36)	0.62 (−0.46; 1.72); 0.250	0.23 (−2.09; 2.56) $p = 0.839$
Non-TS	14.03 (3.18)		12.22 (5.11)		1.81 (−0.44; 4.06) $p = 0.113$
ER/IR ratio (%)					
TS	93.01 (26.38)	−3.01 (−10.44; 4.42); 0.414	105.19 (24.05)	−3.85 (−12.04; 4.32); 0.342	−12.18(−25.59; −1.23) $p = 0.009$
Non-TS	96.02 (21.14)		109.05 (26.73)		−13.01(−25.79; −0.25) $p = 0.025$
Extensibility					
TS	−11.60 (8.68)	−8.73 (−11.12; −6.34); <0.001	−3.86 (8.40)	−4.35 (−6.47; −2.23); <0.001	−7.83 (−12.42; 3.23) $p = 0.006$
Non-TS	−2.87 (7.58)		0.50 (7.71)		−3.25 (−7.35; 0.83) $p = 0.116$

HB: handball; TS: throwing shoulder; non-TS: non-throwing shoulder; IR: internal rotation; ER: external rotation.

Table 4 presents the myotonometry results of the teres major. The teres major muscle of the TS in the HB group achieved a higher tone and stiffness, and a lower relaxation time compared to the non-TS of the same group and to the TS of the control group ($p < 0.05$). No between-shoulders or between-groups differences were found for elasticity or creep ($p > 0.05$).

Table 4. Analysis of mechanical properties of the teres major muscle.

	HB Group		Control Group		
Outcomes		**Differences (*p*-Value)**		**Differences (*p*-Value)**	**Between-Groups Differences *p*-Value**
Tone (Hz)					
TS	11.44 (0.51)	0.34 (0.15; 0.53); 0.001	11.10 (0.72)	0.05 (0.10; −0.17); 0.646	0.36 (0.02; 0.70) $p = 0.035$
Non-TS	11.09 (0.45)		11.05 (0.75)		0.03 (−0.30; 0.34) $p = 0.896$

Table 4. *Cont.*

Outcomes	HB Group		Control Group		
		Differences (*p*-Value)		Differences (*p*-Value)	Between-Groups Differences *p*-Value
Stiffness (N/m)					
TS	173.34 (25.57)	30.86 (23.04; 38.68); 0.001	147.93 (19.22)	4.39 (−0.16; 8.94); 0.060	27.03 (15.24; 38.83) $p < 0.001$
Non-TS	142.48 (18.73)		143.54 (19.94)		−0.28 (−10.62; 10.05) $p = 0.928$
Elasticity					
TS	1.08 (0.21)	0.05 (−0.01; 0.12); 0.106	1.10 (0.14)	0.02 (−0.04; 0.08); 0.515	−0.01 (−0.11; 0.08) $p = 0.806$
Non-TS	1.03 (0.15)		1.08(0.14)		−0.05 (−0.13; 0.01) $p = 0.120$
Relaxation time (ms)					
TS	25.56 (1.67)	−0.69 (−1.15; −0.24); 0.004	26.78 (2.40)	−0.16 (−0.67; 0.33); 0.501	−1.37 (−2.44; −0.29) $p = 0.013$
Non-TS	26.26 (1.79)		26.95 (2.19)		−0.80 (−1.86; −0.25) $p = 0.133$
Creep (D)					
TS	1.33 (0.11)	0.01 (−0.02; 0.03); 0.764	1.37 (0.13)	0.01 (−0.01;0.03); 0.535	−0.04 (−0.10; 0.02) $p = 0.222$
Non-TS	1.33 (0.12)		1.36 (0.11)		−0.03 (−0.09; 0.02) $p = 0.149$

HB: handball; TS: throwing shoulder; non-TS: non-throwing shoulder.

4. Discussion

The objective of this study was to determine if elite HB athletes with GIRD presented changes in the TS in maximal isometric strength, posterior stiffness, and mechanical properties in the teres major muscle compared to the non-TS and to non-HB healthy athletes. The results of the study confirmed the hypotheses: HB athletes presented lower ER isometric strength, a lack of extensibility in the tissues of the posterior part, and an increased tone and stiffness in the teres major muscle.

Shoulder ROM was assessed mainly for inclusion criteria. The mean value of IR ROM in the TS was 17.57° and in the non-TS was 41.30°, and the mean difference between them was 23.58°. These data are similar to other studies that included elite HB athletes [19]. The role of GIRD was investigated as a primary risk factor for shoulder injury in HB athletes, establishing the mean value between 12.9° to 15° [8]. The reduction of tROM in the TS compared to the non-TS has been also described as a risk factor for shoulder injury [20]. Deficits greater than 10° are needed to be considered as a contributing factor [5]. The HB athletes included in this study presented a mean difference between shoulders of 30.00°. Wilk et al. [5] concluded that elite athletes with GIRD and tROM reduction presented at least twice the risk of suffering shoulder injuries than those without GIRD and tROM differences. Therefore, the HB athletes included in the study presented the biomechanical adaptations described for this type of patient, which makes an adequate sample to assess other variables such as strength, extensibility, and mechanical properties.

No differences were found for IR or ER isometric strength between shoulders or between both groups. However, the ER/IR ratio in the HB group showed that the IR strength was greater than the ER strength and was statistically significant different from the control group. The optimal balance between IR and ER muscle strength allow one to stabilize the glenohumeral joint and maintain the correct position of the humeral head [36]. ER weakness may alter the stability and position of the humeral head. These results are similar to the results obtained by Clarsen et al. [17], that found that isometric ER weakness in elite HB athletes increased the probability of shoulder injuries during the season.

Both groups showed a statistically significant decrease of the extensibility of the tissues of the posterior part of the TS compared to the non-TS. However, the TS of the HB group showed a higher extensibility restriction than the TS of the control group. It is important to emphasize that these differences were higher than the SEM and MDC calculated from our test–retest reliability. Thus, HB athletes with GIRD presented a higher restriction in the extensibility of the tissues of the posterior part of the TS. These results are similar to previous studies [19] and agree with other authors, who hypothesized that overhead athletes with GIRD may present a lack of extensibility of the posterior part of the tissues [6,7]. However, the lower values showed in this test for the TS of the HB athletes may be caused by the restriction of the posteroinferior capsule, the posterior band of the inferior glenohumeral ligament [6,7], the stiffness of the posterior shoulder muscles [21], or by both tissues. For this reason, the measurement of the mechanical properties of the soft tissues is important in overhead athletes. And according to a recent hypothesis [25], and clinical trials [19], the teres major muscle seemed to be an important muscle to assess.

The teres major muscle in the TS of the HB athletes has shown a statistically significant increased tone and stiffness and a decreased relaxation time compared to the non-TS and to the TS of the healthy athletes. Previous cross-sectional studies assessed the asymmetries in mechanical properties between the dominant and non-dominant side. They showed no differences in masseter, biceps brachii, or quadriceps muscles [34,37,38]. The differences achieved in this study in tone, stiffness, and relaxation time were higher than the SEM calculated for this study, but only the differences in stiffness were higher than the MDC. These results determined that the tissues of the posterior part of the shoulder present a lack of extensibility and, at least, the teres major muscle plays an important role in it, showing a higher tone and stiffness. The humeral head rests directly on the teres major muscle [25]. The increased tone and stiffness may provoke the shift of the humeral head upward, changing the center of rotation to posterosuperior and causing the biomechanical adaptations [6,7,21,22]. This hypothesis has been clinically addressed in a recent clinical trial using the dry-needling technique in the teres major muscle and concluding that the treatment of teres major muscle increased the extensibility of the tissues of the posterior part of the shoulder and decreased the GIRD in elite HB athletes [19].

Strengths and Limitations

The clinical relevance of the study is the finding of differences in the strength ratio, extensibility, and mechanical properties of the teres major muscle. Shoulder pain and injuries are a severe impediment for elite HB athletes, affecting training and daily living activities. Several studies have considered different variables analyzed in this study (such as the GIRD and the isometric strength) as key variables for prevention protocols or training programs [39,40]. However, to the best of our knowledge, this is the first study that has shown an extensibility decrease and an increase in tone and stiffness of the teres major muscle in elite HB athletes compared to the non-TS and to non-HB athletes. Thus, using symmetry of the mechanical properties as a measure with other functional variables, such as strength or extensibility in throwing athletes, should be taken into consideration for the treatment of HB athletes with shoulder pain or should be included in prevention programs for overhead athletes.

The present study has several limitations. First, only male elite HB athletes or male healthy athletes were included, so the results cannot be extrapolated to other populations. Second, the HB athletes were not divided in subgroups according to the mean value of GIRD, which could elucidate the role of GIRD in the other variables. Third, the number of athletes included in each group is limited and may not be sufficiently representative of the population. Fourth, the mechanical properties of all the posterior muscles that could show other significant results were not assessed. Finally, the cross-sectional design does not allow associating the cause–effect of the differences achieved.

Future studies should investigate other genders and other athletes with different training levels. In addition, a methodological design would be necessary, that allows subjects to be followed over time to establish casual associations.

5. Conclusions

HB athletes with GIRD present a lack of extensibility of the tissues of the posterior part of the TS shoulder and an increase in the tone and stiffness of the teres major muscle compared to the non-TS and to healthy non-HB athletes.

Author Contributions: Conceptualization, L.C.-L. and S.J.-d.-B.; methodology, L.C.-L., S.J.-d.-B., J.J.J.-R. and M.R.-S.; software, M.T.M.-G. and A.L.-M.; formal analysis, M.T.M.-G. and A.L.-M.; investigation, L.C.-L., S.J.-d.-B., J.J.J.-R. and M.R.-S.; data curation, M.T.M.-G. and A.L.-M.; writing—original draft preparation, L.C.-L., S.J.-d.-B., J.J.J.-R., M.T.M.-G., A.L.-M. and M.R.-S.; writing—review and editing, L.C.-L., S.J.-d.-B., J.J.J.-R., M.T.M.-G., A.L.-M. and M.R.-S.; visualization, L.C.-L., S.J.-d.-B., J.J.J.-R., M.T.M.-G., A.L.-M. and M.R.-S.; supervision, L.C.-L., S.J.-d.-B., J.J.J.-R., M.T.M.-G., A.L.-M. and M.R.-S.; project administration, L.C.-L. and S.J.-d.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study was approved by the Research Ethics Committee of Valladolid Este (CASVE-NM-21-538).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

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

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