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Whole-Body Morphological Asymmetries in High-level Female Tennis Players: A Cross-Sectional Study

Laurent Chapelle[1]*, Nikki Rommers[1,2,3], Peter Clarys[1,4], Eva D'Hondt[1,3]

[1] Department of Movement and Sport Sciences, Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium.

[2] Research Foundation Flanders (FWO), Belgium.

[3] Department of Movement and Sports Sciences, Faculty of Medicine and Health Sciences, Ghent University, Ghent, Belgium.

[4] Erasmus University College, Brussels, Belgium

* Corresponding author

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Abstract

This cross-sectional study aimed to examine the degree of whole-body morphological asymmetries in female tennis players. Data were collected in 19 high-level female tennis players (21.3 ± 3.4 years). Based on anthropometric measurements (upper arm, lower arm, wrist, upper leg and lower leg circumferences as well as elbow and knee widths) and dual x-ray absorptiometry research scans (bone mineral density (BMD), bone mineral content (BMC), lean mass (LM), fat mass (FM) as well as humerus, radio-ulnar, femur and tibia bone lengths), within-subject morphological asymmetries for both upper (dominant vs. non-dominant) and lower (contralateral vs. ipsilateral) extremities were examined. Upper arm ($p = 0.015$), lower arm ($p < 0.001$) and wrist circumferences ($p < 0.001$), elbow width ($p = 0.049$), BMD ($p < 0.001$), BMC ($p < 0.001$), LM ($p = 0.001$), humerus ($p = 0.003$) and radio-ulnar bone length ($p < 0.001$) were all greater in the dominant upper extremity. BMC ($p < 0.001$) and LM ($p < 0.001$) were greater in the contralateral lower extremity, whereas FM ($p = 0.028$) was greater in the ipsilateral lower extremity. This is the first study to report significant side-to-side differences in both upper and lower extremities in high-level female tennis players.

Keywords: Anthropometry; Dual x-ray absorptiometry; body composition; side-to-side difference; women; unilateral sport

Introduction

Tennis is one of the most popular sports worldwide as demonstrated by the fact that 83 million people play tennis and over 200 countries are affiliated with the International Tennis Federation (Casper, 2008; Pluim, Staal, Windler, & Jayanthi, 2006). In Belgium, there are over 680.000 registered tennis players and 950 official tennis clubs, involving players of different age groups and various levels of play. In 2019, Belgium had 54 internationally ranked players (ITF, 2019).

Tennis is characterised by short high-intensity efforts alternated by recovery bouts, especially at higher levels of play (Fernandez-Fernandez, Ulbricht, & Ferrauti, 2014). During these efforts, tennis strokes are performed with the player's racket being the final link of the kinetic chain involving a sequential activation of the lower extremity, trunk and upper extremity muscles (Elliott, Fleisig, Nicholls, & Escamilia, 2003). Since the arm holding the racket during the service stroke (i.e. the dominant upper extremity) is summited to a greater mechanical loading compared to the opposite arm (i.e. the non-dominant upper extremity), tennis is ideally suited to explore bilateral tissue composition differences (Ireland, Degens, Maffulli, & Rittweger, 2015; Sanchis-Moysi et al., 2016).

Morphological asymmetries between the dominant and non-dominant upper extremity in terms of bone mineral density (BMD), bone mineral content (BMC) and lean mass (LM) have already been widely reported in both youth and adult male tennis players using different measurement methods, such as anthropometrical assessment (Kontulainen et al., 1999), bio-electrical impendence analysis (BIA; Filipcic, Cuk, & Filipcic, 2016), dual x-ray absorptiometry (DXA; Sanchis-Moysi, Dorado, Olmedillas, Serrano-Sanchez, & Calbet, 2010b), peripheral quantitative computer tomography (pQCT; Ireland, Maden-Wilkinson, Ganse, Degens, & Rittweger, 2014; Ireland et al., 2013), and magnetic resonance imaging (MRI; Sanchis-Moysi, Idoate, Serrano-Sanchez, Dorado, & Calbet, 2012).

The repetitive performance of tennis strokes will also impose a certain load on the contralateral lower extremity (i.e. the lower extremity opposed to the dominant upper extremity) due to its role in counterbalancing the torques of the dominant upper extremity (Akutagawa & Kojima, 2005).

Additionally, the contralateral lower extremity has an important role as the first component in the kinetic chain during the execution of different tennis strokes (Elliott, 2006). Several previous studies examined lower extremity morphological asymmetries using different outcome measures in male youth (Filipcic et al., 2016; Sanchis-Moysi, Dorado, Olmedillas, Serrano-Sanchez, & Calbet, 2010a; Sanchis-Moysi et al., 2010b) and professional male adult (Calbet et al., 1998) tennis players, but reported varying results. For instance, two of these 'male only' studies observed no significant lower extremity BMD, BMC, LM and fat mass (FM) asymmetries using DXA (Sanchis-Moysi et al., 2010a, 2010b), one study demonstrated a significantly higher FM in the ipsilateral lower extremity measured by means of DXA (Calbet et al., 1998) whilst another study found a significantly higher upper leg circumference for the contralateral lower extremity based on BIA estimates (Filipcic et al., 2016). Hence, more research into lower extremity morphological asymmetries in tennis players seems warranted.

Morphological asymmetries are reported to be an injury risk factor (Hides et al., 2008). As such, a previous study reported a significant association between upper extremity morphological asymmetry (determined by anthropometrical assessment) and injury history in recreational adult tennis players (Rogowski et al., 2016). In addition to an increased injury risk, a high degree (i.e. > 10%) of lower extremity asymmetry (determined by DXA) has been reported to have a negative impact on jumping performance, and thus the functional ability of collegial athletes (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014). Similarly, a recent systematic review examined the influence of lower extremity side-to-side differences on athletic performance and reported that within-subject interlimb asymmetries do hamper optimal performance in a range of sports such as track and field, basketball and futsal (Bishop, Read, Lake, Chavda, & Turner, 2018b).

As established by a recent meta-analysis, existing research on the topic of morphological asymmetries focuses primarily on (youth) male tennis players and on the upper extremity (Chapelle, Rommers, Clarys, D'Hondt, & Taeymans, 2019). Only a handful of studies have examined these upper extremity morphological asymmetries in (youth) female tennis players using anthropometrical assessment, MRI, DXA and/or pQCT whilst BIA data are lacking (Ducher et al., 2005; Ermin, Owens, Ford, & Bass, 2012; Haapasalo et al., 1998; Ireland et al., 2014; Lucki & Nicolay, 2007). To the best of our knowledge, no study has simultaneously examined both upper and lower extremity morphological asymmetries in female tennis players until now. In addition, given the suggested association between morphological asymmetry, injury incidence and sport-specific performance, enhancing knowledge regarding the occurrence of whole-body morphological asymmetries seems beneficial as it could serve as a basis to design targeted screening as well as training strategies in order to minimize negative consequences of playing tennis (C. Bishop, Turner, & Read, 2018b). Therefore, the present study aims to examine the degree of whole-body morphological asymmetries in high-level female tennis players.

Methods

Participants

A total of 19 high-level female tennis players aged between 17 and 27 years (21.3 ± 3.4 years) participated in this cross-sectional observational study. To be eligible to participate, these tennis players had to be female, had to be injury free at the moment of measurement, and had to have a WTA ranking, an ITF ranking, or had to be in the top 200 of the Belgian circuit ranking (and thus compete in the highest division of Belgian tennis). The design and test protocol of the present study was approved by the local university's medical ethics committee (B.U.N. 143201836107) and all participants, together with their legal representative in case they were still minors, signed an informed consent prior to data collection.

Procedure and measurements

Data collection took place in the university's kinanthropometry lab facilities. Upon arrival, eligible participants filled in a questionnaire to provide basic demographic and sport-specific information (i.e.

date of birth, dominant upper extremity, playing a one- or two-handed backhand, starting age of playing tennis, average training hours per week, current and highest tennis ranking). Subsequently, participants were instructed to wear minimal clothing during testing and to void their bladder beforehand. Their body height and weight were measured to the nearest 0.1 cm and 0.002 kg using a stadiometer (SECA 217, Hamburg, Germany) and precision scale (RADWAG WLT 60/120/X/L3, All scales Europe, Veen, The Netherlands), respectively.

Additional anthropometric measurements and DXA research scans were performed by a trained researcher to assess the degree of whole-body morphological asymmetries. These anthropometric measurements included the upper arm, lower arm, wrist, upper leg and lower leg circumference as well as the elbow and knee width. Each measurement was determined to the nearest 0.1 cm in accordance with the International Society for the Advancement of Kinanthropometry guidelines using both a tape measure (Rosscraft innovation, Surrey, British Columbia, Canada) and an anthropometer (Seca, Hamburg, Germany). In addition, research DXA scans (Norland Elite, Swissray, Fort Atkinson, Wisconsin, USA) were conducted to determine the participants' regional bone mineral density (BMD), bone mineral content (BMC), lean mass (LM) and fat mass (FM). Before each test session, the DXA scanner was calibrated in accordance with the manufacturer's guidelines. The participants were instructed to lie as straight as possible in a supine position on the DXA scan table after removing all metal objects. Scan width was set to 6 x 6 mm, while a scan speed of 130 mm/s was applied. The Norland Illuminatus software (Swissray, Fort Atkinson, Wisconsin, USA) was used to analyse these DXA research scans. The upper extremity region included the upper arm, lower arm and hand, and was separated from the trunk by an inclined line passing through the scapula-humeral joint. The lower extremity region included the upper leg, lower leg and foot, and was separated from the trunk by an inclined line passing just below the pelvis (Calbet et al., 1998). Humerus, radio-ulnar, femur and tibia bone lengths were all measured to the nearest 0.1 mm, using the ruler tool included in the Norland Illuminatus software. An excellent inter (ICC = 0.986) and intra-rater (ICC = 0.998) reliabity was found when analysing the research scans. To examine the degree of whole-body morphological asymmetries, side-to-side differences for every outcome measure (i.e. circumferences, widths, BMD, BMC, LM, FM and bone lengths) between the dominant and non-dominant upper extremity as well as between the contralateral and ipsilateral lower extremity were calculated and expressed as a percentage using the percentage difference method (PDM): ((highest value – lowest value) / highest value) x 100 (Chris Bishop et al., 2018a).

Statistical analysis

Data analysis was conducted using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). All variables were tested for normality of distribution using the Shapiro-Wilk test. If data were normally distributed, Paired samples t-tests were used to compare the outcome measures between the dominant and non-dominant upper extremity as well as between the contralateral and ipsilateral lower extremity. If data were not normally distributed, Wilcoxon signed ranks tests were applied. Next, effect size analyses using Cohen's D were conducted. The effect sizes were classified as trivial (< 0.20), small (0.20 – 0.49), medium (0.50 – 0.79) or large (> 0.80; Cohen, 1969). All data are presented as means ± standard deviations, with p-values below 0.05 being considered as significant.

Results

Of the 19 high-level female tennis players (with a mean body height of 169.5 ± 4.7 cm, a mean body weight of 62.8 ± 9.0 kg, and a mean BMI of 21.9 ± 1.2 kg/m²) participating in this study, 6 (31.6 %) had a WTA or an ITF ranking, 1 (5.2 %) was left-handed and 1 (5.2 %) played with a one-handed backhand. The mean starting age of playing tennis for these participants was 6.2 ± 1.9 years and their current training volume at the moment of measurement was 9.6 ± 6.6 hours of tennis per week. All outcome measures were normally distributed, except for the variables knee width (p = 0.030), upper extremity FM (p = 0.012) and lower extremity FM (p = 0.034).

Upper extremity

The morphological asymmetry values for the upper extremity are displayed in Table 1. The degree of morphological asymmetries, based on the PDM, ranged from 3.3 to 5.1 % for the anthropometric measurements, from 6.8 to 15.6 % for the DXA related body composition outcome measures and from 2.5 to 2.9 % for the DXA determined bone lengths. The upper arm ($t = 3.189$, $p = 0.015$, $d = 0.36$), lower arm ($t = 8.881$, $p < 0.001$, $d = 0.68$) and wrist ($t = 5.553$, $p < 0.001$, $d = 0.67$) circumferences as well as the elbow width ($t = 2.252$, $p = 0.049$, $d = 0.13$) were all greater in the dominant upper extremity compared to the non-dominant upper extremity. Similar findings were observed for the DXA research scan related BMD ($t = 8.882$, $p < 0.001$, $d = 1.35$), BMC ($t = 8.236$, $p < 0.001$, $d = 1.02$) and LM ($t = 3.975$, $p = 0.001$, $d = 0.40$) values as well as for humerus ($t = 3.792$, $p = 0.003$, $d = 0.61$) and radio-ulnar bone length ($t = 5.857$, $p < 0.001$, $d = 0.56$). Participants' FM value was not significantly different between the dominant and non-dominant upper extremity ($Z = -0.904$, $p = 0.469$, $d = 0.09$).

*** Table 1 around here ***

Lower extremity

The morphological asymmetry values for the lower extremity are displayed in Table 2. The degree of morphological asymmetries, based on the PDM, ranged from 1.1 to 1.9 % for the anthropometric measurements, from 2.4 to 5.4 % for the DXA related body composition outcome measures and from 0.4 to 0.7 % for the DXA determined bone lengths. There was no significant difference in upper leg circumference ($t = -0.098$, $p = 0.785$, $d = 0.00$), lower leg circumference ($t = 1.166$, $p = 0.278$, $d = 0.04$) and knee width ($Z = -0.742$, $p = 0.480$, $d = 0.00$) between the contralateral and ipsilateral lower extremity. DXA research scan related BMC ($t = 4.273$, $p < 0.001$, $d = 0.25$) and LM ($t = 6.206$, $p < 0.001$, $d = 0.27$) values were greater in the contralateral lower extremity, whereas participants' FM value was greater in the ipsilateral lower extremity (Z = -2.549, p = 0.028, d = 0.12). There was no significant difference in BMD (t = 0.294, p = 0.884, d = 0.01) nor in femur (t = -1.527, p = 0.187, d = 0.00) and tibia bone length (t = 0.063, p = 0.952, d = 0.06) between the contralateral and ipsilateral lower extremity.

*** Table 2 around here ***

A graphical representation of the significant side-to-side differences between the dominant and non-dominant upper extremity as well as between the contralateral and ipsilateral lower extremity is displayed in Figure 1.

Figure 1 around here

Discussion

This is the first study examining the degree of upper as well as lower extremity morphological asymmetries in high-level female tennis players. All outcome measures resulting from the anthropometric measurements as well as the DXA research scans were found to be significantly greater in the dominant upper extremity when compared to the non-dominant upper extremity, with the exception of the resulting FM value, for which no significant side-to-side difference at upper extremity level was shown. Regarding the lower extremity, the female tennis players' contralateral lower extremity showed a significantly greater BMC and LM value, whilst their ipsilateral lower extremity displayed a significantly greater FM value.

In accordance with the results of the present study, significantly greater arm circumferences as well as significantly greater BMD, BMC and LM values of the dominant upper extremity as compared to the other side of the body have been previously reported in youth as well as adult female recreational tennis players (Ducher et al., 2005; Ermin et al., 2012; Haapasolo K, 1998; Lucki & Nicolay, 2007). The significant upper extremity BMD and BMC asymmetries can be attributed to the osteogenic response of the bones caused by the specific loads put on the body in relation to the repetitive performance of tennis strokes (Calbet et al., 1998; Sanchis-Moysi et al., 2016). In the present study, we also found that both the humerus and radio-ulnar bone length of the dominant upper extremity were significantly greater compared to these bone lengths in the non-dominant upper extremity. Our results are thus in line with an earlier study performed in high-level male tennis players (Krahl, Michaelis, Pieper, Quack, & Montag, 1994), but in contrast with two previously executed studies in recreational female tennis players that reported no significant humerus and radio-ulnar bone length side-to-side differences as measured by MRI and DXA (Ducher et al., 2005; Haapasalo et al., 1996). This contradicting result could be explained by the lower training volume and intensity of the recreational female tennis players (on average 1.7 to 4.5 hours per week) in these latter studies as compared to the high-level female tennis players in the present study (on average 9.6 hours per week), since longitudinal bone growth is only reported to occur if training volume and intensity are high enough (Ducher, Daly, & Bass, 2009; Sanchis-Moysi, Dorado, et al., 2010a). In turn, the significantly greater LM value observed in the dominant upper extremity compared to the non-dominant upper extremity in the present sample of high-level female tennis players can be explained by the hypertrophic responses of the muscles to the tennis-specific repetitive (unilateral) loading (Sanchis-Moysi, Idoate, et al., 2010; Sanchis-Moysi et al., 2012). These results are in accordance with a previous study reporting a significantly greater muscle volume of the dominant upper extremity based on MRI assessment in recreational female tennis players (Ducher et al., 2005). The combination of a significantly greater BMC and LM in the dominant upper extremity may consequently explain the significantly greater upper arm, lower arm and wrist circumferences as well as elbow width when compared to the non-dominant upper extremity values observed in this study. To the best of our knowledge, no previous study has examined upper extremity FM asymmetries in female tennis players thus far. Yet, the results of the present study are in accordance with three earlier studies conducted in both youth and elite adult male tennis players using DXA as these studies also reported no significant upper extremity FM asymmetries (Calbet et al., 1998; Sanchis-Moysi, Dorado, et al., 2010b; Sanchis-Moysi, Serrano-Sanchez, Gonzalez-Henriquez, Calbet, & Dorado, 2019).

A higher level of play, which normally implies a higher training volume as well as a greater mechanical loading on the bones and muscles, could have an influence on the degree of morphological asymmetries. Accordingly, lower PDMs of the upper extremities (1.6 to 6.2 %) have been reported in recreational female tennis players (determined by anthropometric assessment and DXA) when compared to the degree of morphological asymmetries of the DXA related outcome measures (6.8 to 15.6 %) of the high-level tennis players included in the present study (Ermin et al., 2012; Lucki & Nicolay, 2007). Starting age has also been reported to have a significant influence on the degree of upper extremity morphological asymmetry. More specifically, it has been shown that starting to play tennis before puberty, which was the case for all players included in the present study (6.2 ± 1.9 years), results in a greater degree of upper extremity morphological asymmetries compared to players who started to play after puberty (Ducher et al., 2005; Ireland, Maden-Wilkinson, Ganse, Degens, & Rittweger, 2014). Correspondingly, similar degrees of upper extremity BMD, BMC and LM asymmetry (around 10 to 15 %) have been reported in two previous studies where female tennis players started to play tennis before the onset of puberty (Ducher et al., 2005; Haapasolo et al., 1998).

The significantly greater BMC and LM values of the contralateral lower extremity can be attributed to the specific role of this body segment being the first part of the kinetic chain also being responsible for counterbalancing the torques when different tennis strokes are executed (Akutagawa & Kojima, 2005; Elliott, 2006). Since BMD, as opposed to BMC, did not significantly differ between both lower extremities in our sample of high-level female tennis players, it can be argued that bones of the lower extremity respond to the tennis-specific mechanical loads by means of bone enlargement, where BMC could increase at the expense of BMD (Ducher et al., 2005). Contrastingly, upper and lower leg circumferences did not differ significantly between the contralateral and ipsilateral lower extremity as anthropometric measurements, whilst this was the case for the bone, muscle and fat related outcome measures determined by the DXA research scan. Besides a difference in accuracy and precision between both assessment methods (Kuriyan, 2018), a different tissue composition of the lower extremities could potentially explain these particular results, given that the contralateral lower extremity demonstrated significantly greater BMC and LM values, whilst the ipsilateral lower extremity of the female tennis players participating in the present study showed a significantly greater FM value. As females tend to have more FM in the gluteofemoral region, this difference in FM distribution could potentially explain why a significant side-to-side FM difference was found in the lower extremities and not in the upper extremities (Karastergiou et al., 2012). Although it should be noted that the FM % of both upper and lower extremities of the female tennis players included in this study varied around 30 % (i.e. 30.5 and 31.5 % for the dominant and non-dominant upper extremity and 28.5 and 30.1 % for the contralateral and ipsilateral lower extremity respectively). In addition, a recently performed study reported that playing tennis does not necessarily implied a lower FM of dominant upper extremity (Sanchis-Moysi et al., 2019).

Several limitations of this study are apparent such as the explorative and cross-sectional nature of this study as well as its limited small sample size. Furthermore, it was not possible to examine the association between the degree of morphological asymmetries and the participant’s injury risk as well as sports performance (e.g. sprinting and jumping performance; Bishop et al., 2018). Future longitudinal research is warranted to prospectively examine the influence of the degree of morphological asymmetries on injury incidence and tennis-specific performance, and this already from an early age onwards. Finally, it could be of interest to identify differences within specific muscles using ultrasound or MRI.

To conclude, all anthropometric and DXA related outcome measures were significantly greater in the dominant upper extremity when compared to the non-dominant upper extremity, except for FM, which was not significantly different. Lower extremities morphological asymmetries were also apparent as the contralateral lower extremity showed a significantly greater BMC and LM value, whilst the ipsilateral lower extremity displayed a significantly greater FM value. Future longitudinal research is needed to examine whether, and to what extent, these apparent whole-body morphological asymmetries may increase injury risk and are beneficial or rather harmful for tennis-specific performance.

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Table 1. Morphological asymmetry values for the upper extremity

	Dominant side	Non-dominant side	PDM (%)
Anthropometry			
Upper arm circumference (cm)	28.2 ± 2.4*	27.6 ± 3.0	3.3 ± 2.0
Lower arm circumference (cm)	24.7 ± 1.7*	23.5 ± 1.8	5.1 ± 2.5
Wrist circumference (cm)	15.6 ± 0.8*	15.1 ± 0.7	3.4 ± 1.9
Elbow width (cm)	6.4 ± 0.8*	6.3 ± 0.8	3.9 ± 3.1
DXA scan			
Bone Mineral Density (g/cm²)	0.955 ± 0.092*	0.829 ± 0.095	12.9 ± 6.8
Bone Mineral Content (g)	167.7 ± 24.2*	142.7 ± 24.8	15.6 ± 6.8
Lean mass (g)	2084.3 ± 355.2*	1955.2 ± 286.6	6.8 ± 4.5
Fat mass (g)[$]	987.3 ± 317.0	963.4 ± 389.7	11.5 ± 10.1
Humerus bone length (cm)	27.6 ± 1.1*	26.9 ± 1.2	2.5 ± 1.6
Radio-ulnar bone length (cm)	25.0 ± 1.2*	24.3 ± 1.3	2.9 ± 1.8

Note: data are presented as mean ± standard deviation; PDM = percentage difference method. [$] analysed using the Wilcoxon signed ranks rest; * significantly higher value as compared to the other side of the body ($p < 0.05$).

Table 2. Morphological asymmetry values for the lower extremity

	Contralateral side	Ipsilateral side	PDM (%)
Anthropometry			
Upper leg circumference (cm)	57.4 ± 4.7	57.4 ± 4.9	1.4 ± 0.9
Lower leg circumference (cm)	34.9 ± 2.9	34.8 ± 2.8	1.1 ± 0.9
Knee width (cm)$^{\$}$	9.1 ± 1.0	9.1 ± 1.0	1.9 ± 1.5
DXA scan			
Bone Mineral Density (g/cm²)	1.101 ± 0.126	1.102 ± 0.118	2.4 ± 1.4
Bone Mineral Content (g)	546.3 ± 85.8*	524.7 ± 86.4	4.6 ± 2.5
Lean mass (g)	8444.8 ± 1300.4*	8080.3 ± 1362.4	4.8 ± 2.8
Fat mass (g)$^{\$}$	3583.2 ± 1003.5	3698.1 ± 987.2*	5.4 ± 3.7
Femur bone length (cm)	42.5 ± 1.6	42.5 ± 1.5	0.4 ± 0.3
Tibia bone length (cm)	36.6 ± 1.6	36.5 ± 1.5	0.7 ± 0.3

Note: data are presented as mean ± standard deviation; PDM = percentage difference method.
$^{\$}$ analysed using the Wilcoxon signed ranks test; * significantly higher value as compared to the other side of the body ($p < 0.05$).

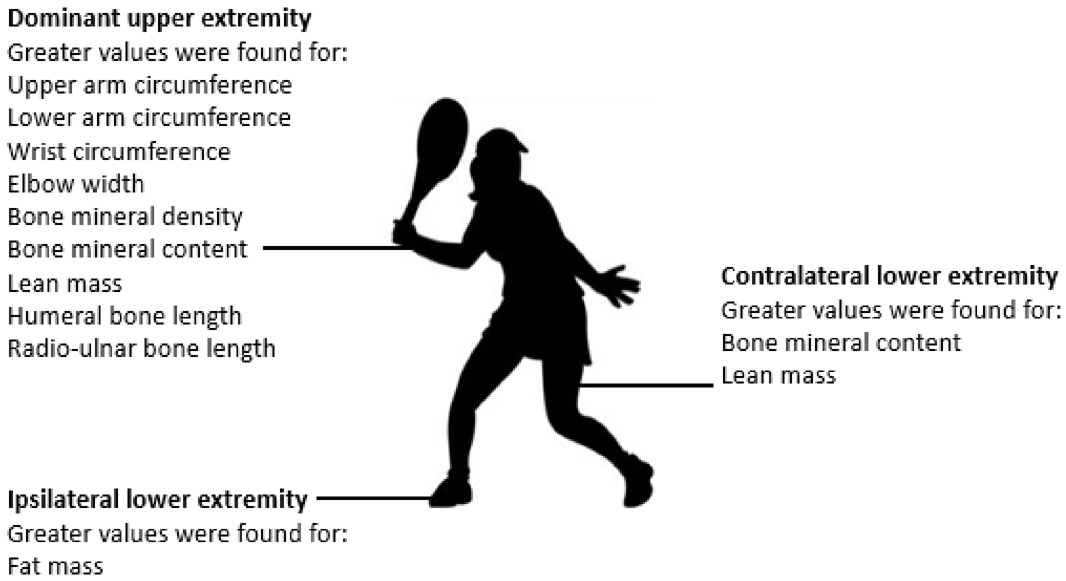

Figure 1. Graphical representation of the significant differences ($p < 0.05$) between the dominant and non-dominant upper extremity and contralateral and ipsilateral lower extremity.