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ASYMMETRIES IN NCAA DIVISION I TENNIS PLAYERS COMPARED TO AN ATHLETIC CONTROL GROUP

by

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of

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in

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Abstract

Limb asymmetries are an expected adaptation to years of training for athletes participating in dominant-sided sports. Previous research on this topic lacks an athletic control group. PURPOSE: To determine the magnitude of upper limb asymmetries in dominant-sided athletes (tennis players) compared to nondominant-sided athletes (cross-country runners). METHODS: Male and female NCAA Division I athletes (10 tennis, 11 cross-country) participated. Dual-energy x-ray absorptiometry (DXA) was used to measure bone mineral content (BMC), bone mineral density (BMD), and lean mass (LM) of the whole body, upper extremities, and forearms. Circumference measurements were taken at mid-biceps and the widest part of the forearms. The bony breadth of the elbow was measured with sliding calipers placed at the medial and lateral epicondyles. Grip strength was assessed with a dynamometer. Mixed-model ANOVA was used to analyze data between dominant/nondominant sides and between sports. RESULTS: There were no significant differences in age ($p = .150$), height ($p =.783$) or body mass ($p = .066$) between teams. No differences were shown between sports for total body BMC ($p = .544$), total body BMD ($p = .535$), or total body LM ($p = .843$). Sport × side interaction was significant ($p < .05$) for lower arm circumference, elbow bony breadths, total upper extremity LM, total upper extremity BMC, total upper extremity BMD, forearm BMC, ultra-distal forearm BMC, mid-distal forearm BMC, one-third forearm BMC, and ultra-distal forearm BMD. CONCLUSION: Morphological differences between sports were localized to the arm. Sport specificity influences mass and volume (circumference, LM, BMC) of the limb, with BMD particularly enhanced in ultra-distal forearm.

Key words: athlete; body composition; bone mineral content; bone mineral density; dual-energy x-ray absorptiometry

Introduction

Interlimb asymmetries (e.g., side-to-side imbalances) are common and sometimes noticeable between dominant and non-dominant sides, or injured and non-injured limbs (Bishop et al., 2023). These asymmetries can develop naturally throughout maturation, through injury, or as a result of training. Asymmetries can be categorized as strength, skill, or morphological asymmetries (Dos Santos et al., 2021). Most morphological, or physical, asymmetries are associated with body composition differences – particularly lean and bone mass asymmetries (Bishop et al., 2023; Bell et al., 2014; Chapelle et al., 2019).

Within sport, training can lead to adaptations and development of asymmetries. Training adaptations can excessively focus, usually unintentionally, on one side of the body. This occurs particularly in sports that emphasize a dominant side (e.g., baseball pitchers, football punters), resulting in an imbalance of lean and bone mass. Training adaptations and asymmetries can be particular depending on the nature of the sport (Ducher et al., 2004). Softball players, for example, primarily use their dominant arm to pitch. Repeated biomechanical forces induce bone adaptations within the mid-humerus, resulting in an increase in lean and bone mass (Bogenschutz et al., 2011). Although training can affect large segments and systems of the body, some adaptations are localized. These adaptations are considered “site-specific” in response to years of training and competition, while other sites remain unaffected.

A prominent example of site-specific adaptation is bone. Bone adapts to mechanical loading and high-impact volume (Ducher et al., 2004). Years of training and skeletal adaptations result in improved bone quality, with increased bone mineral content (BMC) and bone mineral density (BMD). Tennis players are a prime example of site-specific bone adaptations. Repetitive high-volume impact and loading of the tennis racket induces adaptations to players' bones, specifically their dominant upper extremity (Chapelle et al., 2019). Bone adaptations essentially result in the increased quality of bone, but this adaptation is localized to the site that was most active or stressed.

Bone adaptation research (Bogenschutz et al., 2011; Chapelle et al., 2021; Proctor et al., 2002) has determined upper limb asymmetries through the mid-humerus or entire upper extremity across several sports (e.g. tennis, softball, gymnastics). These asymmetries were determined through custom analysis or pre-programmed dual energy x-ray absorptiometry (DXA) analyses of the entire upper extremity (Bogenschutz et al., 2011; Chapelle et al., 2021; Proctor et al., 2002). Surprisingly few studies of dominant-sided athletes have included forearm-specific analysis, despite the forearm being the recommended site to evaluate BMD and BMC of the upper extremity (Long et al., 2017). Particularly in high-volume, dominant-handed collegiate sports, the forearm would most likely exhibit the most adaptation from impact (Chen et al., 2010). In addition, there is minimal research that compares highly trained, dominant-handed collegiate athletes to an equally athletic control group with no upper limb dominance. The primary aim of this study was to examine BMD, BMC, and lean mass asymmetries in the upper extremities of National Collegiate Athletic Association (NCAA) Division I tennis players compared to an equally athletic control group with no sport side dominance. Anthropometric and grip strength imbalances were also evaluated. The purpose was to quantify the amount, or percentage, of asymmetry between dominant and nondominant sides within subjects and across teams. We hypothesize that there will be a greater magnitude of asymmetry in the dominant-sided athletes, with adaptations localized specifically to the forearm.

Methods

Experimental Approach

An observational, cross-sectional study examined whole body and forearm asymmetries in NCAA Division I tennis athletes, a primarily upper body, high-volume impact and loading sport. BMC, BMD, and lean mass asymmetries were assessed. Results from the dominant-sided experimental group were compared to a control group of athletes with no sport-specific dominant side or upper body high-volume impact or loading in their sport. A DXA machine was used to determine these results. All subjects were evaluated in their off-season. Data were collected at Utah State University's Body Composition Laboratory in the Kinesiology and Health Science Department.

Subjects

A power analysis was calculated through G*Power software program (version 3.0.10; Heinrich Heine Universität Düsseldorf, Germany) to estimate sample size. An a priori sample estimate of a repeated measures analysis of variance (ANOVA) analyzing the within-between interaction assuming an alpha of 0.05 and power of 0.95 was run. The correlation between right and left sides of the body and the effect size were conservatively estimated to be 0.85 and 0.25, respectively. Given these parameters, the calculated total sample size was 18. Participants came from a convenience sample of Utah State University NCAA Division I athletes. The dominant-sided athletes were recruited from the men's and women's tennis teams, while the men's and women's cross-country teams served as the athletic control group. Exclusion criteria included pregnancy, amenorrhea, major injury of the upper extremity within the past year (major surgery or bone fractures), missing a limb, and metal in or on the body (screws, rods, permanent jewelry, etc.). Eligible participants provided a written informed consent for the experimental protocol as approved by the Utah State University Institutional Review Board (protocol #13655). Subjects were compensated twenty-five dollars for their time.

Procedures

Demographic information including age, race, sport, position, dominant upper extremity, years of competitive experience, class standing, and self-report of menstrual cycle regularity were collected. Height was measured to the nearest 0.1 cm with a wall-mounted stadiometer (Seca 222, Seca Corp., Chino, CA), and weight was measured to the nearest 0.1 kg with a digital scale (Seca 869, Seca Corp., Chino, CA). Body composition assessments were performed with a DXA machine (Horizon W, Hologic, Inc., Marlborough, MA). Subjects wore light clothing (e.g., shorts and T-shirt) without metal and removed any jewelry or additional metal. A state licensed bone densitometry operator appropriately positioned and scanned the subjects per standardized procedures consistent with the manufacturer’s guidelines. Three scans were conducted: whole body, dominant forearm, and non-dominant forearm. For the whole-body scan, the subject was centered on the table, supine, with arms at their sides, hands pronated (palms on table), and feet slightly rotated inwards. For the forearm scans, the subject was seated next to the table with their arm placed on the scanning table. The forearm scans provided a detailed analysis of the distal part of the forearm, divided into three regions of interest (Long et al., 2017): ultra-distal (the most distal site of the radius), distal one-third (33%), and mid-distal (an intermediate region between ultra-distal and one-third) (Figure 1). BMD, BMC, and lean mass were obtained from the DXA machine's software (APEX System Software Version 5.6.0.5).

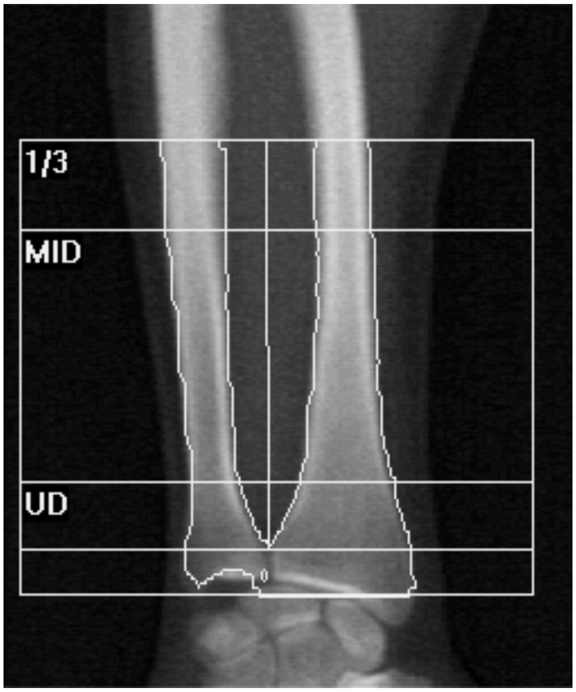

Figure 1. DXA scan of forearm and regions of interest.

Circumferences were measured to the nearest 0.1 cm on the dominant and non-dominant upper limbs with an anthropometric tape measure with a Gulick spring-loaded handle (Fabrication Enterprises, Inc., White Plains, NY). Upper arm circumference measurements were measured at the mid-humerus, mid-acromial-radial landmark, with the arm relaxed (ISAK, 2001). Lower arm circumferences were measured distal to the elbow at the maximal girth of the forearm (ISAK, 2001). Elbow bony breadth was measured to the nearest 0.1 cm with a sliding caliper (Lafayette 01291, Lafayette Instrument Co., Lafayette, IN) placed at the medial and lateral epicondyles of the humerus (ISAK, 2001).

Grip strength was assessed to the nearest 0.5 kg with a handgrip dynamometer (TKK 5001, Grip-A, Takei, Tokyo). Grip size of the dynamometer was adjusted for each subject. The subject was in a standing position with feet hip-width apart and arms fully extended at their sides (NHANES, 2013). Three trials were recorded and averaged. There was one minute of rest between trials, alternating between the dominant and non-dominant sides. All measurements were taken in a single session. Each session averaged 30 min.

Statistical Analyses

Data were assessed for outliers. SPSS software (Version 29, IBM, Inc., Chicago, IL) was used for a mixed model ANOVA to compare dominant and non-dominant arms within subjects and between groups (control vs dominant-sided athletes) with sex as a covariate for each variable of interest including: BMC, BMD, lean mass, anthropometric measurements, and grip strength. Significant findings were indicated as p-value below .05.

Results

Ten collegiate athletes participated from the men's (n=3) and women's (n=7) tennis teams for the experimental group. The control group consisted of eleven athletes from the men's (n=5) and women's (n=6) cross-country teams. Descriptive characteristics of the sample are in Table 1. The tennis players had more years of competitive experience than the runners (p < .001), but there were no significant differences in age (p = .150), height (p =.783) or body mass (p =.066) between teams.

Table 1. Descriptive characteristics of study sample.

	Tennis players	Controls
Age (years)	19.8 ± 0.9	20.9 ± 2.2
Body height (cm)	172.2 ± 11.5	173.4 ± 7.9
Body mass (kg)	69.0 ± 5.3	62.8 ± 8.6
Years competitive experience	12.6 ± 1.6	7.9 ± 2.8

Data are presented as mean ± SD.

There were no differences between tennis players and athletic controls for total body BMC (2632.36 ± 443.38 g vs. 2515.52 ± 423.61 g; p =.544), total body BMD (1.24 ± 0.09 g/cm^3 vs. 1.22 ± 0.09 g/cm^3; p =.535), or total body LM (46.3 ± 7.7 kg vs. 45.6 ± 8.8 kg; p =.843). Main effects of sport and contralateral differences are detailed in Table 2. The sport × side interaction was significant for lower arm circumference (p <.001), elbow bony breadth (p =.018), total upper extremity LM (p =.006), total upper extremity BMC (p < .001), total upper extremity BMD (p < .001), forearm BMC (p < .001), ultra-distal forearm BMC (p = .004), mid-distal forearm BMC (p < .001), one-third forearm BMC (p = .002), and ultra-distal forearm BMD (p = .015). For all significant interactions, there were higher values for the dominant arm of the tennis players creating larger contralateral asymmetries for the tennis players compared to the runners. The main effect of side was significant (p < .001) with greater values for the dominant arm compared to the nondominant side for lower arm circumference, total upper extremity LM, total upper extremity BMC, total upper extremity BMD, BMC for the ultra-distal, mid-distal, and one-third forearm, as well as the total forearm, and grip strength. The only significant main effect between groups was the tennis players had larger upper (p =.010) and lower (p =.019) arm circumferences compared to runners.

Table 2. Morphological asymmetry values for NCAA tennis players (n=10) versus control (n=11). Data are mean ± SD.

	Tennis players			Controls		
Variable	D value	ND value	PD (%)	D value	ND value	PD (%)
Anthropometry						
Circumference upper arm (cm)[*]	27.7 ± 1.5	27.6 ± 1.9	0.2 ± 4.1	25.6 ± 2.5	25.7 ± 2.7	0.0 ± 3.0
Circumference lower arm (cm)[*†‡]	25.4 ± 1.7	24.1 ± 1.5	5.3 ± 1.5	23.9 ± 2.1	23.5 ± 1.9	1.6 ± 1.8
Elbow bony breadth (cm)[‡]	6.0 ± 0.5	5.9 ± 0.5	2.5 ± 3.6	6.2 ± 0.5	6.2 ± 0.6	-1.2 ± 2.6
DXA – Upper Limb						
Lean mass (g)[†‡]	2522.5 ± 666.6	2246.8 ± 695.2	13.8 ± 7.8	2471.4 ± 627.1	2353.3 ± 652.8	5.7 ± 5.0
BMC (g)[†‡]	184.25 ± 34.06	144.72 ± 25.05	27.3 ± 6.4	165.29 ± 35.91	152.24 ± 33.54	8.8 ± 4.4
BMD (g/cm^3)[†‡]	0.846 ± 0.051	0.747 ± 0.037	13.3 ± 3.9	0.790 ± 0.081	0.784 ± 0.080	0.8 ± 2.7
DXA – Forearm						
UD BMC (g)[†‡]	1.85 ± 0.35	1.55 ± 0.23	18.5 ± 11.0	1.72 ± 0.34	1.60 ± 0.28	6.9 ± 6.6
UD BMD (g/cm^3)[‡]	0.471 ± 0.058	0.446 ± 0.046	5.9 ± 9.4	0.460 ± 0.067	0.463 ± 0.069	-0.7 ± 3.8
MID BMC (g)[†‡]	5.20 ± 1.25	4.53 ± 1.01	14.9 ± 9.0	5.17 ± 1.25	5.00 ± 1.08	2.9 ± 4.2
MID BMD (g/cm^3)	0.614 ± 0.062	0.607 ± 0.059	1.1 ± 5.1	0.635 ± 0.065	0.628 ± 0.051	1.0 ± 3.7
1/3 BMC (g)[†‡]	3.83 ± 0.41[†]	3.50 ± 0.36	9.4 ± 7.6	3.78 ± 0.72	3.74 ± 0.70	1.0 ± 3.7
1/3 BMD (g/cm^3)	0.718 ± 0.053	0.706 ± 0.055	2.0 ± 5.6	0.717 ± 0.062	0.709 ± 0.050	1.0 ± 3.4
Forearm BMC (g)[†‡]	9.09 ± 1.78	7.88 ± 1.33	15.2 ± 8.0	8.86 ± 1.96	8.55 ± 1.69	3.2 ± 3.8
Forearm BMD (g/cm^3)	0.599 ± 0.054	0.586 ± 0.051	2.4 ± 5.8	0.606 ± 0.064	0.604 ± 0.055	0.3 ± 3.1
Grip strength (kg)[†]	31.0 ± 6.5	28.2 ± 7.1	11.4 ± 11.8	31.6 ± 9.7	28.9 ± 9.2	10.4 ± 6.4

D: dominant side; ND: nondominant side; PD: percentage difference; BMC: bone mineral content; BMD: bone mineral density; Forearm is divided into three segments: UD (ultra-distal), MID (mid-distal), 1/3 (one-third)

[*] Significant main effect of sport ($p < .05$; tennis > control).

[†] Significant main effect of side ($p < .05$; dominant > nondominant).

[‡] Significant interaction effect ($p < .05$).

Discussion

This study supports the hypothesis that dominant-sided athletes have greater asymmetry compared to a control group, additionally supporting evidence of site-specific training adaptations to the dominant forearm. Many collegiate athletes have years of experience, resulting in long-term exercise adaptations specific to their sport. The main findings of the present investigation were that upper extremity LM, BMC, and circumferences are significantly greater for tennis players compared to age-, height-, and weight-matched athletic controls. This is supported by additional research (Chapelle et al., 2022; Ireland et al., 2013) confirming a morphological asymmetry in the upper dominant limb of the tennis athletes. Sports specificity is the likely cause for the one-sided development in mass and volume of the upper extremity in the tennis athletes. These adaptations can be attributed to primary use and training of the dominant extremity over an extended period of time (Chapelle et al., 2019). The years of competitive experience for the tennis players in this study ranged from 9 to 15 y (12.6 ± 1.6), which is more than half of their lives.

Another main finding from this study is the evidence of site-specific bone adaptation. Aside from sport-specific adaptations localized to the dominant upper extremity, there were specific adaptations within the forearm sites. All sites of the dominant forearm had greater BMC asymmetry for tennis players compared to runners, but only the ultra-distal site of the dominant forearm of tennis players had a significantly larger BMD. These findings are similar to another study (Ducher et al., 2004) that determined that areas of bone that do not experience targeted high impact or loading will not increase BMC or BMD. This supports the principle that bone improvements are site-specific in response to external forces (Ducher et al., 2004).

This phenomenon is reinforced by Wolff’s Law, which describes the process of bone tissue formation and remodeling in response to mechanical forces that act on it (Chen et al., 2010). Ducher et al. (2004) suggest that these responses can differ based on the type of bone that is experiencing mechanical force. Bone can be further categorized into cortical and trabecular bone, the compact outer shell and the spongy structure within bone, respectively. Research findings suggest that in response to an external force, cortical bone reacts by increasing in size (or content) and trabecular bone responds by increasing in density (Ducher et al., 2004). This may explain why the ultra-distal site, primarily made up of trabecular bone (Augat et al., 1998), experienced increased BMD. Additionally, the mid- and one-third sites, primarily consisting of cortical bone (Augat et al., 1998), experienced increased BMC.

Our findings suggest that sport asymmetries are unique to training. Softball players, specifically overhand throwers, exhibited greater bone adaptations in the mid-humerus, compared to windmill pitchers (Bogenschutz et al., 2011). This can be attributed to repetitive overhand and underhand throwing mechanics and forces acting on the upper extremity (Bogenschutz et al., 2011). In comparison to tennis players, the high impact and loading of the racket induces further adaptations in the forearm rather than the humerus (Chapelle et al., 2021; Ducher et al., 2004). Even though the forces contributing to adaptations may differ, tennis and softball athletes saw an increase in mass and volume of the primary area; namely, BMC, lean mass, and circumference (Bogenschutz et al., 2011; Chapelle et al., 2021). In addition, training technique, such as a one-handed versus two-handed backhand in tennis, influences the magnitude of asymmetry (Ducher et al., 2005). Tennis players that primarily use a one-handed backhand experienced almost four times greater cortical volume compared to two-handed backhand counterparts (Ducher et al., 2005). This confirms that even within a sport, the position on the team and training technique can influence adaptations.

Anthropometric measures were affected in the dominant side of the tennis players. These measures included lower arm circumference, elbow bony breadths, LM, and BMC. Morphological asymmetries are pronounced in dominant-sided sport (Chapelle et al., 2022; Ireland et al., 2013; Lucki & Nicolay, 2007), regardless of age (Chapelle et al., 2022). Research has found that even young, adolescent, elite tennis players display morphological asymmetries between upper limbs (Chapelle et al., 2022; Ducher et al., 2009), suggesting that high-volume impact training effects can be rapid. Our findings are similar to those of past studies (Chapelle et al., 2021; Ducher et al., 2005; Lucki & Nicolay, 2007), with pronounced morphological asymmetry of the dominant side.

Surprisingly, grip strength was not significantly different between groups. Grip strength was expected to be higher in the tennis group compared to the control, due to the nature of the sport and previous findings (Chapelle et al. 2022; Ducher et al., 2005; Lucki & Nicolay, 2007; Wu et al., 2021). This contradiction may be due to similar athleticism between the sport groups in the present study. Previous research has found significant differences between athletic and general populations (Cronin et al., 2017), but not necessarily between athletic groups. In addition, recent research has found that morphological asymmetries do not entirely account for functional (or skill) asymmetries

(Chapelle et al., 2022). This finding may account for the significant sport × side asymmetry in lean mass, but not a significant sport × side interaction for grip strength. Interestingly, grip strength in the non-dominant hand of the tennis group was lower than the control. Although this was not significant, it may suggest lack of use of the non-dominant hand, leading to further functional asymmetry.

The main limitation of this study was a small sample size. Subjects were recruited from a limited, convenience sample of NCAA athletes at a single university. Although additional subjects would strengthen the study, we do not believe the main findings would differ from our present results. Additionally, the findings are limited to highly trained, young adult, tennis players. The magnitude of dominant-nondominant asymmetries may be very different for youth or senior players (Chapelle et al., 2019). The main strength of the study was the comparison of the experimental group to an equally athletic control group. Past research has determined whole body asymmetries within subjects (Chapelle et al., 2021; Chapelle et al., 2022), but very rarely in comparison to an equally athletic control group with no sport-side dominance. Other researchers investigating morphological asymmetries of athletes typically used a control group matched in age and sex, but not in physical size or athletic level (Bogenschutz et al., 2011; Chapelle et al., 2022; Proctor et al., 2002). The body composition and morphology of athletes versus the general population can vary widely, which would influence the magnitude of bone and lean mass adaptations between groups. By introducing an equally athletic control group, we were able to focus on the magnitude of asymmetry by sport-specific adaptations rather than physical activity levels.

In summary, we found that physical asymmetries are more pronounced in dominant-sided sports than in controls, with bone and LM affected more than grip strength. These long-term exercise adaptations are site and training specific. In general, considering the upper extremities, the differences between the tennis and cross-country athletes were primarily localized to the forearm. Sport specificity appeared to influence mass and volume (circumference, bony breadths, LM, BMC) more than density. Although, at a closer glance, the BMD of tennis players was enhanced locally at the ultra-distal site of the dominant forearm.

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