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Original research

Descriptive profile of hip range of motion in elite tennis players

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A B S T R A C T

Objective: To describe the range of motion (ROM) profile (flexion, extension, abduction, internal and external rotation) of the hip in elite tennis players; and (b) to analyse if there are sex-related differences in the hip ROM.
Design: Cohort study.
Setting: Controlled laboratory environment.
Participants: 81 male and 28 female tennis players completed this study.
Main outcome measures: Descriptive measures of passive hip flexion, extension and abduction, and internal and external active and passive hip rotation ROM were taken. Magnitude-based inferences on differences between sex (males vs. females) and hip (dominant vs. non-dominant) were made by standardising differences.
Results: No clinically meaningful bilateral and sex-related differences in any of the hip ROM measures. In addition, it was found that both males and females had restricted mobility measures on hip flexion (<80°), extension (<0°) and abduction (<40°). Furthermore, the 30% of males also presented restricted active and passive hip internal rotation ROM values (<25°). Finally, both males and females had normal mobility measures of hip external rotation ROM (active [>25°] and passive [35°])
Conclusions: Asymmetric hip joint ROM measures found during clinical examination and screening may indicate abnormalities and the need of rehabilitation (e.g., flexibility training). In addition, clinicians should include specific exercises (e.g., stretching) in their conditioning, prevention and rehabilitation programmes aiming to avoid restricted mobility of hip flexion (males = 74°; females = 78°), extension (males = −1.5; females = −0.4), abduction (males = 35°; females = 34°) and internal rotation (males = 30°; females = 35) that might be generated as a consequence of playing tennis.

1. Introduction

Tennis has experienced a significant increase in popularity in recent years, becoming one of the most popular sports in the world, with more than 75 million people participating both, at recreational or at professional levels (Pluim et al., 2007). At professional level, the demanding competitive calendar of players can result in athletes focusing on competition and thus compromising training, leading to suboptimal recovery and preparation (Ellenbecker, Pluim, Vivier, & Stineman, 2009; Sell, Hainline, Yorio, & Kovacs, 2014). Furthermore, in a tennis match, players usually perform a high number of multidirectional and cutting movements, together with asymmetric rotational actions produced by the serve and groundstrokes (Roetert, Kovacs, Knudson, & Groppel, 2009). These above-mentioned aspects could lead to an overload in the joints, impairing their normal motion and thus increasing the relative risk of injury (Chandler, Kibler, Uhl, Wooten, Kiser, & Stone, 1990).

Previous studies analysed the impact of these high repetition loads on the upper extremity joints at elite levels in order to effectively plan and establish successful prevention and rehabilitation programs, and reported a deficit in glenohumeral internal rotation range of motion (ROM) of the dominant arm (Ellenbecker, Roetert, Bailie, Davies, & Brown, 2002; Kibler, Chandler, Livingston, & Roetert, 1996; Moreno-Pérez, Moreside, Barbado, & Vera-Garcia, 2015; Roetert, McCormick, Brown, & Ellenbecker, 1996). This deficit has been suggested as a predisposing factor for increasing the

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likelihood of several shoulder and elbow pathologies (Moreno-Perez et al., 2015; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Shanley, Rauh, Michener, Ellenbecker, Garrison, & Thigpen, 2011). Thus, tennis health care professionals began to include stretching exercises of the glenohumeral external rotator muscles in the dominant arm, during both, the pre- and in-season training schedules (Kovacs, 2006).

As previously mentioned, during tennis play the lower extremities are also subjected to repetitive loading forces (e.g., cutting movements). However, joint ROM in the lower extremity has not been studied with the same vigour as that of the upper extremity. To the best of our knowledge, only two studies have examined the tennis-related alterations on the lower extremity joints (i.e., hip internal and external rotation ROM profile) in elite or professional players (Ellenbecker, Ellenbecker, Roetert, Silva, Keuter, & Sperling, 2007; Young, Dakic, Stroia, Nguyen, Harris, & Safran, 2014), showing no specific hip alterations in rotational ROM.

Thus, it remains to be clarified whether the repetitive loading forces generated during tennis play induce alterations in the complete hip joint ROM profile in elite tennis players, such as bilateral differences or deficit in one or more ROM. If these alterations do occur it may predispose tennis players to be more prone to several pathologies, such as: osteochondral and groin injuries (deficit in hip abduction ROM) (Verrall, Slavotinek, Barnes, Esterman, Oakeshott, & Spriggins, 2007), low back pain (deficit in hip flexion and internal rotation ROM) (Vad, Gebeh, Dines, Altchek, & Norris, 2003), abdominal strain (deficit in hip extension ROM) (Young et al., 2014), patello-femoral pain and hamstring strains (deficit in hip extension ROM) (Witvrouw, Danneels, Asselman, D'Have, & Cambier, 2003; Witvrouw, Van Tiggelen, & Willems, 2011).

Therefore, the aims of the present study were twofold: (a) to describe the hip ROM profile in elite tennis players; and (b) to analyse if there are sex-related differences in the ROM.

2. Methods

2.1. Participants

A total of 109 elite tennis players (81 males and 28 females) volunteered to participate in the study. Participants were recruited from 10 different high performance Spanish tennis academies. To qualify as an elite tennis player for the purpose of this study, participants held national rankings in their respective sex-related categories (48 males and 18 females) or played on the professional tennis tours (ATP or WTA) (34 males and 9 females). The exclusion criteria were: (a) history of orthopaedic problems in the previous three months that prevented practice or competition; and (b) presence of delayed onset muscle soreness at the testing session. The study was conducted during the pre-competitive phase of the year 2013. Demographic information was recorded from the participants before data collection (Table 1).

Table 1
Demographic variables for the elite tennis players.[a]

	Men	Women
Age (years)	19.7 ± 4.8	17.7 ± 2.2
Height (cm)	180.1 ± 6.5	171.3 ± 6.2
Body mass (kg)	72.1 ± 8.4	62.5 ± 5.7
Years playing tennis (years)	12.4 ± 5.3	10.7 ± 3.4
Weekly practice frequency ± SD	5.1 ± 1.2	4.7 ± 0.8
Hours of tennis practice per week ± SD	12.2 ± 2.1	10.8 ± 1.3
Hours of tennis practice per day ± SD	2.6 ± 0.5	2.1 ± 0.5

[a] All values are mean ± standard deviation.

Prior to any participation, the experimental procedures and potential risks were fully explained to the participants and all provided written informed consent. The study was approved by the University Office for Research Ethics, and conformed to the Declaration of Helsinki.

2.2. Procedure

Passive hip flexion (passive straight leg raise test [Fig. 1a]), extension (modified Thomas test [Fig. 1b]) and abduction (hip abduction with knee extended test [Fig. 1c]) ROM of the dominant and non-dominant limbs was assessed following the methodology previously described (Cejudo, Sainz de Baranda, Ayala, & Santonja, 2015). Furthermore, active and passive hip rotation (internal [Fig. 1d and f for passive and active modalities, respectively] and external [Fig. 1e and g for passive and active modalities, respectively]) ROMs was also measured using a previously described methodology (Almeida, de Souza, Sano, Saccol, & Cohen, 2012).

All tests were carried out by the same two physical therapists with more than 10 years' experience (one conducted the tests and the other ensured proper testing position of the participants throughout the assessment manoeuvres) and under stable environmental conditions.

The dominant limb was determined according to the definition of Ellenbecker et al. (2007) for assigning lower extremity dominance in tennis players, defining the dominant leg as the lower extremity of the ipsilateral side of the forehand ground stroke and the same side as the upper extremity with which the player served.

Prior to the testing sessions, all participants performed a warm-up consisting of 5-min jogging and 8-min standardised static stretching exercises, emphasising the lower-limb muscles (Cejudo et al., 2015). Participants performed 2 repetitions of 5 different unassisted static stretching exercises, holding the stretched position for 30s.

After the warm-up, participants were instructed to perform, in a randomised order (using the software at http://www.randomizer.org), 2 maximal trials of each ROM test for each limb, and the mean score for each test was used in the subsequent analyses. When a variation >5% was found in the ROM values between the two trials of any test, an extra trial was performed, and the two most closely related trials were used for the subsequent statistical analyses. Participants were examined wearing sports clothes and without shoes. A 30 s rest was given between trials, limbs and tests.

2.3. Measurements

An ISOMED inclinometer (Portland, Oregon) with a telescopic arm was used as the key measure for all hip ROM except for hip abduction, where a flexible adjustable long arm goniometer was employed. A low-back protection support (Lumbosant, Murcia, Spain) was used to standardise the lordotic curve (15°) during the assessments. The inclinometer was placed approximately over the external malleolus (for hip flexion ROM [Fig. 1a]), the mid-point of the distal end of the fibula (for hip internal and external rotation ROM [Fig. 1d–g]), and the greater trochanter of the femur (for hip extension [Fig. 1b]), and the distal arm was aligned parallel to an imaginary bisector line of the limb throughout each trial (Cejudo et al., 2015). For the assessment of hip abduction, one arm-goniometer was placed joining both anterior-superior iliac spines and the other arm was placed over the anterior face of the tested limb following its bisector line (Cejudo et al., 2015).

Variations in pelvic position and stability may affect the final score of several hip ROM measurements (Bohannon, Gajdosik, & LeVeau, 1985). Thus, to accurately evaluate hip ROM, the assistant

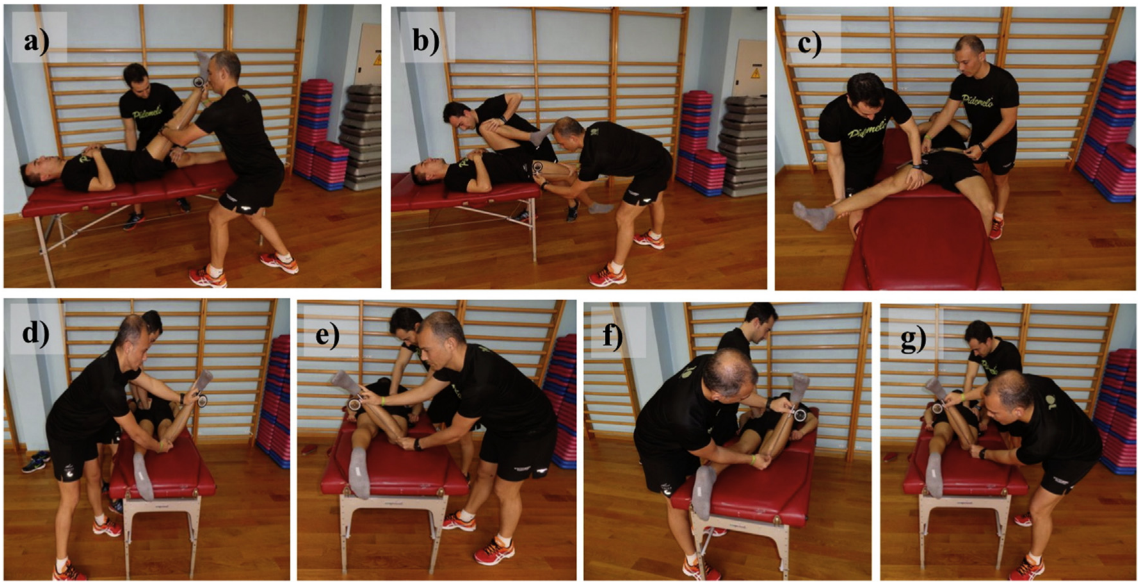

Fig. 1. Hip range of motion assessment tests used in this study (a: passive straight leg raise test; b: modified Thomas test; c: hip abduction with knee extended test; d: passive hip internal rotation test; e: passive hip external rotation test; f: active hip internal rotation test; g: active hip external rotation test).

physical therapist ensured the suitable stabilisation of the pelvis during all the tests in this study.

One or both of the following criteria determined the endpoint for each test: (a) palpable onset of pelvic rotation, and/or (b) the participant feeling a strong but tolerable stretch, slightly before the occurrence of pain. An extra endpoint criterion was established for the passive tests, i.e., the examiner's perception of firm resistance.

2.4. Statistical analysis

Prior to the statistical analysis, the distributions of raw data sets were checked using the Kolomogorov–Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Descriptive statistics including means and standard deviations were calculated for hip flexion, extension, abduction and rotation (external and internal) ROM measures separately by sex and limb. Based on Ellenbecker et al. (2007), the number of athletes with side-to-side differences >10° in each ROM measures were also calculated. Furthermore, for each participant, the hip ROM scores were categorised as normal or restricted according to the reference values previously reported to consider an athlete as being more prone to suffer an injury (Holla et al., 2012; Peterson-Kendall, Kendall-McCreary, & Geise-Provance, 2005; Roach, San Juan, Suprak, & Lyda, 2013; Young et al., 2014). Where no cut-off scores for detecting athletes at high risk of injury had been previously reported (i.e. passive hip abduction ROM, passive and active hip external rotation ROM), comparing them with those which the general population have shown. Thus, ROM values were reported as restricted according to the following cut-off scores: <80° for passive hip flexion (Peterson-Kendall et al., 2005), <0° for passive hip extension (Young et al., 2014), <40° for passive hip abduction (Gerhardt, Cocchiarella, & Lea, 2002), <25° for passive hip internal rotation (Roach et al., 2013), <35° for passive hip external rotation (Roach et al., 2013), <25° for active hip internal rotation and <30° for active hip external rotation ROM (Holla et al., 2012; Roach & Miles, 1991).

Data were log-transformed prior to analysis to reduce the non-uniformity of error and back-transformed to obtain differences in means and variation as percentages. Magnitude-based inferences on differences between sex (male vs. female) and limb (dominant versus non-dominant) were made by standardising differences following the procedure reported by Batterham and Hopkins (2006). Magnitudes of standardized differences in means were assessed with the following scale: 0 to 0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, 2.0 to 4.0 very large, and ≥4.0 extremely large. To reduce the likelihood of errors about inferred magnitudes, 99% was chosen as the level for the confidence intervals. A difference was reported as unclear when the confidence interval of the standardized difference crossed the threshold for both substantially positive (0.2) and negative (−0.2) values. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, v. 20.0 for Windows; SPSS Inc, Chicago) and a spreadsheet design by Hopkins (2007). The level of significance was set at $\alpha = .05$.

3. Results

Tables 2 and 3 show the descriptive ROM values (mean ± SD) for passive hip flexion (males = 75.1 ± 8.2°; females = 81.0 ± 9.2°), extension (males = −1.1 ± 5.6°; females = −0.7 ± 7.6°), abduction (males = 34.5 ± 5.6°; females = 33.5 ± 5.7°) and passive (internal [males = 31.1 ± 9.4°; females = 36.0 ± 7.5°] and external [males = 51.2 ± 8.0°; females = 49.4 ± 5.7°]) and active rotation (internal [males = 28.5 ± 8.6°; females = 34.2 ± 9.5°] and external [males = 51.9 ± 7.6°; females = 49.1 ± 8.7°]) from both, males and females, respectively. A large percentage of all participants showed restricted passive hip flexion (males ≈ 76%; females ≈ 45%), extension (males ≈ 55%; females ≈ 50%) and/or abduction (males ≈ 86%; females ≈ 75%) ROM values. In addition, approximately 40% of males had restricted active and/or passive hip internal rotation ROM values. Contrarily, most players had normal active and passive hip external rotation ROM scores, with percentage values ranging from 70% (passive hip external rotation ROM) to 99% (active hip external rotation ROM) and from 95% (passive hip external rotation ROM) to 100% (active hip external rotation ROM) for males and females, respectively.

As presented in Table 2, in males, there were no meaningful differences between dominant and non-dominant passive hip

Table 2
Men's descriptive values and inference about side-to-side difference for hip flexion, extension, abduction and internal and external rotation ranges of motion (n = 81).

Range of motion (°)	Dominant limb		Non-dominant limb		Players with bilateral differences >10°	Standardised difference[T]	Qualitative outcome
	Mean ± SD	Qualitative outcome[a]	Mean ± SD	Qualitative outcome[a]			
Passive hip flexion	75.1 ± 8.2	Restricted (61)	73.6 ± 8.2	Restricted (63)	0	0.20 ± 0.15	Small +
Passive hip extension	−1.1 ± 5.6	Restricted (40)	−1.75 ± 5.5	Restricted (49)	0	−0.12 ± 0.10	Trivial
Passive hip abduction	34.5 ± 5.6	Restricted (72)	35.6 ± 5.1	Restricted (68)	2	−0.20 ± 0.15	Small −
Passive hip internal rotation	31.1 ± 9.4	Normal (25)	28.9 ± 9.7	Normal (28)	10	0.28 ± 0.15	Small +
Passive hip external rotation	51.2 ± 8.0	Normal (4)	49.9 ± 7.9	Normal (2)	16	0.13 ± 0.17	Trivial
Active hip internal rotation	28.5 ± 8.6	Normal (33)	30.6 ± 8.4	Normal (26)	0	−0.11 ± 0.05	Trivial
Active hip external rotation	51.9 ± 7.6	Normal (1)	52.7 ± 7.6	Normal (0)	1	−0.06 ± 0.02	Trivial

°: degrees.
[a] Qualitative score of the mean range of motion, in parentheses the number of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or −indicates an increase or decrease from dominant limb to non-dominant limb.

Table 3
Women's descriptive values and inference about side-to-side difference for hip flexion, extension, abduction and internal and external rotation ranges of motion (n = 28).

Range of motion (°)	Dominant limb		Non-dominant limb		Players with bilateral differences >10°	Standardised difference[T]	Qualitative outcome
	Mean ± SD	Qualitative outcome[a]	Mean ± SD	Qualitative outcome[a]			
Passive hip flexion	81.0 ± 9.2	Normal (11)	77.2 ± 10.1	Restricted (15)	0	0.41 ± 0.31	Small +
Passive hip extension	−0.7 ± 7.6	Restricted (15)	0.2 ± 7.0	Normal (14)	0	0.11 ± 0.20	Trivial
Passive hip abduction	33.7 ± 5.7	Restricted (22)	35.7 ± 5.3	Restricted (20)	0	−0.33 ± 0.21	Small −
Passive hip internal rotation	36.0 ± 7.5	Normal (2)	35.2 ± 8.8	Normal (3)	2	0.18 ± 0.26	Trivial
Passive hip external rotation	49.4 ± 5.7	Normal (0)	49.2 ± 7.9	Normal (1)	2	0.10 ± 0.40	Trivial
Active hip internal rotation	34.2 ± 9.5	Normal (4)	36.9 ± 9.9	Normal (2)	0	−0.04 ± 0.02	Trivial
Active hip external rotation	49.1 ± 8.7	Normal (1)	48.1 ± 7.3	Normal (0)	0	0.05 ± 0.09	Trivial

°: degrees.
[a] Qualitative score of the mean range of motion, in parentheses the number of players with a restricted range of motion score according to previously published cut-off scores (see Statistical analysis section). T: mean ± 90% confidence limits; + or −indicates an increase or decrease from dominant limb to non-dominant limb.

extension, passive hip external rotation and active hip internal and external rotation (standardized differences in means <0.20). However, small but statistically significant differences (standardized differences in means from 0.20 to 0.60) were found for passive hip flexion, passive hip abduction and passive hip external rotation between dominant and non-dominant limb. In females, there were no significant differences between dominant and non-dominant passive hip extension, passive hip external and internal rotation and active hip internal and external rotation (standardized differences in means <0.20). However, small differences were found in passive hip flexion and abduction ROM measures between dominant and non-dominant limb.

Statistical analysis also reported trivial differences between sexes for passive hip abduction, passive hip flexion, passive hip extension and active hip external rotation ROM measures (standardised difference <0.20). However, moderate differences (standardized differences in means >0.60) between sexes were found for passive and active internal rotation ROM measures, with females showing higher scores than males.

4. Discussion

The results obtained in the present study reported statistically significant bilateral differences between the dominant and non-dominant hip flexion and abduction ROM in both sexes, and in hip internal rotation ROM for males. However, from a clinical standpoint application, the magnitude of these differences (<6°) could be considered as non-relevant because none of them exceed the threshold of 10° proposed in previous studies for male and female elite tennis players (Ellenbecker et al., 2007; Young et al., 2014). Furthermore, by calculating the number of players with bilateral differences greater than 10° in any hip ROM measure, fewer than 14% of the players were identified (passive hip flexion = 0%, extension = 0%, abduction = 1.8%, internal = 10.9% and external rotation = 13.8%; and active hip internal = 0.9% and external rotation = 0%).

Unlike glenohumeral internal rotation in elite tennis players, for which tennis-specific bilateral differences have been consistently measured and identified (Kibler et al., 1996; Moreno-Pérez et al., 2015), the results of the current study support previous findings and stated that there doesn't seem to be similar bilateral differences in hip ROM patterning (Ellenbecker et al., 2007; Young et al., 2014). A possible explanation for this above-mentioned discrepancy between hip and shoulder ROM might be due to the fact that tennis requires different movement patterns between the upper and lower body. The demands of the game (e.g., velocity of the ball) require the players to use “open stance” positions for both, forehand and backhand strokes (Roetert et al., 2009), and repetitive loading forces may be more balanced across the hip than in the shoulder, in which the kinetic chain mainly involves one upper limb. In addition, it may also be that bony rather than soft tissue constraints to ROM are more relevant in the hip joint, which in turn would be less prone to adaptations such as capsular tightness than in the shoulder (Young et al., 2014). Thus, based on the results of this study, the identification of hip ROM bilateral differences between extremities cannot be thought to represent a tennis-specific adaptation. However, Sanchis-Moysi, Idoate, Izquierdo, Calbet, and Dorado (2011), using magnetic resonance imaging, found that iliopsoas and gluteal muscles were asymmetrically hypertrophied in professional tennis players (i.e., the non-dominant iliopsoas was 13% greater than the dominant) compared to a healthy control group. Based on these results and taking into account the dynamic nature of tennis, it seems that a more functional testing (e.g., unilateral countermovement jump, Y-balance test, etc.) could be recommended in order to analyse these bilateral asymmetries.

To consider an athlete as being more prone to suffer an injury, ROM values should be compared to reference values, normally obtained from general and healthy populations. Analysing the present results, a large number of male and female players showed restricted ROM values for passive hip flexion (cut-off score <80°; mean ± SD: males = 75.1 ± 8.2°; females = 81.0 ± 9.2°), extension (cut-off score <0°; mean ± SD: males = −1.1 ± 5.6°; females = −0.7 ± 7.6°) and abduction (cut-off score <40°; mean ± SD: males = 34.5 ± 5.6°; females = 33.5 ± 5.7°). These restricted ROM values might be explained by the on-court body positions adopted by players, as they need to show a "low ready position" which helps to generate power during tennis strokes (Kovacs, 2006; Roetert et al., 2009). Together with the short and repetitive on-court movements, players are required to maintain the hip flexor, extensor and adductor muscles in a shortened contracted position for long periods. Comparisons are not possible as there is no previous study analysing the restricted mobility of hip flexion, extension and abduction in elite tennis players. Based on the present results, preventive stretching exercises of the hip, enhancing flexion, extension and abduction ROM would be recommended, and they should be an integral part of a tennis player's conditioning and injury prevention programmes.

Another interesting finding of the present study was that the mean ROM values obtained for the hip internal and external rotation might be considered as normal, based on the reference values reported in previous research (>25° for active [mean ± SD: males = 28.5 ± 8.6°; females = 34.2 ± 9.5°] and passive [mean ± SD: males = 31.1 ± 9.4°; females = 36.0 ± 7.5°] internal rotation; >35° for active [mean ± SD: males = 51.2 ± 8.0°; females = 49.4 ± 5.7°] and passive [mean ± SD: [males = 51.9 ± 7.6°; females = 49.1 ± 8.7°] external rotation). In addition, the greater passive and active hip external rotation found, compared with internal rotation, is consistent with values reported in different athletes, including elite tennis players (Ellenbecker et al., 2007; Young et al., 2014), as well as in general population (Kouyoumdjian, Coulomb, Sanchez, & Asencio, 2012; Roach et al., 2013).

When analysing the number of tennis players with restricted hip internal and/or external rotation ROM more in detail, a large number of male players reported a restriction in both passive and active hip internal ROM (34% and 40%, respectively) in contrast with their counterpart females. A possible explanation for these sex-related differences could be related to the higher training volume (i.e., hours per week and day) reported in males (Table 1), combined with a bigger sample size also in males (81 vs. 28), although when the number of players with restricted mobility in hip internal rotation were transformed to percentages, the differences were still high (40% and 14% for males and females, respectively). Since we are not aware of similar studies addressing this issue in elite tennis players, comparisons are not possible. We could speculate that the higher training volumes reported for male players could lead to a higher number of repetitive and powerful rotational movements (i.e., serves and groundstrokes) during both, training sessions and matches (Brown & O'Donoghue, 2008; Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009). It is plausible that these high torsional forces could lead to micro-trauma and capsular contracture, causing a hip internal rotation ROM deficit in many of the male players (Vad et al., 2003). Therefore, preventive stretching exercises of the hip external rotation muscles would be also recommended for males.

While the results of this study have provided information regarding the profile of hip ROM in elite tennis players, limitations to the study must be acknowledged. The age distribution of participants was relatively narrow and the female sample size was small. Moreover, the use of different testing methodologies (i.e., active hip internal rotation) (Ellenbecker et al., 2007) makes comparisons difficult.

5. Conclusions

The current study provides a profile of passive hip flexion, extension and abduction, as well as passive and active internal and external rotation ROM in elite tennis players; which might be used to assist clinicians and tennis professionals in the identification of athletes with possible hip abnormalities and therefore, at high risk of injury. Bilateral measurement of hip flexion, extension, abduction and internal and external rotation ROM did not identify clinically significant differences between extremities. Restricted values of hip flexion, extension and abduction were found in both limbs for males and females. Furthermore, male tennis players also had restricted passive and active hip internal rotation ROM values. However, both males and females had normal mobility measures on active and passive hip external rotation. Thus, the inclusion of stretching exercises, or an increase in their dose should be included in tennis-conditioning and preventative programs, with the aim of achieving or maintaining normal or low injury risk values for hip flexion, extension, abduction and internal rotation ROM.

Conflict of interest

None declared.

Ethical approval

The study was approved by the Ethics and Research Committee of the Miguel Hernandez University of Elche.

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