Dual-Energy X-Ray Absorptiometry Body Composition in NCAA Division I Athletes: Exploration of Mass Distribution

Jennifer Sanfilippo, BS, LAT,*[†] Diane Krueger, BS, CBDT, CCRC,[‡]
Bryan Heiderscheit, PT, PhD,[†§] and Neil Binkley, MD[†‡]

Background: Body composition assessment is frequently used in sports medicine and athletic performance environments to assess change in response to strength training and nutrition programs. However, to effectively do so requires knowledge regarding expected body composition values relative to sport and sex. Dual-energy x-ray absorptiometry (DXA) is widely used to evaluate body composition, although its utility in relationship to specific sports, performance, or rehabilitation is not clearly defined.

Hypothesis: Body composition metrics and distribution of National Collegiate Athletic Association Division I collegiate athletes will vary based on sport and sex.

Level of Evidence: Level 4.

Study Design: Cross-sectional study.

Methods: A convenience sample of 337 athletes (229 men and 108 women) participating in football, wrestling, soccer, hockey, basketball, golf, softball, or volleyball was evaluated. DXA-measured total body composition, including bone mineral density (BMD), % lean mass, % fat, and regional distribution, were compared by sex, sport, and with an age-matched National Health and Nutrition Examination Survey (NHANES) population.

Results: Men had higher BMD, lower % fat (16.4% vs 25.2%) and higher % lean mass (79.2% vs 70.6%) ($P < 0.001$). Regional composition varied by sport and sex, with women having a greater proportion of lean mass at the trunk and men in their arms ($P < 0.0001$). Leg lean mass was distributed similarly between sexes (35%). Overall, the normative group (NHANES) had lower BMD and higher percentage fat.

Conclusion: DXA-measured body composition and lean mass distribution varies by sport and sex in Division I athletes. The observed difference to the NHANES population emphasizes challenges in identifying appropriate comparison populations, reinforcing the need to compare athletes with their own baseline.

Clinical Relevance: These findings establish a framework to investigate the relevance of these variances and determine the utility of body composition analysis in elite athletes.

Keywords: lean mass; fat mass; body fat; collegiate

Dual-energy x-ray absorptiometry (DXA) is a well-accepted method to assess body composition[2,11] and is increasingly being used in the fields of sports medicine and sports performance.[15,35] An international survey conducted by the Medical Commission of the International Olympic Committee found that 38% of groups assessing body composition used DXA, second only to skinfold assessments.[28] Other techniques to assess body composition exist, and reports comparing and contrasting the methods have been published;[4,22] however, in-depth discussion in this regard is outside the scope of this study. DXA is rapid, relatively inexpensive compared with other imaging techniques, and uses only a small amount (effective radiation dose of 3 µGy per scan)[23] of ionizing radiation. Additionally, it allows for highly precise total and regional composition measurements, which may be important for evaluation of athletic performance, training regimens, or

From [†]University of Wisconsin Badger Athletic Performance Program, Madison, Wisconsin, [‡]University of Wisconsin Osteoporosis Clinical Research Program, Madison, Wisconsin, and [§]University of Wisconsin Orthopedics and Rehabilitation, Madison, Wisconsin

*Address correspondence to Jennifer Sanfilippo, BS, LAT, University of Wisconsin Badger Athletic Performance, 1440 Monroe Street, Madison, WI 53711 (email: js1@athletics.wisc.edu).

The authors report no potential conflicts of interest in the development and publication of this article.
DOI: 10.1177/1941738119861572

progress of rehabilitation postinjury.[6,10] This ability to evaluate not only total fat and lean mass but also mass in specific regions, such as the extremities, is a distinct advantage of DXA compared with other measures of body composition such as bioelectrical impedance or hydrodensitometry.[11]

Although the concept of assessing body composition in elite athletes is attractive, there are little data to guide how to fully integrate this measurement into performance and training programs. Most available data investigating body composition in elite athletes tend to focus on individual sports,[10,15] as only a few report comparisons between sports or longitudinal changes of athletes in a specific sport.[34,36] Some publications evaluating links between body composition and performance exist but, again, are limited to a specific sport and/or activity.[9,16] Additionally, none of these offers concrete recommendations as to specific training alterations in response to body composition measures. Perhaps a challenge to providing comprehensive guidance stems from the heterogeneity of elite athletes due to differences in sport and sex. For example, it is suggested that a least significant change for assessing biologic difference in serial scans of National Collegiate Athletic Association (NCAA) Division I collegiate athletes should be calculated using a population of similar size and body composition.[6] Least significant change is a precision calculation used to determine biological differences from method variance in serial scans. Therefore, characterizing the body composition differences between, or within, sport and sexes of elite athletes will serve as a platform by which to start assessing the role of DXA-measured body composition in relation to sport performance evaluation, training, or even injury prevention or rehabilitation assessment. Knowing normative values can help coaching and sports medicine staff identify undesirable changes that may lead to negative performance outcomes or potentially put the athlete's body at risk for injury. To this end, the purpose of this work is to describe DXA-measured body composition data in different sports and between sexes in Division I collegiate athletes and provide rudimentary comparison with a normal US population. These data may offer a foundation for researchers to further explore the mechanisms of the differences described in this work, and subsequent plans for use to create adaptive programing for improving performance.

METHODS

Participants

NCAA Division I collegiate athletes receiving DXA-measured body composition assessment as part of a preseason performance evaluation were utilized for this report. A convenience sample of 337 athletes (229 men and 108 women) participating in football, wrestling, soccer, hockey, basketball, golf, softball, or volleyball was evaluated. Mean (± SD) age was 20.0 (±1.6) years (range 17-27 years); for men 20.2 (±1.6) years with a mean body mass index (BMI) of 27.6 (±4.3) kg/m^2 and women 19.5 (±1.4) years with a mean BMI of 23.8 (±2.4) kg/m^2. Race was self-reported with a distribution of 270 identifying as Caucasian, 54 identifying as Black, and 13 identifying as other. The distribution by sex and sport is noted in Table 1; sports with athletes of both sexes include soccer, hockey, basketball, and golf. Body composition records were retrospectively accessed after approval from the University of Wisconsin–Madison's Health Science Institutional Review Board. Because this study was a record review, patient informed consent was not required.

Procedures

A GE Healthcare Lunar iDXA densitometer was used for all whole-body measurements and generated measurements of fat, lean, and bone as bone mineral content (BMC). All of these direct measures were reported as a percentage of total body mass. The latter is corrected for size by calculating the ratio of BMC/area, which equals bone mineral density (BMD). The lead technologist, trained by an International Society for Clinical Densitometry (ISCD)–certified technologist, acquired most scans and analyzed all in a routine clinical manner following standard operating procedures based on published recommendations.[21,32] To ensure acquisition uniformity, only one other technologist performed scans, who was trained by the lead technologist and followed protocols developed for this Division I athletic performance assessment facility. One physician with extensive total body DXA experience reviewed all scans to validate correct acquisition and analysis. Athletes were scanned in their usual hydration state after bladder voiding; no fasting or other limitations on their usual activities were implemented. All scans were acquired and analyzed using enCORE software version 14.1 (GE Healthcare). Scans were analyzed using the software auto analysis feature followed by manual correction of analysis markers when necessary to ensure appropriate identification of the trunk, arms, and legs. Athletes were fit to the scan field; some wide individuals were wrapped in wide cloth straps to allow inclusion of all tissue; no estimations were obtained using the hemiscan software feature. Athletes that exceeded the length of the scan field were positioned such that a portion of their head was excluded from measurement. Percentage coefficient of variation for total body DXA results from this performance center have been published elsewhere[6] and range between 0.07% and 1.46% for measurement of total body fat and lean mass, which falls within the ISCD-recommended range.[14]

Percentage BMC, lean mass, and fat mass were calculated in relationship to total body mass. Additionally, the distribution of lean mass in the legs, trunk, and arms was determined by calculating the percent lean measured at these sites in relationship to total body lean mass.

The DXA manufacturer's software provides the capacity to compare with various "normal" populations, and it has been our experience that individuals are interested in how they compare with "normal." To facilitate understanding of the utility of such comparisons in an athlete population, BMD and percentage fat mass data from an age- and sex-matched National Health and

Table 1. Demographics and body composition in athletes by sex and sport[a]

Sport	n	Age, y	Height, cm	Weight, kg	BMD Total, g/cm^2	BMC Total	Fat Total, g	Fat Total, %	Lean Total, g	Lean Total, %
Women (overall)	108	19.5 ± 1.4	170.9 ± 8.6	69.9 ± 9.4	1.277 ± 0.091	4.2 ± 0.4	17799 ± 5252	25.2 ± 4.9	49320 ± 5817	70.6 ± 4.6
Basketball	14	20.6 ± 1.6	180.5 ± 7.0	76.3 ± 12.6	1.313 ± 0.048	4.3 ± 0.4	18704 ± 9356	23.6 ± 7.5	54607 ± 4382	72.1 ± 7.2
Golf	10	20.7 ± 1.8	166.7 ± 4.7	64.6 ± 9.5	1.166 ± 0.054	4.0 ± 0.4	19956 ± 6865	30.2 ± 5.3	42190 ± 4274	65.8 ± 4.9
Hockey	22	20.1 ± 1.1	168.0 ± 5.3	69.8 ± 5.8	1.260 ± 0.071	4.1 ± 0.4	17548 ± 3567	25.0 ± 3.8	49454 ± 4274	70.9 ± 3.6
Soccer	26	19.8 ± 1.1	167.3 ± 6.8	65.3 ± 7.8	1.276 ± 0.105	4.3 ± 0.3	16227 ± 3527	24.5 ± 3.7	46686 ± 4917	71.2 ± 3.5
Softball	20	19.9 ± 1.3	168.6 ± 6.8	70.4 ± 9.3	1.303 ± 0.094	4.2 ± 0.4	17788 ± 5138	25.1 ± 4.7	49515 ± 5221	70.8 ± 4.5
Volleyball	16	20.1 ± 1.3	178 ± 10.1	73.6 ± 7.9	1.310 ± 0.086	4.2 ± 0.3	18574 ± 3424	24.8 ± 3.5	53005 ± 5175	71.0 ± 3.4
Men (overall)	229	20.2 ± 1.6	184.4 ± 8.4	94.5 ± 44.9	1.470 ± 0.133	4.4 ± 0.5	16193 ± 9080	16.4 ± 5.6	73843 ± 11503	79.2 ± 5.2
Basketball	16	20.1 ± 1.5	192.9 ± 8.9	92.1 ± 11.9	1.473 ± 0.108	4.8 ± 0.5	11092 ± 2468	12.2 ± 2.0	74836 ± 8325	82.9 ± 1.9
Football	117	20.6 ± 1.5	187.4 ± 7.0	105.9 ± 20.1	1.525 ± 0.116	4.3 ± 0.5	19734 ± 10797	17.9 ± 6.6	80550 ± 9577	77.9 ± 6.2
Linemen	32	20.3 ± 1.4	192.7 ± 6.1	131.6 ± 15.8	1.598 ± 0.107	3.7 ± 0.4	34147 ± 8707	26.0 ± 4.8	90131 ± 7707	70.3 ± 4.5
Nonlinemen	85	20.0 ± 1.5	185.4 ± 6.3	96.2 ± 10.9	1.497 ± 0.108	4.5 ± 0.4	14308 ± 4905	14.8 ± 4.1	76947 ± 7525	80.7 ± 3.9
Golf	9	20.2 ± 1.4	181.6 ± 6.2	76.7 ± 8.1	1.217 ± 0.093	4.1 ± 0.3	14917 ± 4365	19.2 ± 3.9	58325 ± 5521	76.7 ± 3.7
Hockey	26	21.7 ± 1.7	181.1 ± 6.8	85.9 ± 7.5	1.399 ± 0.089	4.4 ± 0.3	13314 ± 2888	15.2 ± 2.6	70007 ± 5686	80.4 ± 2.6
Soccer	30	21.0 ± 1.9	179.4 ± 2.3	76.7 ± 9.0	1.406 ± 0.101	4.7 ± 0.3	10746 ± 2877	13.7 ± 2.6	63518 ± 6760	81.6 ± 2.6
Wrestling	31	20.5 ± 1.5	177.0 ± 7.0	82.2 ± 5.4	1.459 ± 0.136	4.7 ± 0.4	13514 ± 6727	15.7 ± 4.7	65722 ± 10060	79.6 ± 4.5

[a]Data are presented as mean ± SD. BMC, bone mineral content; BMD, bone mineral density.

Nutrition Examination Survey (NHANES) cohorts were included to allow comparison of these athletes with a normal US population. The cohort is composed of NHANES data utilized by the manufacturer as normative databases. For this comparison, it was composed of 1174 athletes aged 18 to 24.5 years from the 1999-2004 NHANES sample as characterized in the University of California, San Francisco, final study report.[5] As these data were collected on Hologic instruments, GE Lunar software converts raw data to Hologic equivalent values using validated equations.[12]

Statistical Analyses

Sport and sex differences related to each body composition metric were evaluated with factorial analysis of variance ($P < 0.05$). Our data were compared with NHANES data using a Z-test. Analyses and box plots were generated with StatView v 4.5 (Abacus Corp.). Evaluation of differences in variance were assessed using F test in Microsoft Excel.

RESULTS

Whole Body Composition

Over twice as many men were included in the sample than women, as 117 football players comprised 35% of this cohort. Overall, men had higher BMD (1.470 vs 1.277 g/cm^2), percentage BMC (4.4% vs 4.2%), and a greater percentage lean mass (79.6% vs 70.6%), while women had a greater percentage fat mass (16.4% vs 25.2%) (all $P < 0.01$) (Table 1).

Body composition differences by sport were observed for both men and women ($P < 0.01$). In women, the only BMD difference was a lower value in golfers. BMD differences were also seen in men with male golfers having lower values than all other groups. Additionally, between-sport differences were present with football players having higher BMD than hockey and soccer players ($P < 0.01$) and wrestlers having greater BMD than hockey athletes ($P < 0.04$) (Figure 1). Certain sports also demonstrated substantial BMD variance among the athletes. In men, basketball had greater variation than golf or hockey but less than football ($P < 0.05$). In contrast, women demonstrated a lesser variance in basketball compared with softball, soccer, and volleyball ($P < 0.05$).

Both men and women demonstrated differences in mean percent body fat by sport ($P < 0.05$). For example, percent body fat in women was highest in golf, and not significantly different between any other sports. Men were more diverse with basketball and soccer having lower percent body fat than all other sports ($P < 0.05$) and football and golf were both higher than hockey ($P < 0.05$) (Figure 2). Differences in extent of athlete variation within sport was also observed in percent fat. Notably, greater variance ($P < 0.05$) was seen in women's basketball, with a standard deviation of 7.5% compared with hockey, softball, soccer, and volleyball, for which the standard deviation ranged from 3.4% to 4.6%. Men demonstrated a wide range of percent fat by sport (12.2% to 19.2%), with higher SDs in football and wrestling, 6.6% and 4.7% respectively, compared with basketball, hockey, and soccer at 2.0% to 2.6% ($P < 0.05$). Additionally, football percentage fat variation was greater than wrestling ($P > 0.05$). As would be expected, an inverse relationship was seen with percentage lean mass, and identical trends as described for percentage fat were observed ($P < 0.05$).

Overall, women had a higher proportion of their lean mass within the trunk compared with men (48.3% vs 46.7%, respectively), while men demonstrated greater distribution of

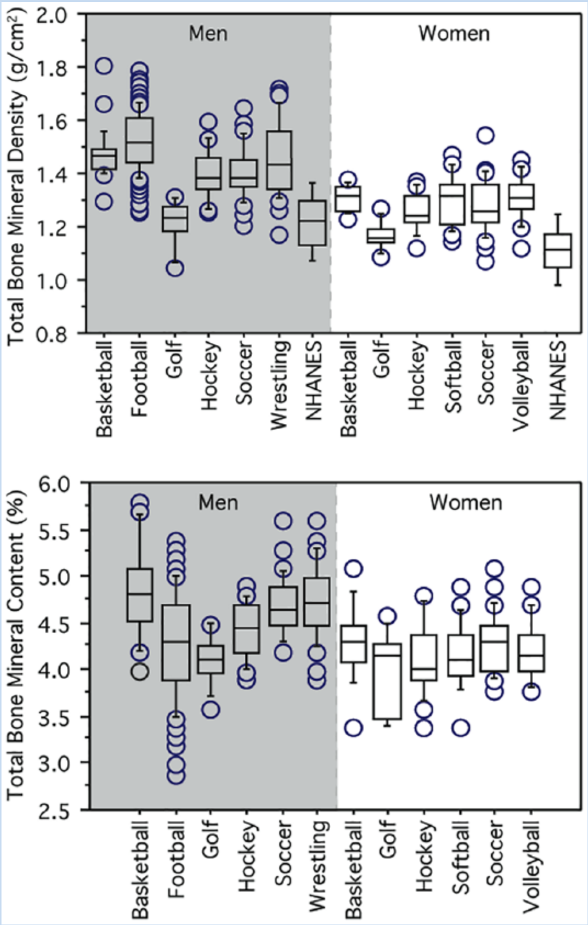

Figure 1. Total body bone parameters by sex and sport. Box and whisker plots are used to illustrate the mean total body bone parameters (total BMD [top]; total bone mineral content as a percentage of total body mass [bottom]) by sex and sport, and the corresponding variance. The NHANES male and female normative data used by GE Lunar for this age group are added for reference in the BMD plot. This demonstrates that the athletes tend to have higher BMD ($P < 0.001$) than "normal," highlighting the low utility of a general population reference for athletes. The box represents the 25th to 75th percentile with the midline being the median. The whiskers represent the 10th and 90th percentile with the circles depicting outliers. BMD, bone mineral density; NHANES, National Health and Nutrition Examination Survey.

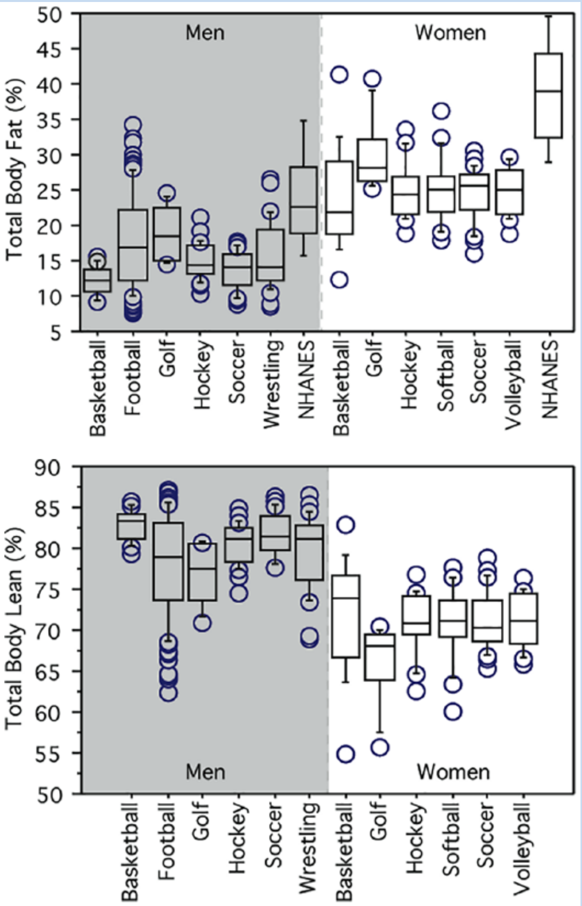

Figure 2. Total body composition by sex and sport. Box and whisker plots are used to illustrate the mean total body soft tissue composition (% fat [top] and lean [bottom] mass of total body mass) parameters by sex and sport, as well as the corresponding variance. Women have greater fat mass (%) than men, with men having greater lean mass (%) ($P < 0.001$). Variability in the body composition across sports was more evident in men, as only golf differed from the other women's sports. The athletes tend to have lower % fat ($P < 0.001$) than the comparative NHANES normative data used by GE Lunar, highlighting the low utility of a reference for body composition. The box represents the 25th to 75th percentile with the midline being the median. The whiskers represent the 10th and 90th percentile with the circles depicting outliers. NHANES, National Health and Nutrition Examination Survey.

lean mass at the arms (13.1% vs 10.2%) ($P < 0.01$). No difference was observed at the leg site with men on average having 35.4% of their lean mass in their legs and women 35.5%. Women demonstrated variation of lean mass distribution at all sites in all sports ($P < 0.01$), although the range of difference between sport by site did not exceed 2.3% (Figure 3). Sport differences in lean mass distribution were only observed at the arms and legs in men ($P < 0.05$), with no variation exceeding 1.6%.

When comparing these athletes with a normal US population using age- and sex-matched NHANES data, the mean BMD was higher and mean percentage fat lower among these athletes. Specifically, both sexes had higher BMD ($P < 0.01$; males, 1.470 vs 1.216 g/cm^2; females, 1.277 vs 1.107 g/cm^2) and a lower percentage fat ($P < 0.01$; males, 16.4% vs 22.7%; females, 25.2% vs 38.6%), than the NHANES sample (Table 1; Figures 1 and 2). In summary, for men and women in all sports, excluding golf, the NHANES mean BMD was lower (by 14% to 25%) and mean percentage fat higher (by 21% to 46%), depending on sex and sport.

DISCUSSION

Body composition and lean mass distribution precisely measured by DXA is variable by sex and sport in Division I collegiate athletes, with some sports showing considerable within-sport variation. For example, athletes participating in football and wrestling not only differ in body composition when compared with other sports but also demonstrate substantial variability within their respective sport. This within-sport variation is likely a reflection of the different physical requirements of various positions in football, or it may simply be due to size, as is likely the case with wrestlers. Indeed, position-specific differences in total and regional lean and fat mass has been observed in collegiate and professional football players and collegiate softball players.[10,31,33] Women displayed more homogeneous body composition values across sports compared with men with some noticeable differences in the basketball players and golfers, which agrees with previous research looking at total body values across sports.[34] Such between- and within-sport differences make comparison with "normal" body composition values largely irrelevant. Moreover, athletes differ substantially from a "normal" population. For example, using the NHANES reference data, the mean BMD was 14% to 25% higher and percentage body fat values 21% and 46% lower for all teams, demonstrating that this sample differed substantially from the "normal" population.[17] The fact that the athletes are so different from a normative population, and even from each other, suggests that comparison with any existing reference population does not offer beneficial information from a sport performance standpoint. It appears that sport-, sex-, and perhaps position-specific databases should be developed to optimize use of normative data comparisons. Alternatively, it may be more appropriate to implement personal goal setting and compare athletes with their own baseline or prior measurements.

Not surprisingly, male and female athletes have different body composition of bone, fat mass, and lean mass.[25] Previous findings also suggest males have greater BMD, percentage BMC, and percentage lean mass than comparable females.[6] The greater BMD observed in men likely reflects the fact that male bones are larger than female bones. Specifically, as DXA is an areal measurement, that is, g/cm^2, larger bones of identical volumetric composition will impart a higher BMD as measured by DXA.[30] Additionally, as

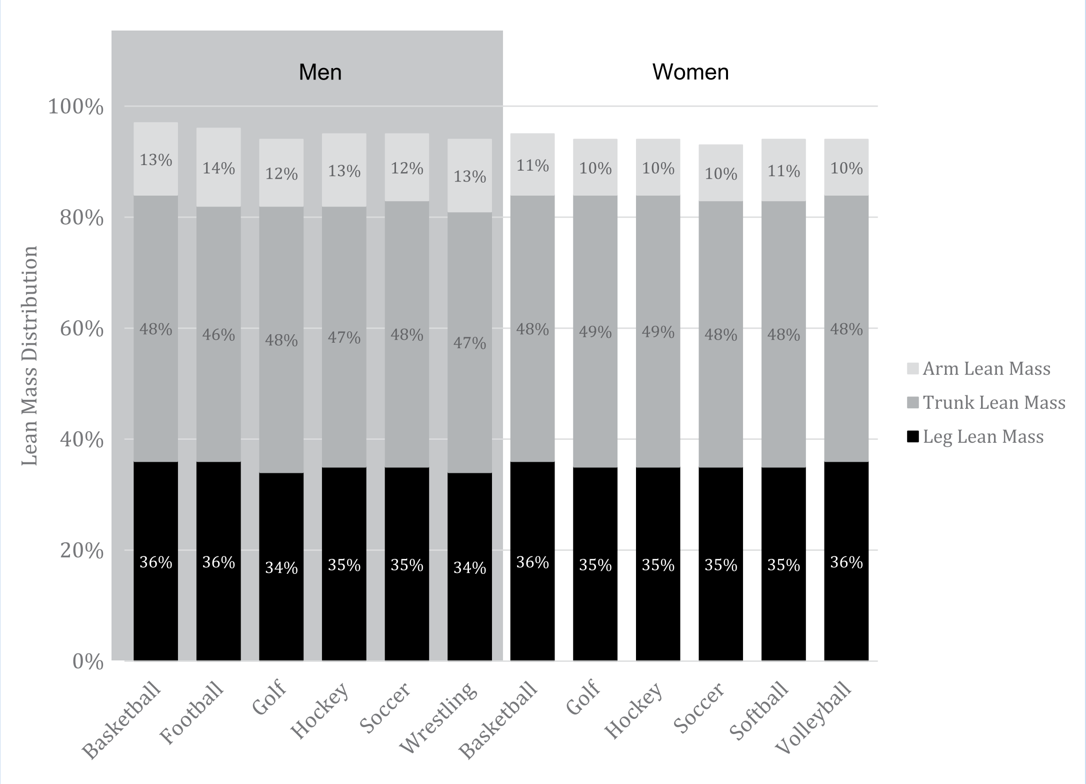

Figure 3. Distribution of percentage lean mass by sport and sex. The percentage of lean mass in the trunk is relatively stable by sex and sport, while the distribution in the arms and legs appears more variable across sport for men.

expected and widely previously reported, we found females to have a greater percentage fat mass than males.[19] Multiple physiologic mechanisms including sex steroid hormones, corticosteroids, and peptide hormones may explain this phenomenon.[3,26] These sex differences further reinforce the necessity of using sport-, sex-, and potentially position-specific normative databases when comparing athletes with a "normal" population.

From a whole body standpoint, the homogeneity of the female athlete is interesting; the only sport that differs in women is golf, with lower mean BMD and lean mass and higher fat percentage observed. Despite overall similarity, there is wide individual variance in lean and fat mass in the female basketball team. This finding is contrary to work by Carbuhn et al,[8] who observed intersport composition differences in female athletes participating in basketball, volleyball, and softball; with greatest differences in swimming and track athletes, the latter of which we did not study.[8] Perhaps the lack of significance in our data is due to the athletes or sports studied; it is plausible that inclusion of swimming, track, rowing, or tennis would demonstrate variations similar to those observed in the men. Body composition in men has been characterized in rugby, cricket, and football, but these are the first data to evaluate differences between a wide range of sports.[10,15] Football and wrestling, in particular, likely contributed to the between-sport difference observed, as participation in these sports necessitates a wide range of body sizes. Both sports have a wide size variation between athletes, small to large, and football additionally has differing physical requirements based on position. This variation in football players has been characterized[10]; however, the significance of how these differences affect performance evaluation or associated training modifications is unknown. Furthermore, within-team variation in body composition may be partially attributed to the year in school of the team members. Changes in body composition, in particular an increase in lean mass, has been demonstrated in athletes in some female collegiate sports across each year of competition and training.[36]

Despite overall similarity of whole body composition, differences in lean mass distribution were observed by sport in women and men. These small observed lean mass distribution differences may suggest that local lean mass is important for certain performance activities. Specific activities related to a sport (eg, throwing) likely lead to accumulation of lean mass to different regions (such as the arms), validating findings by others.[36] This may suggest that total body lean mass is linked to general movements, related to ambulation and function and less affected by repetitive or dominant use of a specific region related to an activity, such as running or swinging.

Body composition measurement is an important factor for sports medicine and sports performance, with high utilization by a variety of related professions.[28] Very low body fat mass and extreme mass fluctuations have been a common focus within sports medicine communities, especially as it relates to female athletes.[29] Relationships between body composition and injury in collegiate athletes have only begun to be investigated.[7,13,37] Furthermore, strength and conditioning programs are typically designed with the underlying goal of optimizing the amount and distribution of lean mass as it relates to the sport or position.[1,27] Our findings may be useful to these groups by characterizing the degree of difference in body composition that exists between various collegiate sports and by recognizing the variability between athletes within certain sports. This variability emphasizes the necessity of evaluating an individual's change over time compared with one's own baseline data when monitoring for the effects of conditioning/training, and also potential health ramifications such as the female athlete triad. Such monitoring requires high-quality DXA performance[20] and knowledge of least significant change.[6]

Finally, this work emphasizes the lack of utility in comparing athletic populations with a "normal" population. Importantly, the US population has experienced an epidemic of obesity over the recent decades, thus comparing percentage fat of elite athletes with an obese quasi "normal" population will provide little to no insight into how an athlete compares with his or her athletic counterparts. Such futility of comparing with existing normative populations further emphasizes the need to develop sport-specific normal population data or utilize personal goal setting.

Limitations of this study include a relatively small sample size within each sport and sex. The large number of football players offers less power when one begins to segment the group by size or position. Additionally, although this study offers the largest number of sports evaluated together, only 8 were evaluated, which does not span the full diversity of athletic activities; for example, inclusion of gymnasts, track/field, swimming, or tennis athletes might have offered more diversity of the groups. The implications of the body composition differences reported here have not been linked to any sports-related performance outcome. Furthermore, this sample is composed of Division I collegiate athletes, a group of relatively elite individuals. Whether these findings are applicable or will be relevant for a midlevel or recreational athlete is unknown. These data were included in some comparisons to offer reference of how these athletes measure in relationship to a US population. Finally, it is important to appreciate that DXA measured lean mass includes all nonfat soft tissue (ie, muscle, skin, organs, and connective tissue)[24] and consequently is only a surrogate for muscle mass, which may limit associations with performance. There are several methods to assess body composition, and technique correlations vary; however, DXA demonstrates strong correlations with magnetic resonance imaging and computed tomography.[18]

CONCLUSION

Our findings reveal substantial and important sport- and sex-specific differences in whole body and anatomical composition among NCAA Division I athletes. The large variation within certain sports may offer insight into the relevance of these differences. Normative sport- and position-specific values, but more importantly, serial assessment of the individual athlete on follow-up studies could assist the coaching and sports medicine staff to identify undesirable changes that may have negative consequences on athletic performance, injury risk, and overall health and well-being with potential long-term consequences such as the female athlete triad. Finally, but importantly, this work emphasizes the lack of utility in comparing athletic populations with a normal US population reference data set.

ACKNOWLEDGMENT

The authors would like to acknowledge Neel Kapoor for assistance with data management and literature search, as well as the sports medicine staff at the University of Wisconsin–Madison Division of Intercollegiate Athletics, for their commitment to the welfare of the student-athletes and contributions to the Badger Athletic Performance program.

REFERENCES

1. Ackland TR, Lohman TG, Sundgot-Borgen J, et al. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Med*. 2012;42:227-249.
2. Albanese CV, Diessel E, Genant HK. Clinical applications of body composition measurements using DXA. *J Clin Densitom*. 2003;6:75-85.
3. Allison KF, Keenan KA, Sell TC, et al. Musculoskeletal, biomechanical, and physiological gender differences in the US military. *US Army Med Dep J*. 2015;April-June:22-32.
4. Bentzur KM, Kravitz L, Lockner DW. Evaluation of the BOD POD for estimating percent body fat in collegiate track and field female athletes: a comparison of four methods. *J Strength Cond Res*. 2008;22:1985-1991.
5. Borrud LG, Flegal KM, Looker AC, Everhart JE, Harris ST, Shepherd JA. *Body Composisiton Data for Individuals 8 Years of Age and Older: U.S. Population, 1999-2004*. Washington, DC: National Center for Health Statistics, US Department of Health and Human Services; 2010.
6. Buehring B, Krueger D, Libber J, et al. Dual-energy X-ray absorptiometry measured regional body composition least significant change: effect of region of interest and gender in athletes. *J Clin Densitom*. 2014;17:121-128.
7. Burkhart TA, Schinkel-Ivy A, Andrews DM. Tissue mass ratios and the reporting of distal lower extremity injuries in varsity athletes at a Canadian University. *J Sports Sci*. 2013;31:684-687.
8. Carbuhn AF, Fernandez TE, Bragg AF, Green JS, Crouse SF. Sport and training influence bone and body composition in women collegiate athletes. *J Strength Cond Res*. 2010;24:1710-1717.
9. Collins SM, Silberlicht M, Perzinski C, Smith SP, Davidson PW. The relationship between body composition and preseason performance tests of collegiate male lacrosse players. *J Strength Cond Res*. 2014;28:2673-2679.
10. Dengel DR, Bosch TA, Burruss TP, et al. Body composition and bone mineral density of national football league players. *J Strength Cond Res*. 2014;28:1-6.
11. Ellis KJ. Human body composition: in vivo methods. *Physiol Rev*. 2000;80:649-680.
12. Fan B, Shepherd JA, Levine MA, et al. National Health and Nutrition Examination Survey whole-body dual-energy X-ray absorptiometry reference data for GE Lunar systems. *J Clin Densitom*. 2014;17:344-377.
13. Grant JA, Bedi A, Kurz J, Bancroft R, Gagnier JJ, Miller BS. Ability of preseason body composition and physical fitness to predict the risk of injury in male collegiate hockey players. *Sports Health*. 2015;7:45-51.
14. Hangartner TN, Warner S, Braillon P, Jankowski L, Shepherd J. The official positions of the International Society for Clinical Densitometry: acquisition of dual-energy X-ray absorptiometry body composition and considerations regarding analysis and repeatability of measures. *J Clin Densitom*. 2013;16:520-536.
15. Harley JA, Hind K, O'Hara JP. Three-compartment body composition changes in elite rugby league players during a super league season,

measured by dual-energy X-ray absorptiometry. *J Strength Cond Res*. 2011;25:1024-1029.

16. Hart NH, Nimphius S, Spiteri T, Newton RU. Leg strength and lean mass symmetry influences kicking performance in Australian football. *J Sports Sci Med*. 2014;13:157-165.
17. Kelly TL, Wilson KE, Heymsfield SB. Dual energy X-ray absorptiometry body composition reference values from NHANES. *PLoS One*. 2009;4:e7038.
18. Kendler DL, Borges JL, Fielding RA, et al. The official positions of the International Society for Clinical Densitometry: indications of use and reporting of DXA for body composition. *J Clin Densitom*. 2013;16:496-507.
19. Lemieux S, Prud'homme D, Bouchard C, Tremblay A, Despres JP. Sex differences in the relation of visceral adipose tissue accumulation to total body fatness. *Am J Clin Nutr*. 1993;58:463-467.
20. Lewiecki E, Binkley N, Morgan S, et al. Best practices for dual-energy x-ray absorptiometry measurement and reporting: International Society for Clinical Densitometry guidance. *J Clin Densitom*. 2016;19:127-140.
21. Libber J, Binkley N, Krueger D. Clinical observations in total body DXA: technical aspects of positioning and analysis. *J Clin Densitom*. 2012;15:282-289.
22. Loenneke JP, Wray ME, Wilson JM, Barnes JT, Kearney ML, Pujol TJ. Accuracy of field methods in assessing body fat in collegiate baseball players. *Res Sports Med*. 2013;21:286-291.
23. Lunar GE. *Healthcare enCORE-based X-ray Bone Densitometer User Manual* (LU43616EN:270). Madison, WI: GE Healthcare; 2012.
24. Lustgarten MS, Fielding RA. Assessment of analytical methods used to measure changes in body composition in the elderly and recommendations for their use in phase II clinical trials. *J Nutr Health Aging*. 2011;15:368-375.
25. Makovey J, Naganathan V, Sambrook P. Gender differences in relationships between body composition components, their distribution and bone mineral density: a cross-sectional opposite sex twin study. *Osteoporos Int*. 2005;16:1495-1505.
26. Marwaha RK, Tandon N, Garg MK, Narang A, Mehan N, Bhadra K. Normative data of body fat mass and its distribution as assessed by DXA in Indian adult population. *J Clin Densitom*. 2014;17:136-142.
27. Melvin MN, Smith-Ryan AE, Wingfield HL, Ryan ED, Trexler ET, Roelofs EJ. Muscle characteristics and body composition of NCAA division I football players. *J Strength Cond Res*. 2014;28:3320-3329.
28. Meyer NL, Sundgot-Borgen J, Lohman TG, et al. Body composition for health and performance: a survey of body composition assessment practice carried out by the Ad Hoc Research Working Group on Body Composition, Health and Performance under the auspices of the IOC Medical Commission. *Br J Sports Med*. 2013;47:1044-1053.
29. Nattiv A, Loucks AB, Manore MM, Sanborn CF, Sundgot-Borgen J, Warren MP. American College of Sports Medicine position stand. The female athlete triad. *Med Sci Sports Exerc*. 2007;39:1867-1882.
30. Nieves JW, Formica C, Ruffing J, et al. Males have larger skeletal size and bone mass than females, despite comparable body size. *J Bone Miner Res*. 2005;20:529-535.
31. Peart A, Wadsworth D, Washington J, Oliver G. Body composition assessment in female National Collegiate Athletic Association Division I softball athletes as a function of playing position across a multiyear time frame [published online May 17, 2018]. *J Strength Cond Res*. doi:10.1519/JSC.0000000000002600
32. Petak S, Barbu CG, Yu EW, et al. The official positions of the International Society for Clinical Densitometry: body composition analysis reporting. *J Clin Densitom*. 2013;16:508-519.
33. Raymond CJ, Dengel DR, Bosch TA. Total and segmental body composition examination in collegiate football players using multifrequency bioelectrical impedance analysis and dual x-ray absorptiometry. *J Strength Cond Res*. 2018;32:772-782.
34. Santos DA, Dawson JA, Matias CN, et al. Reference values for body composition and anthropometric measurements in athletes. *PLoS One*. 2014;9:e97846.
35. Santos DA, Silva AM, Matias CN, Fields DA, Heymsfield SB, Sardinha LB. Accuracy of DXA in estimating body composition changes in elite athletes using a four compartment model as the reference method. *Nutr Metab*. 2010;7:22.
36. Stanforth D, Lu T, Stults-Kolehmainen MA, Crim BN, Stanforth PR. Bone mineral content and density among female NCAA Division I athletes across the competitive season and over a multi-year time frame. *J Strength Cond Res*. 2016;30:2828-2838.
37. Watson A, Brindle J, Brickson S, Allee T, Sanfilippo J. Preseason aerobic capacity is an independent predictor of in-season injury in collegiate soccer players. *Clin J Sport Med*. 2017;27:302-307.