Positional Body Composition of NCAA Division I Volleyball Players, Consortium of College Athlete Research (C-CAR) Study

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Katie Lyn Bisch

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Abstract

PURPOSE: The primary objective was to identify normative values for total and regional body composition by position among female NCAA Division I collegiate volleyball players using dual X-ray absorptiometry (DXA). The secondary objective was to analyze pre- to post-season body composition changes. **METHODS:** Ninety female volleyball players (age=19.8±1.4 years, height=179.7±8.5 cm, body mass=74.7±9.9 kg) from multiple NCAA Division I universities received a DXA scan. Athletes were categorized by position: Middle Blocker (MB=31), Outside Hitter (OH=32), Setter (ST=9), and Libero (LB=18). Total and regional fat mass (FM), lean masses (LM), and bone mineral density (BMD) were measured by DXA, as well as abdominal visceral adipose tissue (VAT). Upper total mass to lower total mass ratio (ULR), total upper mass to lean lower mass ratio (TULLR), lean upper mass to lean leg mass ratio (LULLR), and gynoid lean mass to leg lean mass ratio (GLR) were also calculated. Pre- to post-season changes in body composition were assessed among 39 volleyball players in the cohort from three universities (age=19.3±1.0 years, height=179.7±9.0 cm, body mass=73.4±8.7 kg). An analysis of variance with TukeyHSD post-hoc comparisons assessed differences in body composition measures between positions, while paired t-tests assessed pre- to post-season differences. Effect size was calculated for each variable and magnitude based inferences were computed to draw inferences from the data. **RESULTS:** As expected, height was statistically significant between all positions: MB (185.9±4.6 cm, $p<0.001$), OH (181.7±4.1 cm, $p<0.001$), and ST (174.7±3.7 cm, $p=0.009$) were all significantly taller than LB (167.8±8.0 cm). Weight was significantly greater in MB and OH (80.0±9.2 kg, 76.7±7.8 kg) compared to LB (64.5±7.6 kg, $p<0.001$), and in MB compared to ST

(69.7±5.7 kg, p=0.006). Percent body fat (p=0.74), body mass index (BMI) (p=0.94), and VAT (p=0.143) were not significant between positions. Total LM was greater in MB and OH (55.7±4.6, 54.1±4.7 kg) compared to LB (45.9±4.9 kg, p<0.001) and ST (48.3±3.2 kg, p=0.002, p=0.006, respectively). Total FM was significantly greater in MB compared to LB (21.0±6.9, 16.1±4.0 kg, p=0.016). Trunk LM was greater in MB and OH (26.0 ± 2.0 kg, 25.3 ± 2.3 kg) compared to LB (22.1 ± 2.3 kg, p<0.001, both) and ST (23.1 ± 1.4 kg, p=0.003, p=0.03, respectively). Leg LM was greater in MB and OH (20.4 ± 2.1 kg, 19.4 ± 2.1 kg) compared to LB (15.7 ± 2.0 kg, p<0.001, both) and ST (17.0 ± 1.3 kg, p<0.001, p=0.009, respectively). Arm LM was greater in MB and OH (6.2 ± 0.7 kg, 6.1 ± 0.7 kg) compared to LB (5.1 ± 0.7 kg, p<0.001, both) and ST (5.2 ± 0.6 kg, p=0.003, p=0.004, respectively). Leg FM was significantly greater in MB compared to LB (8.7 ± 2.6 kg, 6.5 ± 1.6 kg, p=0.002). However, trunk FM, arm FM, and VAT mass were not significantly (p>0.05) different between positions. ULR was lower in MB (1.48±0.11, p<0.001) and OH (1.51±0.11, p=0.012) compared to LB (1.61±0.1), and lower in MB versus ST (1.59±0.07, p=0.043). In relation to LB (0.48±0.03), GLR was lower in MB (0.44±0.02, p<0.001) and OH (0.46±.04, p=0.021), and lower in MB compared to ST (0.48±0.02, p=0.021). LULLR was also significantly lower in MB (1.58±0.1, p<0.001) and OH (1.63±0.12, p=0.012) compared to LB (1.73±0.09), but not ST (1.67±0.06). TULLR was not significantly different (p=0.054). After adjusting for mass, total BMD was significantly greater in MB (1.39±0.1 g/cm^2, p<0.001) and OH (1.41±0.09 g/cm^2, p=0.002) compared to LB (1.30±0.08 g/cm^2), but not ST (1.31±0.07 g/cm^2, p>0.05). Leg BMD was greater in MB and OH (1.54±0.11, 1.53±0.11 g/cm^2) compared to LB (1.38±0.09 g/cm^2, p<0.001, both) and ST (1.4±0.06 g/cm^2, p=0.004, p=0.008, respectively). Spine BMD was greater in MB

and OH (1.32±0.15, 1.33±0.12 g/cm^2) compared to LB (1.22±0.09 g/cm^2, p=0.03), but not ST (1.25±0.1 g/cm^2, p>0.05). Arm BMD was not statistically significant between positions (p=0.11). Leg FM significantly decreased from the pre- (7.4±1.7 kg) to post-season (7.0±1.4 kg, p=0.001), a moderate effect size was observed (r=-0.36). No further significant seasonal changes were identified at an adjusted p-value (p<0.007). **CONCLUSION:** Total body composition measures vary significantly by position; however, differences in total lean mass (p<0.001) are significantly influenced by height. Positional analysis revealed that front row players (MB and OH) have a greater amount of lean mass in their legs compared to non-front row players (ST and LB). Lean mass distribution among front row players is more evenly dispersed between the upper and lower body. BMD differences may be influenced by repeated impacts of jumping during the attacking and blocking actions of front row players. The moderate effect size observed in leg FM suggests that ~95% of players experienced a trivial reduction in leg FM from pre- to post-season. Future studies should longitudinally evaluate the relationship between regional body composition and sport performance.

Key Words: Dual- X-ray Absorptiometry, Body Composition, Volleyball, Bone-mineral Density

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List of Abbreviations

AT: Adipose tissue

BIA: Bioelectrical Impedance Analysis

BMC: Bone mineral content

BMD: Bone mineral density

BMI: Body mass index

FFM: Fat-free mass

FFSTM: Fat-free soft tissue mass

FM: Fat mass

GLR: Gynoid lean mass to leg lean mass ratio

LM: Lean tissue mass

LULLR: lean upper mass to lean leg mass ratio

SMM: Skeletal muscle mass

TULLR: Total upper mass to lean lower mass ratio

ULR: Upper total mass to lower total mass ratio

VAT: Visceral adipose tissue

CHAPTER 1: INTRODUCTION

The competitive nature of NCAA Division I collegiate volleyball necessitates both the identification of potential recruits, and the implementation of successful performance enhancing training programs. Multiple methods are utilized to assess athletes' physical attributes (e.g., anthropometry, body composition) (Kutáč & Sigmund, 2017; Lidor & Ziv, 2010; Pion et al., 2015), sports performance (e.g., vertical jump, anaerobic capacity, agility, speed) (Ferris, Signorile, & Caruso, 1995; Jones & Thompson, 2011; Sheppard et al., 2008), biomechanical load monitoring (Montgomery et al., 2017; Tillman, Hass, Brunt, & Bennett, 2004), and game performance (e.g., aces, kills, blocks, errors) (Eom & Schutz, 1992; Nikos, Karolina, & Elissavet, 2009).

Within the sport of volleyball, individual positions have different sport specific positional demands that require distinct anthropometric (e.g., height, body mass) and body composition (e.g., fat mass, mass distribution) characteristics. Front row players, including right, opposite, and outside hitters as well as middle blockers (i.e., centers), are required to hit and block over the net, mandating that they be taller and/or have an exceptional vertical jump. Alternatively, the libero is a back-row defensive specialist and is rarely required to jump. Lastly, the setter coordinates the offensive set up, and is required to complete tasks of both front and back-row players.

Previous studies have indicated a significant relationship between body composition and competition level, indicating that there may be an ideal body composition profile (Kutáč & Sigmund, 2017; Schaal, Ransdell, Simonson, & Gao, 2013). A relationship has also been identified between body composition and sports specific skills such as the vertical jump, countermovement jump, and attack height

(Ćopić , Dopsaj, Ivanović, Nešić, & Jarić 2014; González-Ravé, Arija, & Clemente-Suarez, 2011; Kutáč & Sigmund, 2017; Sheppard et al., 2008). Longitudinally monitoring changes in body composition within season can guide strength and conditioning goals and athlete nutrition recommendations to achieve optimal performance (González-Ravé et al., 2011; Hedrick, 2007; Holmberg, 2013). Previous studies have identified seasonal and multi-year changes in body composition measures among collegiate volleyball players in total lean (LM) and fat mass (FM), as well as bone mineral density (BMD) (Carbuhn, Fernandez, Bragg, Green, & Crouse, 2010; D. Stanforth, Lu, Stults-Kolehmainen, Crim, & Stanforth, 2016; P. R. Stanforth, Crim, Stanforth, & Stults-Kolehmainen, 2014).

To date, few studies have assessed position specific volleyball player body composition measures (Malousaris et al., 2008; Martín-Matillas et al., 2014). Furthermore, research conducted among elite professional volleyball players have only reported position-specific body composition measurements using skinfolds (Malousaris et al., 2008; Martín-Matillas et al., 2014). In addition to a lack of position specific data, few studies have utilized multi-compartment methodology, such as dual x-ray absorptiometry (DXA), among female collegiate volleyball players (Carbuhn et al., 2010; Silva et al., 2014; P. R. Stanforth et al., 2014). To our knowledge, there are no current multi-center studies that analyze positional body composition among NCAA Division I female volleyball players.

The primary objective of this study was to expand upon previous research by providing position specific normative values for total and regional body composition measurements for female collegiate NCAA Division I volleyball players using DXA. The

secondary objective was to analyze pre- and post-season changes in body composition. This study improves upon previous studies by utilizing the gold standard for body composition assessment in performance research settings.

CHAPTER 2: LITERATURE REVIEW

Importance of Position Specific Body Composition Assessment in Sport

Body composition is commonly assessed among athletes in order to monitor overall health, training adaptations, and potential muscular imbalances (Clark, Reed, Crouse, & Armstrong, 2003; Johnson, Nebelsick-Gullett, Thorland, & Housh, 1989; McNeal, Poole, & Sands, 1999; Petersen et al., 2006). Body composition is also commonly tracked by team's due to its relationship with athletic performance (Boileau & Horswill, 2000; Ćopić et al., 2014; P. Nikolaidis, Afonso, & Busko, 2015; Sheppard et al., 2008; van den Tillaar & Ettema, 2004). Sports including baseball, football, basketball, and volleyball have diverse physical demands across positions that require different body types (Bosch et al., 2017; Carda & Looney, 1994; Marques, van den Tillaar, Gabbett, Reis, & González-Badillo, 2009; Sallet, Perrier, Ferret, Vitelli, & Baverel, 2005). Position specific data can also be utilized for talent identification, positional suitability, and in guiding training program development for sport specific adaptations.

The ability to identify body composition parameters to meet the demands of each position can be challenging for coaches without normative values of successful players for comparison. In order to achieve this goal, coaches need accurate position specific body composition data to understand the key attributes that make a player successful in their positon. Within the sport of volleyball, few studies have been conducted on position specific volleyball player body composition (Malousaris et al., 2008; Martín-Matillas et al., 2014).

Previous studies have demonstrated that volleyball players in various positions have different body composition measures comparatively (Malousaris et al., 2008;

Marques et al., 2009; Martín-Matillas et al., 2014). A review of the literature also revealed a possible connection between success in sport specific skills and body composition measures (Ćopić et al., 2014; Kutáč & Sigmund, 2017; Malousaris et al., 2008; Sheppard et al., 2008). However, past research primarily utilized two-compartment methodology, such as skin-fold measures and bioelectrical impedance analysis (BIA) (Ćopić et al., 2014; González-Ravé et al., 2011; Kutáč & Sigmund, 2017; Malousaris et al., 2008; Martín-Matillas et al., 2014; PT Nikolaidis et al., 2015).

Highly competitive NCAA Division I female volleyball players competing for top U.S. collegiate teams were chosen for this study. Coaches at this level seek to identify successful players and improve talent. Only 5,406 female volleyball players are on scholarship at the Division I collegiate level, and only 1.2% of U.S. high school players will succeed in acquiring a scholarship (O'Rourke, 2017). Position specific information provided by this study will benefit all collegiate volleyball playing levels, as well as high school athletes aspiring to compete at the collegiate level by identifying normative body composition characteristics.

In order to mitigate the need for accurate positional data, this study will comprise a compendium of position specific body composition profiles of female NCAA Division I collegiate volleyball players. Additionally, DXA enables us to calculate body composition mass distribution ratios, which is a novel metric being introduced to volleyball research in the current study. It is hypothesized that positional differences between front row and back row positions will be observed regarding LM, BMD, and body composition mass

distribution ratios. It is also hypothesized that pre- to post-season body composition changes will not demonstrate statistically significant differences.

DXA: The Gold Standard

DXA is a valid and reliable technique for measuring total and regional LM, FM, and BMD (Bilsborough et al., 2014; Fuller, Laskey, & Elia, 1992; Hart, Nimphius, Spiteri, Cochrane, & Newton, 2015; Mazess, Barden, Bisek, & Hanson, 1990). It uses the speed of two x-ray beams to calculate bone mass, fat mass, and lean body mass. It is preferred over two-compartment methodology, such as skinfold measurements and BIA, due to its increased accuracy (Ackland et al., 2012; Lohman, Harris, Teixeira, & Weiss, 2000). DXA also permits regional analysis by calculating mass distribution in legs, arms, trunk, android area, and gynoid area.

Previous studies conducting position specific comparisons utilized skin folds (Malousaris et al., 2008; Martín-Matillas et al., 2014; P Nikolaidis et al., 2015). Studies comparing body composition to performance metrics also used BIA (Ćopić et al., 2014; Kutáč & Sigmund, 2017). However, DXA is more accurate compared to skinfolds and BIA. It has a 1-3% standard error of estimate (SEE) compared to the four-compartment model (Lohman et al., 2000). Whereas, skinfold measures have a 3-5% SEE when validated against densitometry, and BIA has a 3.5% SEE (Ackland et al., 2012). Skinfolds are an estimation from anthropometric parameters that use equations to devise percent body fat (%BF). However, measurement error by the practitioner can lead to significantly different results, and not all prediction equations are applicable to all populations (Ackland et al.,

2012). BIA uses an electrical current to measure the resistance of tissues, after which a prediction equation estimates both %BF and water percentages. However, a limitation of BIA is that it is highly influenced by hydration (Fornetti, Pivarnik, Foley, & Fiechtner, 1999).

Bilsborough et al., (2014) demonstrated correlation between DXA measures compared to a whole body phantom with predetermined FM, bone mineral content (BMC), and fat-free soft tissue mass (FFSTM). The correlation for FM was acceptable at r=0.67, and it was excellent for BMC (r=1.00) and FFSTM (r=0.99). Additionally, the intra-class correlation demonstrated reliability among regional arm, leg, and trunk lean and fat masses, ranging from 0.89-0.99. Such results demonstrate that DXA is suitable for determining body composition measures in lean team sport athletes. Further, Fuller et al., (1991) found that DXA enables valid and reproducible measures of limb muscle mass in addition to total FM, FFSTM, and BMC. Hart et al., (2015) also demonstrated high intra- and inter-tester reliability across all regional segments for soft-tissue and hard tissue.

DXA has the ability to measure regional body composition, allowing the calculation of the regional distribution of mass. Regional body fat distribution is important because it indicates where individuals have greater amounts of lean and fat mass distributed (e.g., legs, arms, and trunk). Many of the previous studies conducted on volleyball players only measured total %BF, FM, or fat free mass due to their chosen method of measurement (Ćopić et al., 2014; Kutáč & Sigmund, 2017; Malousaris et al., 2008; Sheppard et al., 2008).

Current studies that utilize DXA with volleyball players have sample sizes of 26 or less (Bell, Sanfilippo, Binkley, & Heiderscheit, 2014; Carbuhn et al., 2010; Silva et al., 2014; D. Stanforth et al., 2016; P. R. Stanforth et al., 2014). Carbuhn et al., (2010) longitudinally assessed body composition among female collegiate athletes during off, pre, and post-season for three years. However, there were only 7 volleyball players included in this study. Two publications, completed as part of the same study, utilized DXA to measure pre- to post-season changes in body composition in collegiate Division I female athletes across three years (Stanforth et al., 2014 and Stanforth et al., 2016). The sample size consisted of only 26 volleyball players; as such, positional differences were not assessed due to the limited sample. Another limitation of the study was that hitter/blockers and setters/defensive specialists in volleyball were not separated in the analysis (P. R. Stanforth et al., 2014).

The few previous studies with an adequate sample size to analyze positional differences used indirect measures (skin fold measurements) to assess body fatness. This was identified as a limitation in these studies, and the authors called for a future study with direct body composition assessment methods, specifically DXA (Malousaris et al., 2008; Martín-Matillas et al., 2014; PT Nikolaidis et al., 2015; P Nikolaidis et al., 2015).

The Problem with Assuming Tantamount Body Composition Across Positions

Previous studies conducted with volleyball players neglected to address positional body composition differences. Instead, averages for each variable are created, and represent the entire sport, regardless of position. However, different playing positions in

volleyball have diverse physical demands, and therefore, varied body types. Two of the previous body composition studies identified positional differences in anthropometric and body composition measures (Malousaris et al., 2008; Martín-Matillas et al., 2014). Martín-Matillas et al. (2014) and Malousaris et al. (2008) primarily observed these differences between front row (opposites, centers, hitters) and non-front row (setters and liberos) playing positions. However, Nikolaidis et al. (2015b) did not observe significant differences in body %BF or fat-free mass (FFM) between positions.

A study by Martín-Matillas et al. (2014) measured body composition using skin folds of volleyball players from the highest Spanish national league. The study included 147 players (24.8±4.4 years) in five different positions. Significant differences were observed between positions in height ($p<0.001$), body mass ($p<0.001$), skeletal muscle mass (SMM) ($p<0.001$), and thigh muscle area ($p<0.001$). Skeletal muscle mass was calculated using an anthropometric prediction model based on SMM measured with magnetic resonance imaging (Lee et al., 2000). Arm and thigh muscle and fat area were calculated using revised anthropometric measurement equations for calculating bone-free arm and leg muscle area (Frisancho, 1990; Heymsfield, McManus, Smith, Stevens, & Nixon, 1982).

Height was significantly different between setters and liberos compared to all positions, with liberos being the shortest followed by setters. Centers were also significantly taller compared to hitters. Liberos had less mass compared to all other positions with the exception of setters, who also had less mass compared to other positions. This indicates that front row players are taller and have greater mass on average. Significant

differences in SMM were also observed between positions. Opposites had greater SMM compared to hitters. Setters had significantly less SMM compared to opposites and centers, while liberos had lower SMM compared to all front row positions. Lastly, observed thigh muscle mass was significantly lower in setters compared to opposites and centers (Martín-Matillas et al., 2014).

Malousaris et al. (2008) completed one of the only other sizeable studies reporting on body composition characteristics of volleyball players by position and playing level. This study was conducted on 163 elite female volleyball players (23.8±4.7 years) in the A1 and A2 division of the Greek National League, they were divided into 5 positions. Skin fold measurements were used in this study as well. They found that compared to the three front row positions, liberos were shorter. Liberos also had less total mass and FFM compared to hitters and centers. Setters were shorter compared to centers and opposites, and they had less total and FFM compared to centers. These results indicate that the two non-front row playing positions tended to be shorter and have less total and FFM.

Lastly, Nikolaidis, Afonso, and Busko (2015a) and Nikoladis et al. (2015b) investigated positional differences in 58 (24.9±5.3 years) adult players who competed in the top three Greek volleyball divisions. They also compared the adult players to 62 adolescent players (15.6±1.1 years) participating in internationally competing sports clubs. The adult positional analysis revealed that centers and opposites were significantly ($p<0.05$) taller than setters and liberos, centers were also taller than hitters. Centers have significantly greater body mass compared to liberos, but no further body mass differences were observed between positions. They also discovered no significant differences in %BF

between positions. Additionally, contrary to previous findings, they did not find differences between positions in FFM (Malousaris et al., 2008; Martín-Matillas et al., 2014). This may be influenced by drawing participants from lower level leagues. Unlike the adult players, adolescent players showed significantly greater FFM in centers (50.1±5.7 kg) compared to liberos (42.7±2.7 kg)(P Nikolaidis et al., 2015). Significant differences were also observed between the adolescents and adults in body height and FFM, with adults being taller with greater FFM comparatively (PT Nikolaidis et al., 2015).

A primary positional requirement that leads to these differences is the demand for repetitive jumping and landing in the front row that occurs as a result of attacking and blocking. Repetitive jumping in volleyball leads to high impact loading and increased bone strain. This element of the sport prompts osteogenesis, leading to increased BMD across multiple seasons (Carbuhn et al., 2010; Heinonen et al., 1995; D. Stanforth et al., 2016). Tillman et al. (2004) observed the number of jumps during two games for four NCAA Division I female volleyball teams, all ranked in the top 25 in the U.S. They observed the number of jumps completed by front row players because they perform almost all of the jump-landings within a game, with the exception of offensive attacks from the back row. They found that each player in the front row averaged 22 jumps per game, and the maximum number of jump-landing sequences across the two-game period was 73 jumps for an individual player.

This differentiation between back and front row jumping accumulation can lead to differences in body composition variables such as BMD and lower body lean mass. For instance, jumping and landing are eccentric motions. Chronic exposure to repeated forces

from eccentric exercises has been shown to cause adaptations in muscle stiffness as well as muscle strength and size (LaStayo et al., 2003). In addition, leg lean mass relative to total body mass assists in knee loading when landing from a jump (Montgomery et al., 2017). High levels of lower extremity lean mass are key to safe landing biomechanics during prolonged exercise, such as the back to back games that occur in volleyball (Montgomery et al., 2017). It may be beneficial for front row players to have greater lean mass, specifically in their legs, compared to positions with fewer jumps, in order to prevent injury. DXA has the valuable ability to discern upper and lower body lean mass and BMD differences between positions.

Positional differences in body composition were found in all but one study, highlighting a need for positional data in order to understand the demands of each position on the court. By observing positional requirements, we can see that the physical demands of each position vary. Therefore, we would expect to see differences in body composition and anthropometry. By providing position specific data, the proposed study may assist in identifying those valuable differences.

The Relationship Between Body Composition and Sports Performance

Anthropometric, body composition, and mass distribution parameters can influence performance outcomes in sport. Understanding the normative body composition characteristics of elite NCAA Division I volleyball players can assist coaches with talent identification, positional suitability, and a as a guide for athlete development. There are connections between body composition parameters and athletic performance as well as

jump performance, which is an essential skill in volleyball (Ćopić et al., 2014; Sheppard et al., 2008). In addition, many studies have found relationships between body composition and competition level that enforce these findings (Kutáč & Sigmund, 2017; Marques et al., 2009; Martín-Matillas et al., 2014; PT Nikolaidis et al., 2015). Body composition and anthropometric variables are only one part of athlete success, and should be used in conjunction with other evaluation metrics in guiding decisions regarding athlete potential and training objectives.

Body composition, specifically %BF, influences sport performance both mechanically and physiologically. Mechanically, excess fat has been shown to decrease performance in actions in which acceleration is required, such as a vertical jump (Boileau & Horswill, 2000). This is due to the relationship between force, mass, and acceleration and its influence on velocity. The excess fat mass can impede players change in velocity (Boileau & Horswill, 2000). Metabolically, excess fat mass requires the body to expend more energy during movements, such as jumping, because the body has to move more inactive mass. Consequently, in sports such as volleyball, fat free mass is positively associated with physical performance (Boileau & Horswill, 2000).

Further, studies by Ćopić et al. (2014) and Sheppard et al. (2008) identified a relationship between body composition and jumping performance in volleyball players. Jump height is a crucial aspect for front row offensive players. The connection between these variables is valuable in guiding training parameters for current athletes. Ćopić et al. (2014) conducted a study comparing elite volleyball players (n=35), who competed in the Olympics and national leagues, against physically active females (n=21) to measure jump

performance as it relates to body composition and strength variables. Body composition was estimated using InBody720, an 8-polar bio-impedance method with a multi-frequency current. Vertical jump was measured from a countermovement jump with arms, as well as without arms, and a force plate was utilized to record and process the vertical component of the ground reaction force. Leg extensor strength was evaluated with a standard bilateral leg press test. All strength tests were normalized for body size using the standard scaling formula. They found a moderate-to-strong correlation between jump performance and body composition (%BF and SMM) in both groups ($p<0.05$). Lesser %BF and greater SMM were associated with a higher vertical jump. Comparatively, strength variables had an average to moderate correlation with jump performance ($r=0.33$-0.64; $p<0.01$). Similarly, Sheppard at al. (2008) found a moderate correlation between skinfold ratios and the sport specific spike jump in elite volleyball players who competed at the international level ($r=0.52$; $p<0.01$). Anthropometric variables including absolute height standing reach were strongly correlated with depth jump performance as well as the spike jump and counter movement jump ($p<0.01$).

González-Ravé et al. (2011) conducted a season long strength training program with the highest Spanish division league from which they saw improvements in jump height as well as an increase in FFM and a reduction in FM as a result of the program. However, contrary to the findings in Sheppard et al. (2008), they did not find a direct correlation between body composition changes and jump performance or strength. Only ten participants took part in the study, therefore results should be interpreted with caution.

The literature connecting body composition and jumping performance in volleyball players requires further exploration to definitively determine the relationship.

Nikolaidis et al. (2015a) performed a study that highlights the connection between body composition, anthropometry, and jump height by competition level. Teams from Greek leagues A, B, and C were analyzed, with team A being the highest competitive level. Players in the top competitive level were taller, had lower body fat, and greater FFM compared to group C. Group B had a significantly higher squat jump and counter movement jump compared to group C. Interestingly, group A did not, but their average height was higher than group B's. The height a player can reach above the net is a combination of body height, arm length (e.g. reach), and vertical jump. The differences between the average body height at each level of play explain the difference in jump height from group A to B. However, the limited sample size of 37 participants was a weakness of this study.

Previous studies support a connection between body composition and competitive level. Kutáč and Sigmund (2017) conducted a study analyzing body composition parameters compared to different playing levels. The study boasted a sample size of 164 females, including elite volleyball players, amateur players, and the general population as a control group. They found a moderate to strong correlation between competition level and body composition parameters. As competition level increased, total body fat decreased and SMM increased, but overall body height and weight were similar between elite and amateur players. The authors also included segmental analysis using BIA. Segmental %BF in elite compared to amateur players revealed large differences (d=1.28-1.41) in both arms

and legs (*d*=1.33-1.36), and moderate differences (*d*=1.1) in the trunk. Arm %BF for the right and left arms, respectively, was 17.04% and 17.75% for elite players, and 24.44% and 25.52% for amateurs. The leg %BF for the right and left legs, respectively, was 16.5% and 16.48% for elite players, and 21.2% and 21.09% for amateurs. Lastly, trunk %BF in elite players was 18.52% and 24.37% in amateurs. This indicates that body composition may play a role in volleyball performance.

The findings from Martín-Matillas et al. (2014) also support this. The authors analyzed body composition measures in relation to team ranking in the highest Spanish league. Players who competed on top level teams tended to be taller with greater SMM. However, it is important to note that lower correlation coefficients indicated that this is only a small factor in playing performance. A covariance analysis also revealed that greater FM coincided with poor team performance. Malousaris et al. (2008) also found that higher ranked division players had a significantly lower %BF, more FFM, and were taller.

Typically, lower %BF and higher SMM are associated with better jump performance as well as increased success in higher levels of competition. These findings are in line with previous research that found FFM is the top measure for conveying body size in relation to physical performance (van den Tillaar & Ettema, 2004). Further research is needed to establish the relationship between body composition and volleyball specific performance metrics.

Tracking Body Composition Change

In addition to position specific body composition measures, tracking body composition allows for a quantifiable means of measuring the progress of training and nutrition programs for athletes, as well as the impact of the competitive season over the course of a collegiate career. Body composition changes may also impact athlete health across the lifespan. For instance, increases in bone density early in life can reduce the risk of osteoporosis during aging (Recker et al., 1992). Seasonal changes in body composition have been observed in previous studies (Carbuhn et al., 2010; D. Stanforth et al., 2016; P. R. Stanforth et al., 2014). Often, body composition measures continue to change across multiple seasons.

Carbuhn et al. (2010) analyzed the body composition changes of 7 Division I NCAA collegiate volleyball players at three separate time points: off-season, pre-season, and post-season across a single training year. Significant ($p<0.05$) changes in total FM, total BMD, BMC, leg BMD, and spine BMD were observed. While total FM decreased, total BMD, BMC, and leg BMD all increased from the pre- to post-season. Spine BMD increased from the off-season to pre-season. Additionally, in a multi-year analysis of Division I collegiate volleyball players, Stanforth et al. (2016) observed significant ($p<0.05$) increases in total, leg, and spine BMD between the pre-season of the first competitive year and the post-season of the second competitive year. Stanforth et al. (2014) detected a significant increase in adjusted LM from the pre- to post-season ($p<0.05$). This trend continued across years one and two; significant increases in LM were observed during the first to second, and second to third year ($p>0.05$). Stanforth et al. (2016) found significant ($p<0.05$) increases in total BMD across all three years. Increased leg and trunk

BMD was observed in both the second and third years, and increases in spine BMD were seen in the second year. Lastly, increases in BMC, arm BMD, and pelvis BMD were seen between the first and third year.

Currently, both body height and body mass are used as selection criteria for player talent identification and positional suitability (Malousaris et al., 2008). The evidence compiled within this literature review indicates that higher FFM and lower %BF are indicative of positive sports performance. Therefore, normative body composition parameters derived from elite volleyball teams could serve as another tool for identifying talent and positional suitability. Normative data of successful players may also serve as a guideline for athletic development. This information can be useful by strength and conditioning coaches to develop programs in order to target areas in which players need to improve. Furthermore, in using these normative values, coaches do need to be aware of intra-individual variability among players and tailor programs accordingly (Nikolaidis, Ziv, Arnon, & Lidor, 2012)

The information derived from this literature review substantiates the need for position specific high quality body composition data capable of identifying both total and segmental body composition parameters. Strengths in this field include sizable samples with position specific data, information regarding competition level differences in body composition, and studies on elite level athletes representing multiple countries. Observed weaknesses include a lack of studies with large sample sizes utilizing multi-compartment methodology, the lack of a definitive connection between body composition and sports performance outcomes, and a lack of segmental data. The purpose of this proposed study

is to produce normative values for total and regional body composition by position for female NCAA Division I collegiate volleyball players using DXA. The proposed study will improve upon previous studies by utilizing DXA, providing position specific data, and generating segmental body composition measurements. Coaches can use these normative values as a guide for talent identification, positional suitability, and in athletic development programs. Future studies should address the lack of literature analyzing the relationship between sport specific skills and regional body composition variables.

CHAPTER 3: METHODS

Data Collection

Data for this study were collected as part of the Consortium of College Athlete Research (C-CAR), located at the University of Minnesota (UMN), University of Texas at Austin (UT), Texas Christian University (TCU), University of Kansas (KU), and University of Nebraska (NU). A retrospective analysis was employed using previously collected data from the C-CAR group. The combined data set increases the sample size, and creates a representative sample of total and regional positional body composition measures for NCAA Division I collegiate volleyball players.

Study Participants

Ninety female volleyball players between 17 to 23 years old (mean±SD: age=19.8±1.4 years; height=179.7±8.5 cm; body mass=74.7±9.9 kg; body mass index=23.1±2.3 kg/m^2) from five NCAA Division I universities (UMN, *n*=8; UT, *n*=23; TCU, *n*=17; KU, *n*=18; and NU, *n*=24) received one whole body DXA scan. Scan dates ranged from 2007 to 2016. Players were categorized by the following positions: libero (LB, *n*=18), middle blocker (MB, *n*=31), outside hitter (OH, *n*=32), and setter (ST, *n*=9). Players were informed of the risks and benefits of the study, and all players signed an institution approved informed consent form prior to their DXA scan. Parental/guardian consent was obtained for individuals under the age of 18. Data transfer from other universities was approved separately by each university. The University of Minnesota Institutional Review Board (IRB) approved this study.

Anthropometric Measurements

Body composition was measured by DXA (iDXA/Lunar Prodigy, General Electric Medical Systems, Madison, WI, USA). During all DXA scans players were instructed to maintain their hydration status prior to their scan, and were also required to take a pregnancy test due to the mild radiation emitted from the DXA. Scans were completed on rest days at least 2 hours after a practice session when feasible. Participants were scanned using standard imaging and positioning protocols. Age, ethnicity, and playing position were recorded for each player prior to the DXA scan, as well as height and body mass using a standard stadiometer and electronic scale. Body mass index (BMI) was calculated as body mass in kilograms (kg) divided by height in meters-squared (m^2).

Raw DXA scan files were collected from each university and re-analyzed at the University of Minnesota by the same trained individual using enCore™ software (version 16.2, GE Healthcare, Madison, WI, USA). In order to increase reliability and accuracy, the same trained individual reviewed each scan for the correct placement of the region of interest (ROI) boxes to measure regional body composition. Visceral adipose tissue (VAT) was estimated using CoreScan (GE Healthcare) as described previously (Bosch et al., 2014; Bosch et al., 2015; Glickman, Marn, Supiano, & Dengel, 2004; Kaul et al., 2012). Mass distribution ratios were calculated from these values, including: upper total mass to lower total mass ratio (ULR), total upper mass to lean lower mass ratio (TULLR), lean upper mass to lean leg mass ratio (LULLR), and gynoid lean mass to leg lean mass ratio (GLR).

Scan Selection

For the purpose of this study, pre-season scans from June to August were selected. If no scan was available within this date range, the scan taken closest to pre-season was selected. If a player had more than one pre-season scan within the same year, one was randomly selected.

Pre-Season to Post-Season Differences

Seasonal changes in body composition was examined among 39 volleyball players (age=19.3±1.0 years, height=179.7±9.0 cm, body mass=73.4±8.7 kg) from three NCAA Division I universities (UT, *n*=15; KU, *n*=9; and NU, *n*=15).

Statistical Analysis

All statistical analyses were conducted using R software (R Foundation for Statistical Computing, Vienna, Austria). Position descriptive statistics were calculated using mean and standard deviation. An analysis of variance (ANOVA) with TukeyHSD (honest significant difference) post-hoc comparisons assessed significant differences between positions. Significance was set at α=0.05.

Descriptive statistics for the pre- to post-season sub-set were calculated using mean and standard deviation. Paired t-tests were used to determine significant differences between pre- and post-season measures of body composition, including body mass as well as total, trunk, and leg LM and FM. Cohen's *d* determined effect size for each variable. Wilcoxon signed-rank test was utilized where data transformation was required, reported as Pearson's *r*. Magnitude-based Inferences (MBI) were then calculated to draw inferences

from the data. The significance level was adjusted using a Bonferroni multiple-significance-test correction, $p<0.007$. An ANOVA was conducted to determine if significant differences existed between the original sample and the sub-set.

CHAPTER 4: RESULTS

Physical Characteristics of Players

No significant differences were observed between positions for age (p=0.51). As expected, height was statistically different (p<0.001, all) between all positions: MB (185.9±4.6 cm, p<0.001), OH (181.7±4.1 cm, p<0.001), and ST (174.7±3.7 cm, p=0.009) were all significantly taller than LB (167.8±8.0 cm) (Figure 1). Middle blockers were taller compared to OH (p=0.012) and ST (p<0.001), and OH were taller compared to ST (p=0.003). Positional body mass differences followed a similar trend to height: MB (80.0±9.2 kg, p<0.001) and OH (76.7±7.8 kg, p<0.001) were greater than LB (64.5±7.6 kg), and MB was greater than ST (69.7±5.7 kg, p=0.006) (Figure 2). Body mass index (BMI) was not significantly different between positions (p=0.94).

Total and Regional Body Composition Characteristics by Position

Total LM was greater in MB (54.1±4.7 kg) compared to LB (45.9±4.9 kg, p<0.001) and ST (48.3±3.2 kg, p=0.002). Total LM was also greater in OH (55.7±4.6 kg) compared to LB (p<0.001) and ST (p=0.006) (Figure 3). Total FM was significantly greater in MB (20.9±6.8 kg) compared to LB (16.1±4.0 kg, p=0.019) (Figure 4). However, percent body fat (%BF) and percent lean mass (%LM) were not statistically significant (p>0.05) between positions (Table 1).

Regional body composition averages by position are presented in Table 1. Regional analyses yielded significant differences in lean and fat masses between positions, but regional %LM and %BF did not significantly differ by position (p>0.05). Trunk, arm, and leg LM were all significantly greater in MB compared to LB (p<0.001, all) and ST

(p=0.003, p=0.003, p<0.001, respectively). Trunk, arm, and leg LM were also all significantly greater in OH compared to LB (p<0.001, all) and ST (p=0.03, p=0.004, p=0.009, respectively). Leg FM was significantly (p=0.002) greater in MB compared to LB. However, trunk FM, arm FM, and VAT mass were not significantly (p>0.05) different between positions.

Positional body composition ratios can be found in Table 2. All but one body mass distribution ratio yielded significant differences between positions. Ratios for ULR, GLR, and LULLR were all significantly (p<0.001, all) lower in MB compared to LB. Similarly, ULR (p=0.02), GLR (p=0.02), and LULLR (p=0.01) were all significantly lower in OH compared to LB. The ULR (p=0.043) and GLR (p=0.021) were also significantly lower in MB compared to ST. The TULLR position specific differences were trending towards significance (p=0.054). There were no significant differences in body composition ratios (p>0.05) between MB and OH, ST and OH, or ST and LB.

Total BMD averages by position are presented in Figure 5. After adjusting for body mass, total BMD was significantly greater in MB (1.39±0.10 g/cm^2, p<0.001) and OH (1.41±0.09 g/cm^2, p=0.002) compared to LB (1.30±0.08 g/cm^2). Prior to adjusting for body mass, significant differences were also detected between ST (1.31±0.07 g/cm^2) and OH (p=0.022). Table 3 presents positional averages for leg, spine, and arm BMD measures. Leg BMD was greater in MB compared to LB (p<0.001) and ST (p=0.004). Similarly, OH had greater leg BMD compared to LB (p=0.01) and ST (p=0.008). Spine BMD was greater in MB (p=0.02) and OH (p=0.01) compared to LB. No significant differences (p>0.05) were observed between positions in arm BMD.

Average Pre- to Post-Season Body Composition Differences in Sub-Set

Data for pre- and post-season averages for body mass, total LM, and regional FM and LM for trunk and legs for a sub-set of players (n= 39) is displayed in Table 4. The sub-set was not significantly different (p>0.05) for all analyzed variables compared to the total sample. Average total FM for the pre-season was 18.0±4.2 kg, which decreased to 17.2±3.8 kg in the post season (p=0.011, r=-0.29) (Figure 6). At an adjusted significance level (p>0.007), leg FM (p=0.001, r=-0.36) was the only variable that was significantly lower between pre- (7.4±1.7 kg) and post-season (7.0±1.4 kg) (Figure 7).

CHAPTER 5: DISCUSSION

This study expands upon previous research by providing position specific normative values for total and regional body composition measurements for female collegiate NCAA Division I volleyball players using DXA. The positional analyses yielded significant variance in total and regional body composition measures. As hypothesized, differences were observed in LM, BMD, and mass distribution ratios between front row and back row, positions. Also, as hypothesized, pre- to post-season body composition changes were not statistically significant at an adjusted level of significance ($p>0.007$), with the exception of leg FM.

As expected, height and body mass were statistically significant between positions. Differences in height between MB, OH, and LB are likely the result of differing positional demands. Front row players need to be taller to reach over the top of the net when they jump in order to be proficient at blocking, a defensive action, and attacking, an offensive action. Liberos do not need to be as tall because they are defensive players in the back row that primarily dig and pass. Setters play in the front and back row, and are required to both block and dig. Therefore, it is not surprising that their average height and body mass measures lie between those of front row players and LB.

On average, measures of total FM, LM, and %BF for all positions were between those found in previous DXA studies (Carbuhn et al., 2010; P. R. Stanforth et al., 2014). The mean total FM measures identified by Stanforth et al. (2014), this current study, and Carbuhn et al. (2010) were 16.4±0.4 kg, 19.1±5.6 kg, and 21.8±4.1 kg, respectively. Mean total LM measures were 53.3±0.6 kg (P. R. Stanforth et al., 2014), 52.4±5.9 kg (current

study), and 51.2±4.4 kg (Carbuhn et al., 2010). Lastly, mean %BF was 22.5±0.5% (P. R. Stanforth et al., 2014), 25.3±4.8% (current study), and 28.4±4.7% (Carbuhn et al., 2010).

Positional analyses from the current study revealed greater total LM in front row players compared to non-front row players, and greater FM in front row players compared to LB. Greater total LM in front row players has also been observed in previous studies of professional volleyball players (Malousaris et al., 2008; Martín-Matillas et al., 2014). Malousaris et al. (2008) found that liberos had significantly lower FFM (49.2±2.7 kg) compared to hitters, comparable to OH in the current study, and centers (55.3±5.6 kg, both, $p>0.001$), comparable to MB. An analysis by Martín-Matillas et al. (2014) revealed that opposites, centers, and hitters all had significantly greater calculated SMM compared to liberos ($p<0.05$). They also found that centers and opposites had significantly greater calculated SMM compared to setters. However, after adjusting FFM for stature, FFM was not significant between positions. Similar to the current study, Martín-Malousaris et al. (2008) and Matillas et al. (2014) did not identify a significant difference in %BF between positions ($p>0.05$, $p=0.211$, respectively). Percent body fat similarities observed across positions imply that body composition differences observed in the current study are influenced by height. A significant relationship was observed between total LM ($p<0.001$) and height, however, a significant relationship was not observed between height and total FM ($p=0.28$).

On average, regional LM was consistently greater among front row players compared to non-front row players, but FM was not. The regional analysis of leg, trunk, and arm LM and FM demonstrated a consistent pattern between front row and non-front

row positions. Leg, trunk, and arm LM were all significantly greater in front row players compared to non-front row players. Leg FM measures were not significantly different across positions with the exception of MB being greater than LB. Trunk and arm FM were also not significantly different across the positions.

Differences observed between positions in leg LM could potentially be attributed to hypertrophic muscle adaptations that take place as a result of the repeated impact of eccentric jumping actions during attacking and blocking movements (LaStayo et al., 2003). However, these differences appear to be primarily influenced by height differences between positions. Compared to non-front row players, front row players have a greater total mass in addition to greater height. Taller individuals have longer bones and muscles, therefore, they would be expected to have greater muscle mass (Janssen, Heymsfield, Wang, & Ross, 2000). This indicates longer limb lengths may be a factor contributing to the greater regional mass in front row positions compared to non-front row positions. In addition, regional %BF and %LM were not significantly ($p>0.05$) different across positions, indicating similar regional body composition. Further analyses confirmed that there is a significant relationship between height and regional leg LM ($p<0.001$) as well as trunk LM ($p=0.001$). However, significance did not persist between height and arm LM or regional FM ($p>0.05$).

Regional and total BMD measures varied significantly across positions. Without adjustment, total BMD was significantly greater in front row positions compared to non-front row positions ($p<0.001$). After adjusting for body mass, significance persisted between front row positions and LB ($p<0.001$), but not ST ($p>0.05$). Previous studies have

observed a positive association between BMD and body weight ($p<0.01$) (Fehily, Coles, Evans, & Elwood, 1992; Henderson, Price, Cole, Gutteridge, & Bhagat, 1995). Therefore, BMD was adjusted for mass to allow for comparison across positons due to the sizeable range of masses (46.8-101.3 kg). Previous studies also determined that LM explains approximately 28.3% of total skeletal BMD ($p<0.001$) (Valdimarsson, Kristinsson, Stefansson, Valdimarsson, & Sigurdsson, 1999). In the current study, a significant relationship was observed between total LM and total BMD ($p<0.001$). Front row players have a greater amount of LM, which contributes to their greater BMD measures. Leg BMD was also significantly greater among front row players compared to non-front row players. Conjointly, spine BMD was significantly greater in MB and OH compared to LB. There were no significant differences observed in arm BMD across positions.

Significant positional differences observed across regional BMD measures in conjunction with adjusted total BMD measures indicate that the differences between front and back row positions may lie in lower body BMD. Observed positional BMD differences may be influenced by repeated impacts of jumping during the attacking and blocking actions of front row players (Kato et al., 2006). This finding is in line with previous research. Greater adjusted, lumbar spine, and leg BMD were detected in sports where athletes engaged in high magnitude, short duration actions in which ground forces are applied, such as jumping in volleyball (Fehling, Alekel, Clasey, Rector, & Stillman, 1995). Athletes involved in sports with large doses of high impact movements are exposed to high rates of bone strain which promotes osteogenesis (Carbuhn et al., 2010; Heinonen et al., 1995; D. Stanforth et al., 2016). Further, greater muscle cross-sectional area and tension

development in the lower leg is associated with greater BMC (Rittweger et al., 2000). This may explain, in part, the greater leg, spine, and adjusted BMD observed in front row players.

Mass distribution ratios varied significantly by position. These ratios are relative to each athlete, which allows for comparison of type and distribution of mass across positions, similar to %BF. Interestingly, unlike the lack of differences in both total and regional %BF across positions, the distribution of mass does vary significantly between positions. The significant positional differences observed indicate that there may be an ideal mass distribution for each position. Front row players had consistently lower mass distribution ratios compared to non-front row players in ULR, GLR, and LULLR.

Findings from the ULR analysis indicate that back-row players had greater upper body mass compared to front row players, and setters fall between the two groups: LB had the greatest ULR followed by ST, OH, and MB. Non-front row players had a higher GLR compared to front row players indicating that they carry more lean mass in their glutes compared to their legs: LB and ST had the same GLR, which was greater than OH and MB. Lastly, LULLR is the trunk and arm lean mass divided by the leg lean mass. Positional analysis revealed that front row players have a greater amount of lean mass in their legs compared to back row players, demonstrated by LULLR: LB had the greatest ratio, followed by ST, OH, and then MB. These findings also suggest that lean mass distribution in front row players is more evenly dispersed between the upper and lower body. Mass distribution influences how athletes move through space, although, further research is needed to establish the relationship between mass distribution and performance variables.

Compared to the pre-season, total and leg FM were the only variables analyzed with notable effect sizes in the post-season. A small effect size was observed (r=-0.29) from pre- to post-season in total FM, suggesting that ~88% of volleyball players within the sample experienced a trivial reduction in FM. This was reflected in a ~1% reduction in mean %BF from the pre- (24%) to post (23%) season. There was a moderate effect size (r=-0.36) for leg FM, which indicates that ~95% of players experienced a trivial reduction in leg FM from the pre- to post-season. No significant pre- to post-season differences were observed between positions (p>0.05). Carbuhn et al. (2010) also detected a significant reduction in total FM from the pre- to post-season (21.8±4.1 kg to 20.2±3.9 kg, p<0.05). Additionally, they observed an insignificant decrease in %BF from 28.4% to 27.1%. On the other hand, Stanforth et al. (2014) did not detect a significant change in total FM from pre- to post-season in year 1, however they did observe a significant increase in adjusted total LM (52.0±0.8 to 52.8±0.8 kg, p<0.05). The significant increase in LM was observed across multiple seasons as well (P. R. Stanforth et al., 2014). Similar to the current study, Stanforth, et al. (2014) observed an insignificant decrease in %BF from 22.7% to 22.2%. The results from this study, combined with the findings from Carbuhn et al. (2010) and Stanforth, et al. (2014), suggest that NCAA Division I volleyball players experience a reduction in %BF across the course of a season due to a reduction in FM and/or an increase in LM. The findings from this current study suggest that these changes may result from changes in lower body mass.

Importance and Implications of Findings

Data from this study constitute a compendium of position specific athlete profiles of total and regional body composition measures from NCAA Division I collegiate volleyball players. It also offers insight into body composition changes that occur after a competitive season. This compendium offers position specific body composition measures from high ranking NCAA Division I teams (NCAA, 2017). It can be used as a guide for coaches during recruitment, or for assessing positional suitability. It can also be used by strength and conditioning coaches to create effective athletic training programs and measure their progress by monitoring changes in total and regional lean and fat mass. In addition to creating positon specific normative data, pre- to post season changes were also analyzed. Tracking body composition changes over time can be beneficial for assessing training program success, guiding athlete health decisions, and assessing nutritional interventions. Implementing long-term body composition tracking throughout the career of an athlete may enable practitioners to detect if these changes are more typical in specific positions, if they continue across a collegiate career, and if they primarily occur in new players that have not undergone stressful training regimens.

Limitations of the Present Study

Limitations of the current study include potential technician testing variation, athlete compliance, lack of controlled scan dates, initial scan age variation, unequal position groups within the sample, lack of information about starters and playing time, inability to discern different combinations of body composition distributions on an individual level, and the lack of performance data. Lack of information about playing

time, player statistics, and which players hold starting positions hinders the ability to identify optimal body composition for successful players. Another weakness in large group observations is the fact that the means of the total and regional body composition measures for each position are utilized. This does not allow for the identification of successful individual combinations of body composition distribution. Lastly, the data cannot be directly linked to the performance of these players.

Future Directions

Future studies should look at the relationship between body composition and performance metrics over time, create a competitive ranking of players, observe changes in body composition in relation to physiological and mechanical loading, and increase the number of setters within the sample. In order to investigate the relationship of body composition and performance variables by position, body composition would need to be tracked along with power, strength, and game performance measures to determine the correlation between the variables.

CHAPTER 6: CONCLUSIONS

In conclusion, this study provides a compendium of position specific normative profiles for total and regional body composition measurements for female collegiate NCAA Division I volleyball players using DXA. Body composition measures varied significantly by position. Albeit, similar total and regional %BF across positions indicates that differences are influenced by height ($p<0.001$). Notwithstanding, differing body mass distribution ratios indicate that while %BF is similar in each region, the distribution of mass between the upper and lower body varies in conjunction with positional demands. Front row players have a greater amount of lean mass in their legs compared to non-front row players, indicating that lean mass distribution is more evenly dispersed between the upper and lower body in front row players. Additionally, greater total BMD, leg BMD, and spine BMD identified in front-row players may be a byproduct of positional demands for repetitive jumping during repeated attacking and blocking. The pre- to post-season analysis demonstrated a minimal, but significant, decrease in leg FM experienced by the majority of players across the course of a single competitive season. Tracking these changes over time will allow practitioners to assess the impact of training programs on athlete well-being. Furthermore, this position specific body composition compendium can be used by coaches for athlete talent identification, positional suitability, and for creating and evaluating effective athletic training and nutritional programs. Future studies should track game performance metrics and establish a ranking system in order to determine the most successful body composition profiles within each positon. They should also track physiological performance metrics in conjunction with DXA body composition measures to establish the relationship between sports performance outcomes and body composition

in volleyball players. Body composition should be continuously tracked over time to evaluate the effectiveness of performance and nutrition programs, additionally; longitudinal data can provide insight into the long-term impact of strenuous competition and training on developing athletes. Furthering the research in this area will assist in identifying successful and desirable player traits for each position, allowing the creation of ideal position specific player profiles.

Table 1. Positional Body Composition Characteristics

Position	LB (*n*=18)	MB (*n*=31)	OH (*n*=32)	ST (*n*=9)	P-value
Percent Body Fat (%)	24.7±4.2 (17.5-33.0)	25.7±5.8 (17.2-37.9)	24.9±4.4 (15.3-33.9)	26.5±3.9 (19.8-33.1)	0.744
Trunk Lean Mass (kg)	22.1±2.3[a] (17.2-26.3)	26.0±2.0[b] (22.6-30.4)	25.3±2.3[b] (21.9-31.2)	23.1±1.4[a] (21.6-25.4)	<0.001
Trunk Fat Mass (kg)	6.9±1.9 (2.8-10.5)	9.0±3.6 (4.4-16.8)	8.1±2.7 (3.9-13.8)	8.2±2.2 (5.1-11.8)	0.111
Legs Lean Mass (kg)	15.7±2.0[a] (12.6-18.9)	20.4±2.1[b] (16.5-24.9)	19.4±2.1[b] (15.2-22.8)	17.0±1.3[a] (15.5-19.1)	<0.001
Legs Fat Mass (kg)	6.5±1.6[a] (3.6-9.4)	8.7±2.6[b] (5.4-14.8)	8.0±1.8[ab] (5.4-13.0)	7.2±1.3[ab] (5.2-9.1)	0.004
Arms Lean Mass (kg)	5.1±0.7[a] (3.9-6.2)	6.2±0.7[b] (5.1-7.8)	6.1±0.7[b] (4.6-7.4)	5.2±0.6[a] (4.5-6.4)	<0.001
Arms Fat Mass (kg)	2.0±0.7 (0.8-3.2)	2.3±0.7 (1.1-4.3)	2.3±0.6 (1.0-3.5)	2.4±0.5 (1.4-2.9)	0.342
VAT (g)	57.5±51.6 (0-160.0)	123±126 (0-465.3)	83.4±62.8 (4-232.0)	97.9±98.3 (3-322.0)	0.143

For each row, if a position does not share a letter it is significantly different ($p>0.05$).
Abbreviations: VAT= visceral adipose tissue, LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
All values reported as mean±SD, with range below.

Table 2. Positional Body Composition Ratios

Position	LB (*n*=18)	MB (*n*=31)	OH (*n*=32)	ST (*n*=9)	P-value
ULR	1.61±0.1[a] (1.49-1.87)	1.48±0.10[b] (1.29-1.66)	1.51±0.11[bc] (1.28-1.73)	1.59±0.07[ac] (1.51-1.7)	0.004
TULLR	2.38±0.2 (2.08-2.76)	2.22±0.24 (1.75-2.78)	2.25±0.21 (1.83-2.73)	2.37±0.18 (2.08-2.76)	0.054
LULLR	1.73±0.09[a] (1.58-1.91)	1.59±0.1[bc] (1.33-1.74)	1.63±0.12[bc] (1.38-1.88)	1.67±0.06[ac] (1.57-1.77)	<0.001
GLR	0.48±0.03[a] (0.43-0.53)	0.44±0.02[b] (0.38-0.50)	0.46±.04[bc] (0.39-0.54)	0.48±0.02[ac] (0.45-0.50)	<0.001

For each row, if a position does not share a letter it is significantly different at an adjusted (p<0.05).
Abbreviations: ULR = upper total mass (arms+trunk for fat, bone, lean mass) to total legs mass (fat, bone, lean mass), TULLR = total upper to lean legs ratio, LULLR = Lean upper to lean legs mass ratio, GLR = gynoid (glute) lean mass to lean leg mass ratio, LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
All values reported as mean±SD, with range below.

Table 3. Total and Regional Bone Mineral Density Positional Characteristics

Position	LB (*n*=18)	MB (*n*=31)	OH (*n*=32)	ST (*n*=9)	P-value
Arms BMD (g/cm^2)	0.92±0.14 (0.71-1.14)	0.97±0.11 (0.72-1.15)	1.0±0.13 (0.77-1.24)	0.91±0.09 (0.73-1.02)	0.105
Legs BMD (g/cm^2)	1.38±0.09[a] (1.22-1.57)	1.54±0.11[b] (1.31-1.81)	1.53±0.11[b] (1.33-1.74)	1.4±0.06[a] (1.34-1.53)	<0.001
Spine BMD (g/cm^2)	1.22±0.09[a] (1.08-1.34)	1.32±0.15[b] (1.02-1.74)	1.33±0.12[b] (1.13-1.6)	1.25±0.1[ab] (1.04-1.36)	0.008

For each row, if a position does not share a letter it is significantly different at an adjusted (p<0.05).
Abbreviations: BMD = Bone Mineral Density, LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
All values reported as mean±SD, with range below.

Table 4. Pre-Season to Post-Season Body Composition Characteristics

	Pre-Season (*n*=39)	Post-Season (*n*=39)	*d*	*P*-value
Body Mass (kg)	73.4±8.7	73.2±8.3	-0.02	0.676
Total Lean Mass (kg)	52.3±5.7	53.0±5.7	0.12	0.013
Trunk Lean Mass (kg)	24.7±2.6	24.9±2.7	0.09	0.218
Trunk Fat Mass (kg)	7.7±2.1	7.4±2.1	-0.14	0.150
Legs Lean Mass (kg)	18.5±2.5	18.9±2.4	0.15	0.008

Adjusted significance level ($p<0.007$).
All values reported as mean±SD.

Figure Legend

Figure 1. Box plot comparing height (cm) by position

Figure 2. Box plot comparing body mass (kg) by position

Figure 3. Box plot comparing total lean mass (kg) by position

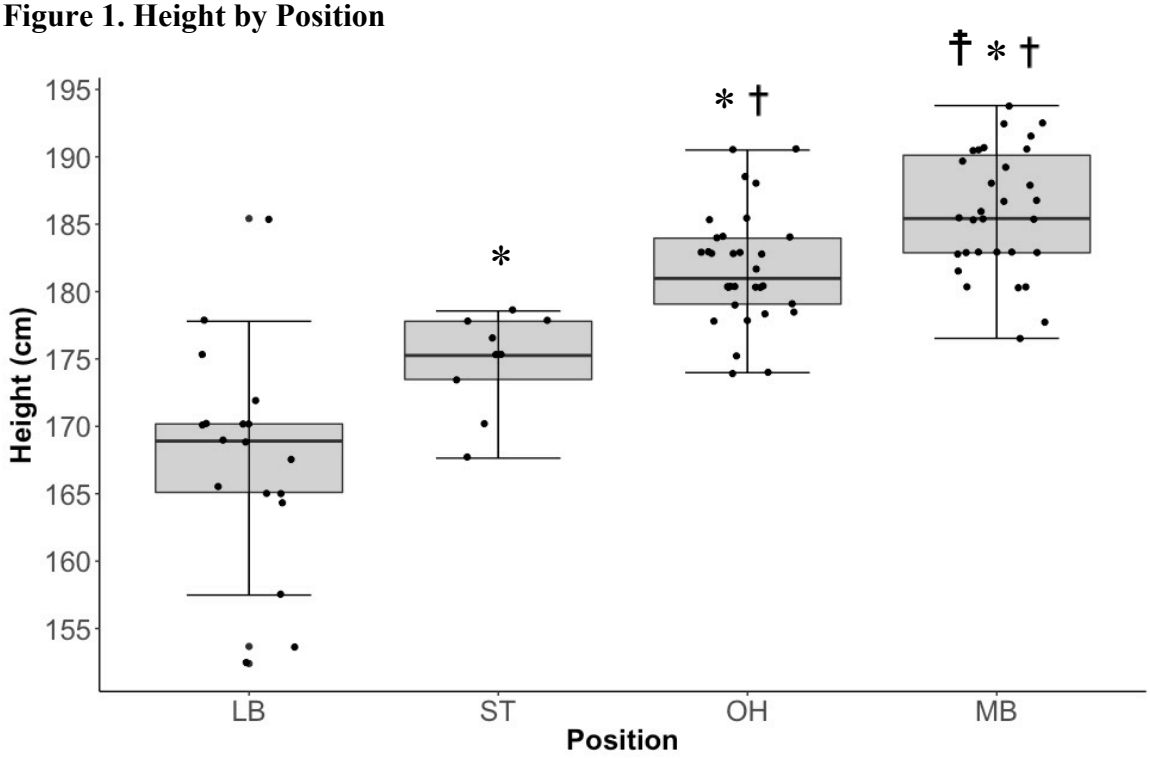
Figure 4. Box plot comparing total fat mass (kg) by position

Figure 5. Box plot comparing total bone mineral density ($g/cm^{2)}$ by position

Figure 6. Bar graph depicting pre- to post-season change in total fat mass (kg) for individual players

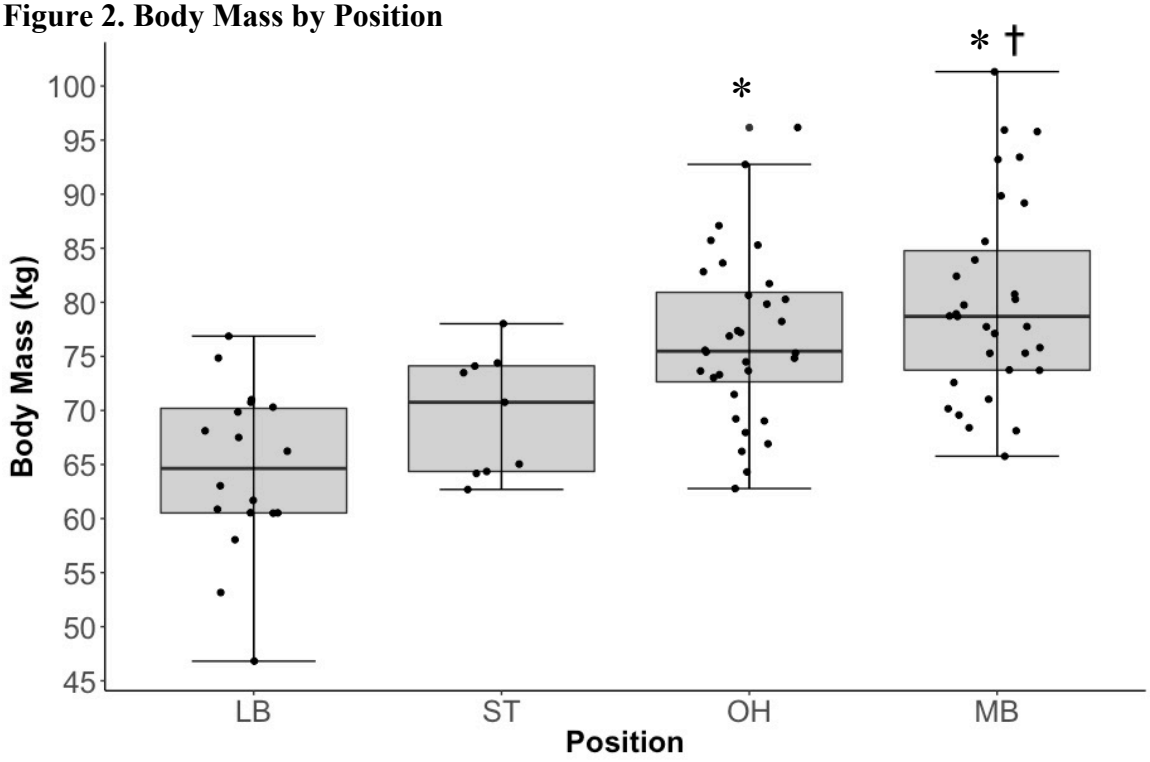
Figure 7. Bar graph depicting pre- to post-season change in legs fat mass (kg) for individual players

Figure 1. Height by Position



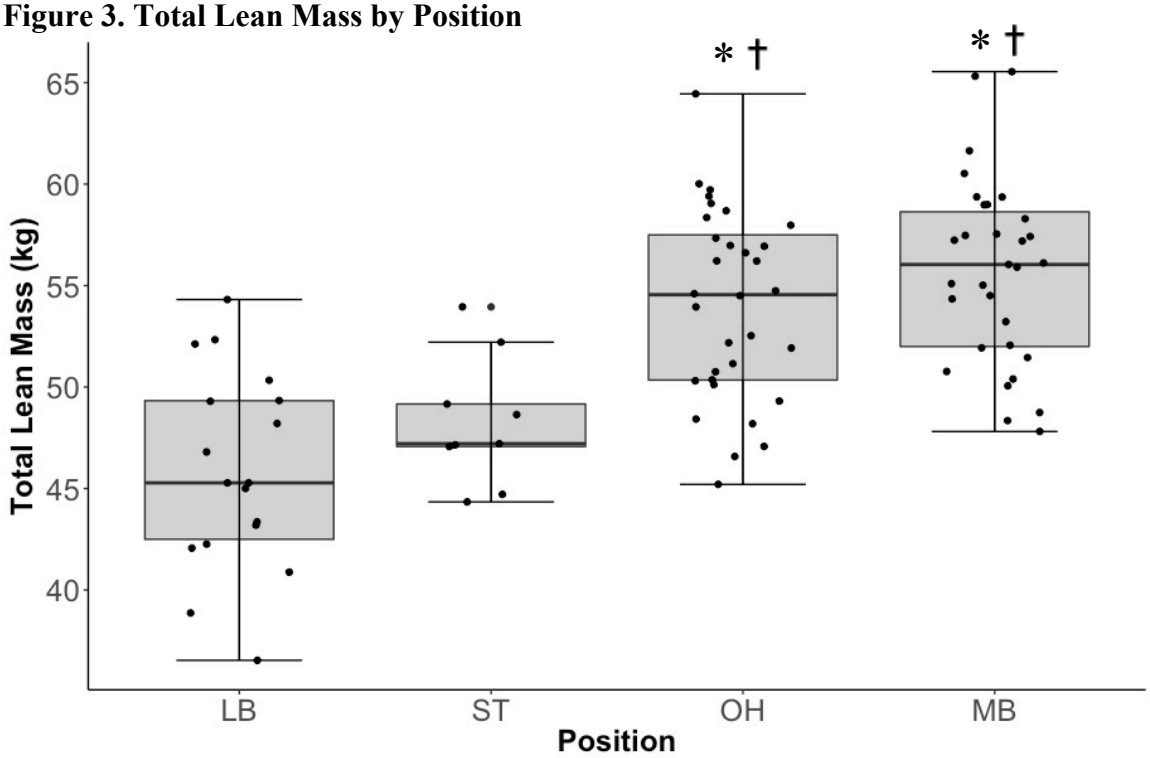
Boxplots represent the first quartile, median, and third quartile with standard error [SE] bars. Each • represents one individual player. Box plots are ordered by mean. Abbreviations: LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
* = significantly different from LB, † = significantly different from ST, ‡ = significantly different from OH, (p<0.05).

Figure 2. Body Mass by Position



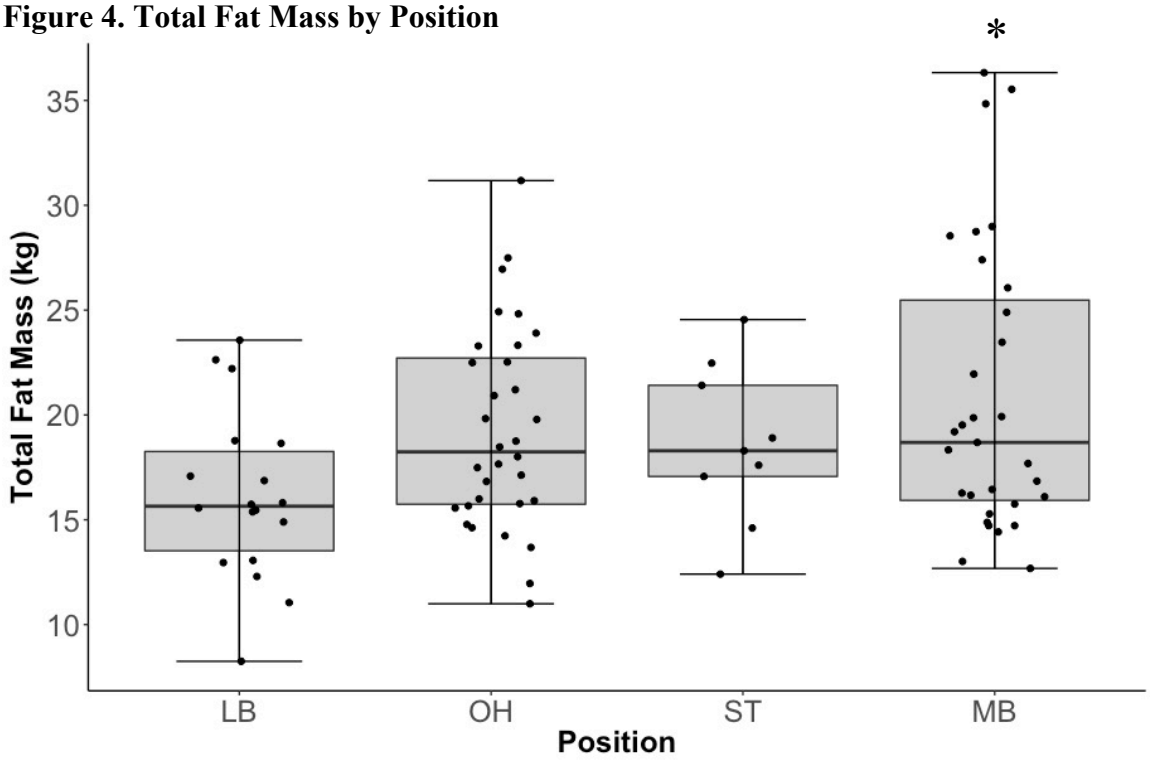
Boxplots represent the first quartile, median, and third quartile with standard error [SE] bars. Each • represents one individual player. Box plots are ordered by mean.
Abbreviations: LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
* = significantly different from LB, † = significantly different from ST, (p<0.05).

Figure 3. Total Lean Mass by Position



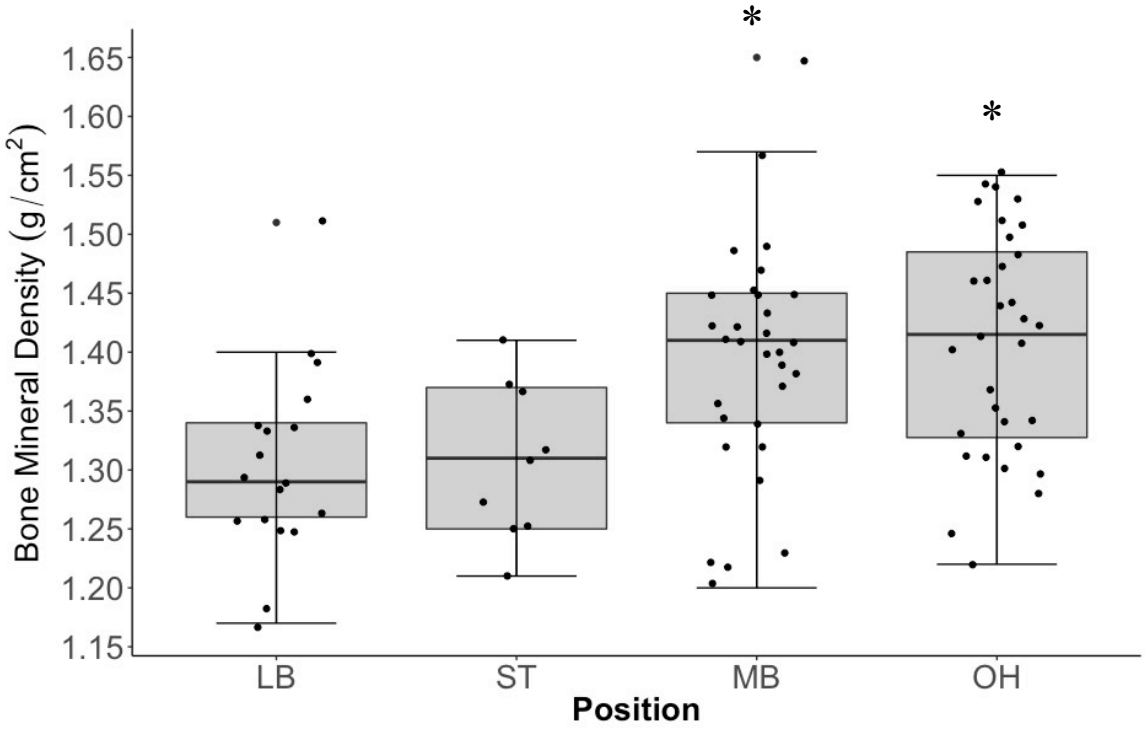
Boxplots represent the first quartile, median, and third quartile with standard error [SE] bars. Each • represents one individual player. Box plots are ordered by mean.
Abbreviations: LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
* = significantly different from LB, † = significantly different from ST, (p<0.05).

Figure 4. Total Fat Mass by Position



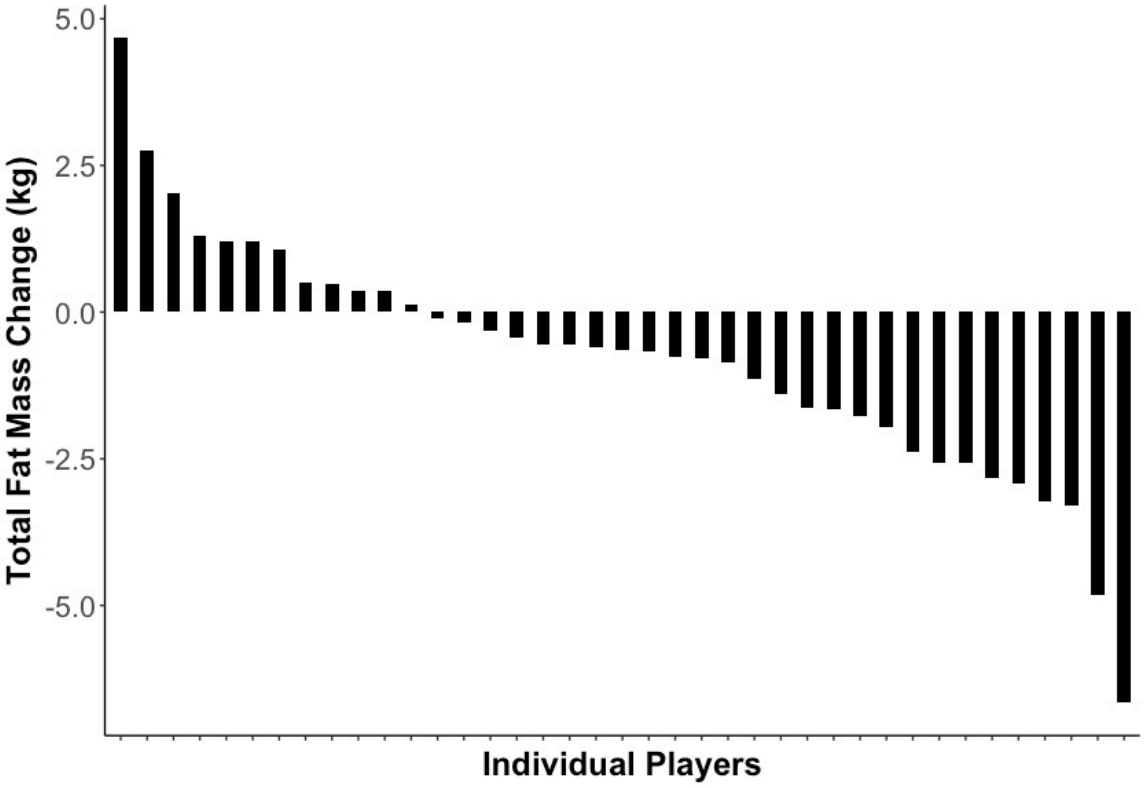
Boxplots represent the first quartile, median, and third quartile with standard error [SE] bars. Each • represents one individual player. Box plots are ordered by mean. Abbreviations: LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
* = significantly different from LB, (p<0.05).

Figure 5. Total Bone Mineral Density by Position



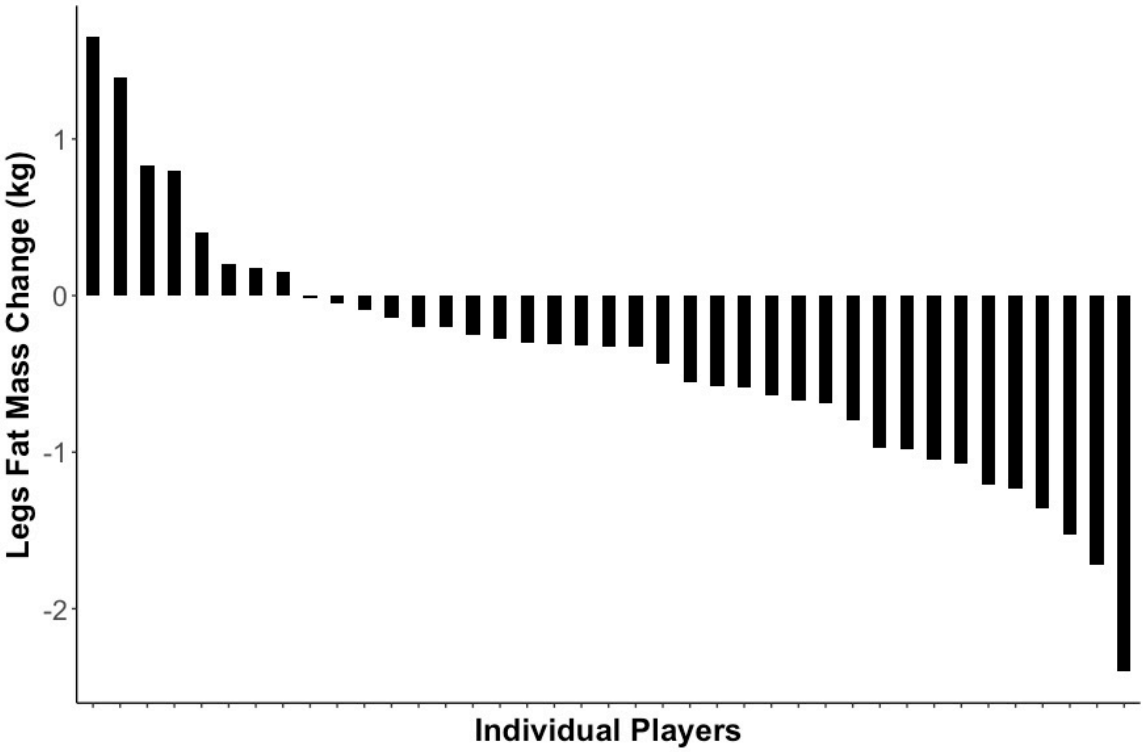
Boxplots represent the first quartile, median, and third quartile with standard error [SE] bars. Each • represents one individual player. Box plots are ordered by mean.
Abbreviations: LB = Libero, MB = Middle Blocker, OH = Outside Hitter, ST = Setter
* = significantly different from LB after adjusting for body mass, (p<0.05).

Figure 6. Pre- to Post-Season Changes in Total Fat Mass (kg) for Individual Players



Pre- to post-season changes in total fat mass (kg) calculated by subtracting pre- from post season. Each bar represents the seasonal change in one individual player, ordered by change.

Figure 7. Pre- to Post-Season Changes in Legs Fat Mass (kg) for Individual Players



Pre- to post-season changes in legs fat mass (kg) calculated by subtracting pre- from post season. Each bar represents the seasonal change in one individual player, ordered by change.

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