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Fat-Free Mass Index in NCAA Division I and II Collegiate American Football Players

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Abstract

Fat-free mass index (FFMI) is a height-adjusted assessment of fat-free mass, with previous research suggesting a natural upper limit of 25 kg·m^{-2} in resistance-trained males. The current study evaluated upper limits for FFMI in collegiate American football players (n=235), and evaluated differences between positions, divisions, and age groups. The sample consisted of two NCAA Division I teams (n=78, n=69), and one Division II team (n=88). Body composition was assessed via dual-energy x-ray absorptiometry and used to calculate FFMI; linear regression was used to normalize values to a height of 180 cm. Sixty-two participants (26.4%) had height-adjusted FFMI values above 25 kg·m^{-2} (mean = 23.7 ± 2.1 kg·m^{-2}; 97.5th percentile = 28.1 kg·m^{-2}). Differences were observed among position groups ($p < 0.001$; $\eta^2 = 0.25$), with highest values observed in offensive and defensive linemen, and lowest values observed in offensive and defensive backs. FFMI was higher in Division I teams than Division II (24.3 ± 1.8 vs. 23.4 ± 1.8 kg·m^{-2}; $p < 0.001$; $d = 0.49$). FFMI did not differ between age groups. Upper limit estimations for FFMI appear to vary by position; while the 97.5th percentile (28.1 kg·m^{-2}) may represent a more suitable upper limit for the college football population as a whole, this value was exceeded by six linemen (3 OL, 3 DL), with a maximal observed value of 31.7 kg·m^{-2}. Football practitioners may use FFMI to evaluate an individual's capacity for additional FFM accretion, suitability for a specific position, potential for switching positions, and overall recruiting assessment.

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Keywords

Body composition; lean mass; body fat percentage; anthropometry; kinanthropometry

Introduction

In 1991, Fry and Kraemer (9) demonstrated that physical performance characteristics could effectively discriminate between position, playing ability, and division of play in American football. In the years since, researchers have investigated American football in relation to endocrine response to gameplay (21, 22), training programs (13, 15, 26, 31, 37, 38), physical characteristics (2, 5, 7, 23, 29, 32, 35), longitudinal body composition changes (4, 13, 14, 18, 38, 40), and predictors of performance (6, 10, 17, 27, 30, 39). Cross-sectional research has demonstrated that body composition differs among position groups (5, 7, 29, 32), and has identified a clear trend of increasing body size in recent decades (2, 16, 33, 35). American football requires a unique combination of speed, size, and power (12); as such, indices of body size and composition have been associated with strength (36), power (30), and career earnings (33) in football players, and extensive research in a variety of populations has documented relationships between various indices of fat-free mass (FFM) and strength, power, speed, and sport performance (1, 3, 24, 27, 28, 41, 43). However, absolute amounts of FFM are influenced by height, with greater height favoring higher FFM. In addition, numerous sport-related movements involve the locomotion or propulsion of one's body, wherein an individual's overall size must be considered in addition to their capacity to generate force. These factors suggest that scaling FFM to height may allow a more accurate characterization of muscularity and physical ability in athletes.

Fat-free mass index (FFMI) is a height-normalized index of FFM, which is calculated by dividing FFM (in kg) by height (in m^2). Although FFMI was initially shown to have diagnostic value in identifying protein-energy malnutrition in individuals with low FFM (42), this metric may have valuable applications to a variety of sports. Acquiring normative data in athletes may allow for identifying ideal FFMI ranges to accommodate the physical demands of a given sport, informing the selection of an appropriate competition weight in weight class and aesthetic sports, and identifying upper limits for FFM accretion in strength-power sports. Fat-free mass index has been evaluated in collegiate baseball players and gymnasts (25), but has not yet been applied to collegiate or professional football players. Fat-free mass index may distinguish inter-position differences in a manner similar to previously used measurements like weight, body mass index, and body fat percentage (BF%) (29, 32), but may relate more directly to the capacity for strength and power. In addition, a height-adjusted upper limit of 25 $kg \cdot m^{-2}$ has been suggested for males with no history of anabolic steroid use (20). This limit was determined from a sample including 74 relatively lean, recreationally trained individuals (BF% = 12.5 ± 5.5%), with at least two years of weight lifting experience. While this sample contained an unspecified number of competitive weight lifters and bodybuilders (20, 34), the minimal inclusion criteria and size of the sample may indicate that more data are needed to evaluate the maximal naturally attainable limit for FFMI in American football. Establishing a more accurate estimation of natural FFMI limits using participants who are more heterogeneous in BF%, have greater access to optimal training and nutrition practices, and are genetically predisposed to carrying maximal levels of FFM, such as collegiate American football players, would be advantageous.

To assess the utility of FFMI in American football, more research is needed to determine realistic upper limits of FFMI in this population, and to determine if FFMI distinguishes between position group, level of play, or age group. By identifying upper limits and differences between positions and levels of play, FFMI may facilitate recruiting and training program design for American football coaches. The purpose of the current study was to characterize FFMI in collegiate American football players, and to determine if FFMI differs between players of different position, division, or age groups. It was hypothesized that FFMI would vary significantly among position groups, division levels, and age groups. It was also hypothesized that the previously proposed limit of 25 $kg{\cdot}m^{-2}$ would underestimate the FFMI upper limit in college football players.

Methods

Experimental Approach to the Problem

To evaluate normative values of FFMI in collegiate American football players, a single cross-sectional body composition assessment was performed via dual-energy x-ray absorptiometry (DEXA). The sample consisted of two Division I teams (Team A, n=78; Team B, n=69) and one Division II team (Team C, n=88). Body composition measurements were used to calculate FFMI, which was then adjusted to account for the influence of height, as previously described (20). To facilitate the establishment of body composition goals and training program design in American football players, measures of central tendency and spread were used to evaluate normative values by position, with maximum values and 97.5th percentile values used to make inferences regarding reasonably attainable upper limits. To determine if FFMI may facilitate recruiting or personnel decisions on American football rosters, group mean comparisons were performed to determine if FFMI discriminates between playing position, division of play, or age group.

Subjects

The current study utilized a convenience sample of 235 male National Collegiate Athletic Association (NCAA) football players (Mean ± SD; Age = 20.0 ± 1.2 years; Height = 184.7 ± 6.9 cm; Weight = 103.6 ± 20.1 kg; BF% = 19.8 ± 7.4%). Procedures were approved by the Institutional Review Board at each participating University (n=3); all procedures were compliant with the principles set forth by the Declaration of Helsinki. Prior to participation, participants were informed of the benefits and risks of the investigation, and all participants signed an approved informed consent document prior to participation. Parental consent was obtained for any participant below 18 years of age (n=1); age of the current sample ranged from 17 to 23 years of age. Body composition data from part of this sample have been presented previously (29, 40), but FFMI values for these participants have not been previously evaluated or presented.

Procedures

Body composition assessments were performed via DEXA (Teams A, B: Discovery W, Hologic Inc., Bedford, MA, USA; Team C: Lunar iDXA, GE Healthcare, Chicago, IL, USA) using the default software for each system. Data collection occurred in July/August for Teams A and B, and in November/December for Team C. Participants were instructed to abstain from eating and exercising for at least 2 hours prior to each visit; due to the high number of scans required, specific time of day could not be standardized for all participants. Upon arrival to the laboratory, height and weight were measured in light clothing with shoes removed. Participants were instructed to remove any metal, hard plastic, or any other materials that could interfere with the scan. A DEXA technician entered the height, weight, sex, and ethnicity of each subject into the device's default software prior to each scan. Participants remained still and rested in a supine position with their hands faced palms-down at their sides. For individuals with shoulders too wide for the scanning area, technicians followed manufacturer's instructions for scanning. If using a Hologic DEXA, subjects were instructed to tuck their thumbs under their buttocks to capture the full upper body. If using a GE DEXA, subjects were positioned so the full right side of the body could be scanned, with internal software used to estimate values for the left side. For both DEXA systems, participants who were too tall for the scanning area were positioned with their head at the top of the scanning area, to minimize the amount of the foot/lower leg tissue that would be omitted from the scan, per manufacturer's instructions. With the Lunar iDXA system, authors of the current study have calculated acceptable test-retest reliability values for fat mass (intraclass correlation coefficient [ICC] = 0.99, standard error of measurement [SEM] = 0.46 kg), lean mass (ICC = 0.99, SEM = 0.81 kg), and BF% (ICC = 0.99, SEM = 0.81%). Similarly, with the Hologic DEXA system, authors of the current study have calculated acceptable test-retest reliability values for fat mass (ICC = 0.98, SEM = 0.85 kg), lean mass (ICC = 0.99, SEM = 1.07 kg), and BF% (ICC = 0.98, SEM = 1.06%).

Fat-free mass index ($kg \cdot m^{-2}$) was calculated using Equation 1, where LM and BMC were measured in kilograms, and height was measured in meters (42).

$$FFMI = \frac{LM + BMC}{(Height)^2} \quad [1]$$

Although FFM was divided by height squared, previous authors (20) have indicated that further height adjustment is necessary to account for greater body width and thickness in taller participants. Height-adjusted values were calculated via linear regression, using procedures similar to Kouri et al. (20). Raw FFMI was regressed against height, using only cases in which FFMI values were above the median. The top 50% of cases were used to select individuals more likely to be approaching their personal upper limit for FFM accretion. The slope of the regression line was used to calculate height-adjusted FFMI ($FFMI_{Adj}$), scaled to a height of 1.8 m, using Equation 2.

$$FFMI_{Adj} = FFMI + (Slope) \cdot (1.8 - Subject\ Height) \quad [2]$$

FFMI_{Adj} values were compared to raw values to evaluate the effect of regression-based height adjustment. In addition, FFMI values were calculated using the equation previously proposed by Kouri et al. (20) (FFMI_{KE}), so that upper limits in the current sample could be directly compared to previous results.

For comparison between position groups, athletes were categorized as offensive linemen (OL; n=38), defensive linemen (DL; n=39), offensive backs (OB; n=65, including quarterbacks [QB], wide receivers [WR], and running backs [RB]), defensive backs (DB; n=56, including corners, safeties, and special teams athletes [SP]), and tight ends/linebackers (TE/LB; n=37). Special teams athletes consisted of a very small group (n=7) whose body composition characteristics were most closely comparable with DBs; accordingly, SP were grouped with DBs for statistical analysis. For age-based comparisons, participants were categorized based on their age at the time of measurement as ≤ 18 (n=23), 19 (n=68), 20 (n=63), 21 (n=55), or ≥ 22 (n=26) years old.

Statistical analyses

Plots and measures of central tendency and variability are presented for FFMI_{Raw}, FFMI_{KE}, and FFMI_{Adj} for comparison between methods of height adjustment, and for evaluation of upper limits. Maximum values and 97.5th percentile values were used to make inferences regarding realistically attainable upper limit values. Unless otherwise noted, regression-adjusted values (FFMI_{Adj}) were used for all statistical analyses. Levene's test was used to assess homogeneity of variance between groups. To determine if FFMI discriminates between position group, level of play, or age group, a series of tests were completed to compare FFMI values between groups. A one-way between subjects analysis of variance (ANOVA) was used to compare FFMI values between position groups. A series of one-way ANCOVAs were used to evaluate comparisons between divisions and age groups. For these comparisons, position group was used as a categorical covariate to account for differing ratios of player position (position makeup) between divisions and age groups. For omnibus tests, effect size (η^2) was calculated. In the event of a significant effect in the omnibus ANOVA, *post hoc* comparisons were performed using pairwise t-tests, with Benjamini-Hochberg p value corrections for multiple comparisons. Effect size (Cohen's d) was reported for pairwise comparisons. Statistical analyses were performed using R software (Version 3.2.2, R Foundation for Statistical Computing, Vienna, Austria), with statistical significance set *a priori* at $\alpha = 0.05$.

Results

Height Adjustment

Raw FFMI (FFMI_{Raw}) is presented in Figure 1A. Regressing FFMI against height yielded a slope of 2.943, which was not significantly different from zero ($r = 0.13$; $p = 0.16$). Height-adjusted FFMI was calculated from the slope of the regression line (FFMI_{Adj}; Figure 1B). On average, this calculation changed FFMI values by an absolute value of 0.20 ± 0.14 kg·m^{-2}. Of 235 subjects, the difference between FFMI_{Raw} and FFMI_{Adj} was greater than 0.5 kg·m^{-2} in six subjects; the largest difference was 0.62 kg·m^{-2} (Figure 2). Adjusted values were also calculated using a previously published equation by Kouri et al. (20), which utilized a slope of 6.1. The Kouri equation (KE) was applied to the current sample, with values ($FFMI_{KE}$) presented in Figure 1C. Values calculated using the KE adjustment changed by an average of 0.41 ± 0.30 $kg \cdot m^{-2}$. Eighty-two FFMI values were adjusted by over 0.5 $kg \cdot m^{-2}$; the largest difference observed was 1.28 $kg \cdot m^{-2}$ (Figure 2).

Upper limits for FFMI

Sixty-two participants (26.4%) had $FFMI_{Adj}$ values above 25 $kg \cdot m^{-2}$ (Figure 1B). When using the KE adjustment, 54 participants (23.0%) had $FFMI_{KE}$ values above 25 $kg \cdot m^{-2}$ (Figure 1C). For $FFMI_{Adj}$, the range of values observed was 19.0 - 31.7 $kg \cdot m^{-2}$, with an interquartile range (IQR) of 22.3 - 25.1 $kg \cdot m^{-2}$. Ninety-five percent of values fell between 20.1 - 28.1 $kg \cdot m^{-2}$ (Figure 3). Values above 28.1 $kg \cdot m^{-2}$ were observed for six athletes (3 OL, 3 DL), with a maximal observed value of 31.7 $kg \cdot m^{-2}$.

Forty-six Division I athletes (31.3%) had $FFMI_{Adj}$ values above 25 $kg \cdot m^{-2}$ (Figure 1B). When using the KE adjustment, 38 participants (25.9%) had $FFMI_{KE}$ values above 25 $kg \cdot m^{-2}$ (Figure 1C). For $FFMI_{Adj}$, the range of values observed was 19.0 - 31.7 $kg \cdot m^{-2}$, with an interquartile range (IQR) of 22.9 - 25.3 $kg \cdot m^{-2}$. Ninety-five percent of values fell between 20.5 - 28.8 $kg \cdot m^{-2}$.

Sixteen Division II athletes (18.2%) had $FFMI_{Adj}$ values above 25 $kg \cdot m^{-2}$ (Figure 1B). When using the KE adjustment, 16 participants (18.2%) had $FFMI_{KE}$ values above 25 $kg \cdot m^{-2}$ (Figure 1C). For $FFMI_{Adj}$, the range of values observed was 19.3 - 28.0 $kg \cdot m^{-2}$, with an interquartile range (IQR) of 21.8 - 24.5 $kg \cdot m^{-2}$. Ninety-five percent of values fell between 20.0 - 27.4 $kg \cdot m^{-2}$.

Differences between positions

A significant effect of position group was observed ($p < 0.001$; $\eta^2 = 0.25$; Table 1). Offensive lineman (25.1 ± 2.0 $kg \cdot m^{-2}$) and DL (25.2 ± 2.3 $kg \cdot m^{-2}$) were significantly greater than OB (22.8 ± 1.8 $kg \cdot m^{-2}$), DB (22.9 ± 1.4 $kg \cdot m^{-2}$), and TE/LB (23.8 ± 1.4 $kg \cdot m^{-2}$; all $p < 0.01$; Cohen's $d = 0.73 - 1.32$). The TE/LB group was significantly greater than OB and DB (both $p < 0.05$; $d = 0.60$ and 0.64, respectively). There were no significant differences between OL and DL ($p = 0.86$), or between OB and DB ($p = 0.86$). Boxplots for individual positions are presented in Figure 4. Due to differences in FFMI values and competition level between divisions, boxplots are presented for Division I athletes to portray target ranges that may support optimal performance in collegiate football players.

Comparisons between divisions

Mean $FFMI_{Adj}$ for Division I and Division II athletes were 24.1 ± 2.0 $kg \cdot m^{-2}$ and 23.1 ± 2.0 $kg \cdot m^{-2}$, respectively. After covarying for differences in position makeup, Division I $FFMI_{Adj}$ values were significantly higher than Division II (24.3 ± 1.8 $kg \cdot m^{-2}$ vs. 23.4 ± 1.8 $kg \cdot m^{-2}$; $p < 0.001$; $d = 0.49$).

Comparisons between age groups

Mean $FFMI_{Adj}$ values for each age group are listed in Table 2, along with $FFMI_{Adj}$ values adjusted to account for differing position makeup of each age group. After covarying for position makeup, $\mathrm{FFMI}_{\mathrm{Adj}}$ values were not significantly different between age groups (p = 0.60).

Discussion

The current results suggest that 25 kg·m^{-2} underestimates the natural FFMI limit in American collegiate football players, regardless of which height adjustment equation is applied. Mean FFMI differed significantly between position groups, which likely reflects unique physical demands of each position. Similarly, FFMI was significantly higher in Division I players compared to Division II, mirroring differences in strength and sprint performance outcomes between divisions (9, 10). Contrary to the hypothesized relationship, FFMI did not differ between age groups. Results suggest that physiological limits for FFM accretion may be higher than previously thought in male athletes, and that FFMI is a metric with valuable applications to the sport of American football.

Determining upper limits for FFMI in football players allows strength and conditioning professionals to assist athletes in establishing appropriate goals for body weight and lean mass accretion. In the seminal study estimating FFMI upper limits, Kouri et al. (20) concluded that 25 kg·m^{-2} represents the natural ceiling in resistance-trained males. However, characteristics of the sample introduce important limitations regarding the generalizability of this value. The subsample of steroid nonusers consisted of only 74 males with a minimum of two years resistance training experience, BF% levels that were relatively low and homogeneous (12.5 ± 5.5%), and an unclear level of athletic achievement within the group as a whole. Assessments of FFMI in male collegiate baseball players and female gymnasts have not identified values above 25 kg·m^{-2} (25), but these populations are unlikely to represent physiological FFMI upper limits due to the physical demands of each sport. In comparison, the current study found a maximal height-adjusted FFMI of 31.7 kg·m^{-2}, and a 97.5th percentile cutoff of 28.1 kg·m^{-2}. Sixty-two participants (26.4%) had $\mathrm{FFMI}_{\mathrm{Adj}}$ values above 25 kg·m^{-2}, including 31.3% of Division I participants. There are likely multiple explanations for the discrepancy compared to the results of Kouri et al. (20). The current sample featured individuals with higher BF% levels, and the coupling of fat mass and lean mass (8) suggests that a sample of lean individuals limits FFM accretion, resulting in an underestimation of maximal FFMI values. As such, research in Sumo wrestlers (11) has documented a mean $\mathrm{FFMI}_{\mathrm{Raw}}$ value of 26.6 kg·m^{-2}, with individual values as high as 37. Furthermore, football has a large talent pool in America due to its widespread popularity (12), and the sport-specific demands for strength and power (12) generally favor individuals with high degrees of lean mass. American universities emphasize strength and conditioning programs in football and support FFM accretion by providing athletes with access to specialized facilities and practitioners for strength training and nutrition (19). These factors increase the likelihood of identifying individuals that approach maximal physiological limits of FFM accretion, and enhance the ability to estimate upper limits of FFMI. The current findings demonstrate that collegiate American football players may realistically strive for FFMI values well beyond 25 kg·m^{-2}.

Characteristics that effectively describe and distinguish between playing positions assist in recruiting and personnel decisions, and allow for the development of position-specific body composition goals. Significant differences were observed between position groups, which reflects differing physical demands of each position. Offensive and defensive linemen had the highest FFMI, with mean values (OL = 25.1 ± 2.0 $kg \cdot m^{-2}$; DL = 25.2 ± 2.3 $kg \cdot m^{-2}$) surpassing the previously suggested upper limit of 25 $kg \cdot m^{-2}$. Positions that emphasize body size and strength had the highest group FFMI values (OL, DL, TE/LB), while positions with comparatively greater speed and lesser strength emphasis had lower values (OB, DB). The position groups with higher FFMI values in the current study (OL, DL, TE/LB) are also typically found to have higher BF% values (29, 40), which supports previous observations of greater FFMI values in Sumo wrestlers with higher BF% (11). Other indices of body mass and body composition have been previously used to distinguish between position groups (5, 7, 29, 32), but FFMI allows for the approximation of relative muscularity by scaling FFM to the individual's height. This quantifies an individual's muscularity in relation to the size of their overall body frame, which may be a particularly suitable predictor of physical ability in football-specific tasks involving the locomotion and propulsion of one's body mass. Coaches and practitioners can apply FFMI to recruiting evaluations, in which a player's FFMI may provide information regarding their suitability for a given position, as well as a player's potential for lean mass accretion. Similarly, FFMI can be used to guide training and nutrition practices, in which athletes may set goals for weight loss or weight gain based on a target FFMI value for their position group (Figure 4).

As noted by Fry and Kraemer (9), physical characteristics that distinguish between competitive divisions are likely to reflect characteristics that are associated with playing ability. Significant FFMI differences were found between division levels, with higher values in Division I compared to Division II. Previous research has identified significant relationships between indices of body size, body composition, and physical performance outcomes relevant to football (3, 30, 33, 36). Differences in FFMI between divisions appear to mirror previously reported differences in physical performance outcomes between divisions (9, 10). Although causation cannot be inferred, these data may indicate that FFMI relates to performance in American football, as Division I is a higher caliber of competition and is associated with greater strength, speed, and power in comparison with Division I (9, 10). More research is needed, with a greater number of teams, to determine if this pattern is consistent across division levels. Nonetheless, the current data indicate that FFMI discriminates between competitive divisions; this suggests that FFMI may be associated with playing ability, and supports the utility of FFMI as a tool for evaluating potential talent.

It was hypothesized that FFMI would be greater in older athletes, based on research showing longitudinal increases in FFM across the career in collegiate American football players (14, 18, 38, 40). However, the current data do not indicate significant FFMI differences between age groups. This lack of significant differences supports previous data in which body composition characteristics did not differ by class or year (16, 32). It is possible that each recruiting class may differ in terms of baseline physical characteristics and FFMI, which would confound the expected increase in FFMI throughout the career. This relationship could be further confounded by athletes who follow different career timelines and trajectories, such as red-shirt seasons, extended time off from injuries, or prematurely entering the professional level of play. Football programs should rely on longitudinal tracking of athletes to assess the physical development of their athletes, rather than making inferences from serial cross-sectional assessments at the team level.

Limitations of the current study must be noted. Although NCAA athletes are subject to random, year-round drug testing, independent drug testing was not conducted in this study. While the presence of steroid users would inflate upper limit values for FFMI, it is highly unlikely that FFMI differences between the current study and previous literature are primarily attributable to steroid use. In this population, anabolic steroid use would involve high financial cost, present risks involving the loss of scholarships and future employment opportunities, and require the athlete to successfully circumvent random drug testing. Explanations relating to the size of the sample, heterogeneous levels of BF%, access to training and nutrition services, and genetic predisposition of high-level athletes are far more likely and parsimonious explanations for the observed outcomes. In addition, there were minor equipment differences between teams, with teams A and B using a DEXA unit produced by a different manufacturer than team C. While it would be ideal to use the same DEXA model, the multi-site nature of the study precluded the research team from collecting the data in this manner.

Practical Applications

The current data suggest that natural upper limits of FFMI extend well beyond the previously proposed limit of 25 $kg \cdot m^{-2}$. In a large sample containing high-level athletes with relatively higher body fat levels, the observed 97.5th percentile value of 28.1 $kg \cdot m^{-2}$ might represent a more suitable upper limit estimation for the collegiate football population (Figure 3), with higher values potentially observed in linemen (Figure 4). These data suggest that coaches can use FFMI to assess an individual’s upper limit for fat-free mass, which may extend well beyond 25 $kg \cdot m^{-2}$ in collegiate football players. Further, FFMI discriminates between competitive divisions and position groups, which can serve as a valuable tool for recruitment, assessment of athletic potential, and guidance for body composition goals in American football. Football practitioners can use FFMI to evaluate an individual’s capacity for additional FFM accretion, suitability for a specific position, potential for switching positions, and overall recruiting assessment. For an athlete that is approaching upper limits for FFMI, coaches may shift their training focus away from hypertrophy-oriented goals, with greater emphasis on speed, power, and sport-specific skills. Conversely, hypertrophy-oriented training blocks and nutritional habits may be recommended for an athlete who is substantially below the median FFMI value for their position. Normative position-specific values observed in the current sample can inform body composition goals; practitioners can use FFMI to determine how much body weight an athlete should aim to gain or lose, and to set acceptable targets for the athlete’s body weight and BF% at a given height. Finally, FFMI may be used to inform recruiting and personnel decisions; a low FFMI may indicate that an athlete has potential to gain substantial lean mass throughout their collegiate career, and an individual with relatively low FFMI may have potential to change positions over time, such as a transition from safety to linebacker, or linebacker to defensive end. Beyond American football, practitioners can use this metric for similar purposes in a variety of sports, particularly in strength-power sports, and to assist in the selection of appropriate competition weight in weight-class sports.

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References

1. Amonette WE, Brown D, Dupler TL, Xu J, Tufano JJ, De Witt JK. Physical determinants of interval sprint times in youth soccer players. J Hum Kinet. 2014; 40:113–120. [PubMed: 25031679]
2. Anzell AR, Potteiger JA, Kraemer WJ, Otieno S. Changes in height, body weight, and body composition in American football players from 1942 to 2011. J Strength Cond Res. 2013; 27:277–284. [PubMed: 23222088]
3. Bilsborough JC, Greenway KG, Opar DA, Livingstone SG, Cordy JT, Bird SR, Coutts AJ. Comparison of anthropometry, upper-body strength, and lower-body power characteristics in different levels of Australian football players. J Strength Cond Res. 2015; 29:826–834. [PubMed: 25226309]
4. Binkley TL, Daughters SW, Weidauer LA, Vukovich MD. Changes in Body Composition in Division I Football Players Over a Competitive Season and Recovery in Off-Season. J Strength Cond Res. 2015; 29:2503–2512. [PubMed: 26313574]
5. Bosch TA, Burruss TP, Weir NL, Fielding KA, Engel BE, Weston TD, Dengel DR. Abdominal body composition differences in NFL football players. J Strength Cond Res. 2014; 28:3313–3319. [PubMed: 25187247]
6. Davis DS, Barnette BJ, Kiger JT, Mirasola JJ, Young SM. Physical characteristics that predict functional performance in Division I college football players. J Strength Cond Res. 2004; 18:115–120. [PubMed: 14971973]
7. Dengel DR, Bosch TA, Burruss TP, Fielding KA, Engel BE, Weir NL, Weston TD. Body composition and bone mineral density of national football league players. J Strength Cond Res. 2014; 28:1–6. [PubMed: 24149760]
8. Forbes GB. The companionship of lean and fat. Basic Life Sci. 1993; 60:1–14.
9. Fry AC, Kraemer WJ. Physical performance characteristics of American collegiate football players. J Appl Sports Sci Res. 1991; 5:126–138.
10. Garstecki MA, Latin RW, Cuppett MM. Comparison of selected physical fitness and performance variables between NCAA Division I and II football players. J Strength Cond Res. 2004; 18:292–297. [PubMed: 15142027]
11. Hattori K, Kondo M, Abe T, Tanaka S, Fukunaga T. Hierarchical differences in body composition of professional Sumo wrestlers. Ann Hum Biol. 1999; 26:179–184. [PubMed: 10195655]
12. Hoffman JR. The applied physiology of American football. Int J Sports Physiol Perform. 2008; 3:387–392. [PubMed: 19211949]
13. Hoffman JR, Kang J. Strength changes during an in-season resistance-training program for football. J Strength Cond Res. 2003; 17:109–114. [PubMed: 12580665]
14. Hoffman JR, Ratamess NA, Kang J. Performance changes during a college playing career in NCAA division III football athletes. J Strength Cond Res. 2011; 25:2351–2357. [PubMed: 21747290]
15. Hoffman JR, Ratamess NA, Klatt M, Faigenbaum AD, Ross RE, Tranchina NM, McCurley RC, Kang J, Kraemer WJ. Comparison between different off-season resistance training programs in Division III American college football players. J Strength Cond Res. 2009; 23:11–19. [PubMed: 19130636]
16. Jacobson BH. Anthropometric cross-sectional comparisons of college football players and potential health implications. J Strength Cond Res. 2012; 26:3358–3364. [PubMed: 22290523]

17. Jacobson BH, Conchola E, Smith DB, Akehi K, Glass R. The Relationship between Selected Strength and Power Assessments to Peak and Average Velocity of the Drive Block in Offensive Line Play. J Strength Cond Res. 2014
18. Jacobson BH, Conchola EG, Glass RG, Thompson BJ. Longitudinal morphological and performance profiles for American, NCAA Division I football players. J Strength Cond Res. 2013; 27:2347–2354. [PubMed: 23238095]
19. Judge LW, Petersen JC, Bellar DM, Craig BW, Cottingham MP, Gilreath EL. The current state of NCAA Division I collegiate strength facilities: size, equipment, budget, staffing, and football status. J Strength Cond Res. 2014; 28:2253–2261. [PubMed: 24476770]
20. Kouri EM, Pope HG Jr. Katz DL, Oliva P. Fat-free mass index in users and nonusers of anabolic-androgenic steroids. Clin J Sport Med. 1995; 5:223–228. [PubMed: 7496846]
21. Kraemer WJ, Looney DP, Martin GJ, Ratamess NA, Vingren JL, French DN, Hatfield DL, Fragala MS, Spiering BA, Howard RL, Cortis C, Szivak TK, Comstock BA, Dunn-Lewis C, Hooper DR, Flanagan SD, Volek JS, Anderson JM, Maresh CM, Fleck SJ. Changes in creatine kinase and cortisol in National Collegiate Athletic Association Division I American football players during a season. J Strength Cond Res. 2013; 27:434–441. [PubMed: 23358319]
22. Kraemer WJ, Spiering BA, Volek JS, Martin GJ, Howard RL, Ratamess NA, Hatfield DL, Vingren JL, Ho JY, Fragala MS, Thomas GA, French DN, Anderson JM, Hakkinen K, Maresh CM. Recovery from a national collegiate athletic association division I football game: muscle damage and hormonal status. J Strength Cond Res. 2009; 23:2–10. [PubMed: 19077734]
23. Kraemer WJ, Torine JC, Silvestre R, French DN, Ratamess NA, Spiering BA, Hatfield DL, Vingren JL, Volek JS. Body size and composition of National Football League players. J Strength Cond Res. 2005; 19:485–489. [PubMed: 16095394]
24. Kubo J, Chishaki T, Nakamura N, Muramatsu T, Yamamoto Y, Ito M, Saitou H, Kukidome T. Differences in fat-free mass and muscle thicknesses at various sites according to performance level among judo athletes. J Strength Cond Res. 2006; 20:654–657. [PubMed: 16937980]
25. Loenneke JP, Wilson JM, Wray ME, Barnes JT, Kearney ML, Pujol TJ. The estimation of the fat free mass index in athletes. Asian J Sports Med. 2012; 3:200–203. [PubMed: 23012640]
26. Mann JB, Thyfault JP, Ivey PA, Sayers SP. The effect of autoregulatory progressive resistance exercise vs. linear periodization on strength improvement in college athletes. J Strength Cond Res. 2010; 24:1718–1723. [PubMed: 20543732]
27. Mayhew JL, Piper FC, Schwegler TM, Ball TE. Contributions of speed, agility, and body composition to anaerobic power measurement in college football players. J Strength Cond Res. 1989; 3:101–106.
28. Mayhew JL, Piper FC, Ware JS. Anthropometric correlates with strength performance among resistance trained athletes. J Sports Med Phys Fitness. 1993; 33:159–165. [PubMed: 8412051]
29. 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. [PubMed: 25187245]
30. Miller TA, White ED, Kinley KA, Congleton JJ, Clark MJ. The effects of training history, player position, and body composition on exercise performance in collegiate football players. J Strength Cond Res. 2002; 16:44–49. [PubMed: 11834106]
31. Moore CA, Fry AC. Nonfunctional overreaching during off-season training for skill position players in collegiate American football. J Strength Cond Res. 2007; 21:793–800. [PubMed: 17685717]
32. Noel MB, VanHeest JL, Zaneteas P, Rodgers CD. Body composition in Division I football players. J Strength Cond Res. 2003; 17:228–237. [PubMed: 12741857]
33. Norton K, Olds T. Morphological evolution of athletes over the 20th century: causes and consequences. Sports Med. 2001; 31:763–783. [PubMed: 11583103]
34. Pope HG Jr. Katz DL. Psychiatric and medical effects of anabolic-androgenic steroid use. A controlled study of 160 athletes. Arch Gen Psychiatry. 1994; 51:375–382. [PubMed: 8179461]
35. Secora CA, Latin RW, Berg KE, Noble JM. Comparison of physical and performance characteristics of NCAA Division I football players: 1987 and 2000. J Strength Cond Res. 2004; 18:286–291. [PubMed: 15142002]

36. Shields CL Jr. Whitney FE, Zomar VD. Exercise performance of professional football players. Am J Sports Med. 1984; 12:455–459. [PubMed: 6507716]
37. Smith RA, Martin GJ, Szivak TK, Comstock BA, Dunn-Lewis C, Hooper DR, Flanagan SD, Looney DP, Volek JS, Maresh CM, Kraemer WJ. The effects of resistance training prioritization in NCAA Division I Football summer training. J Strength Cond Res. 2014; 28:14–22. [PubMed: 23698079]
38. Stodden DF, Galitski HM. Longitudinal effects of a collegiate strength and conditioning program in American football. J Strength Cond Res. 2010; 24:2300–2308. [PubMed: 20703166]
39. Teramoto M, Cross CL, Willick SE. Predictive Value of National Football League Scouting Combine on Future Performance of Running Backs and Wide Receivers. J Strength Cond Res. 2016; 30:1379–1390. [PubMed: 27100168]
40. Trexler ET, Smith-Ryan AE, Mann JB, Ivey PA, Hirsch KR, Mock MG. Longitudinal body composition changes in NCAA Division I college football players. J Strength Cond Res. 2016 Published ahead of print.
41. Trexler ET, Smith-Ryan AE, Roelofs EJ, Hirsch KR. Body Composition, Muscle Quality and Scoliosis in Female Collegiate Gymnasts: A Pilot Study. Int J Sports Med. 2015; 36:1087–1092. [PubMed: 26332905]
42. VanItallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA. Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. Am J Clin Nutr. 1990; 52:953–959. [PubMed: 2239792]
43. Ye X, Loenneke JP, Fahs CA, Rossow LM, Thiebaud RS, Kim D, Bemben MG, Abe T. Relationship between lifting performance and skeletal muscle mass in elite powerlifters. J Sports Med Phys Fitness. 2013; 53:409–414. [PubMed: 23828289]

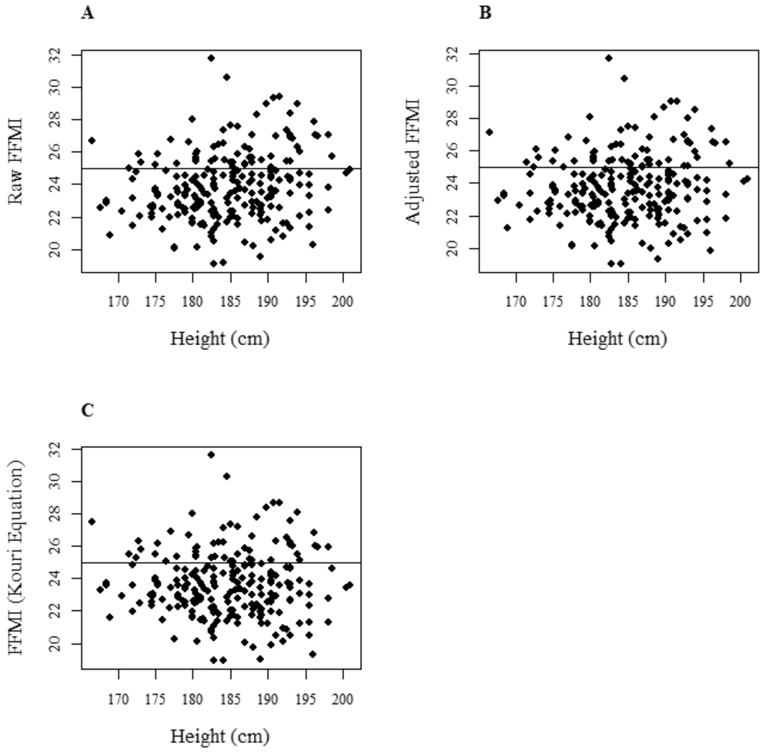

Figure 1.

(A) Raw FFMI values (kg·m^{-2}) plotted against height. (B) FFMI values plotted against height, after using regression to adjust for height (FFMI$_{Adj}$). (C) FFMI values plotted against height, after using previously published equation by Kouri et al. (20) to adjust for height (FFMI$_{KE}$). Horizontal line represents previously reported upper limit value of 25 kg·m^{-2} (20).

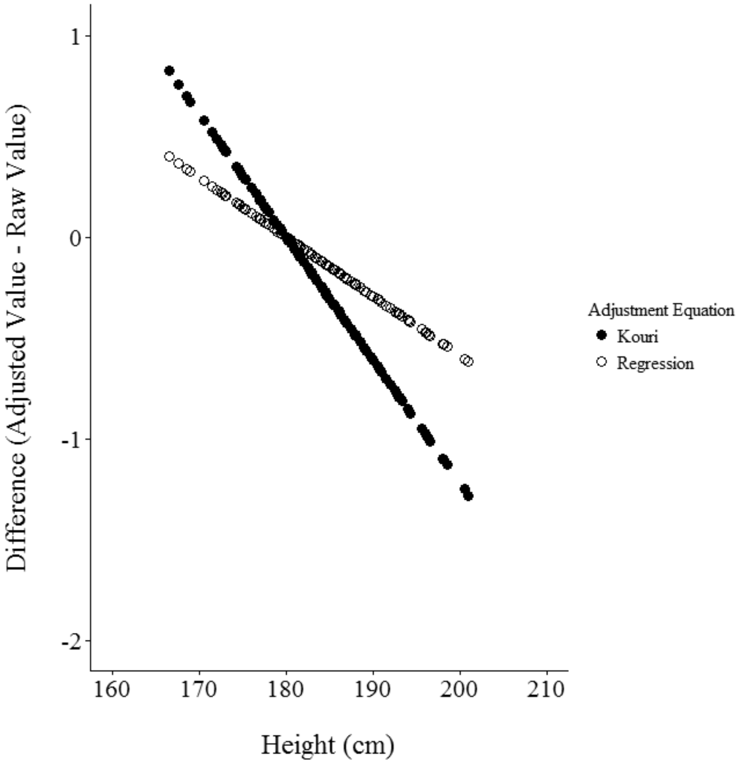

Figure 2.

Differences between raw and height-adjusted FFMI values (kg·m^{-2}) using the Kouri Equation (FFMI$_{KE}$) versus linear regression (FFMI$_{Adj}$).

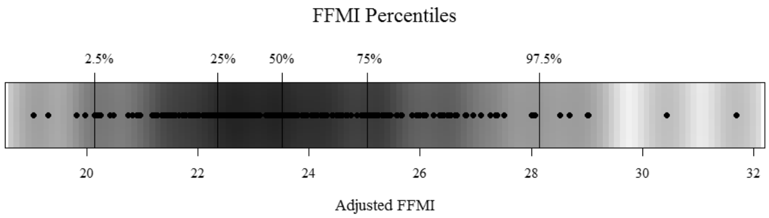

Figure 3.

Percentile cutoffs for $FFMI_{Adj}$ values ($kg{\cdot}m^{-2}$). Individual points are plotted, with grayscale shading to indicate areas of high density (dark) and low density (light).

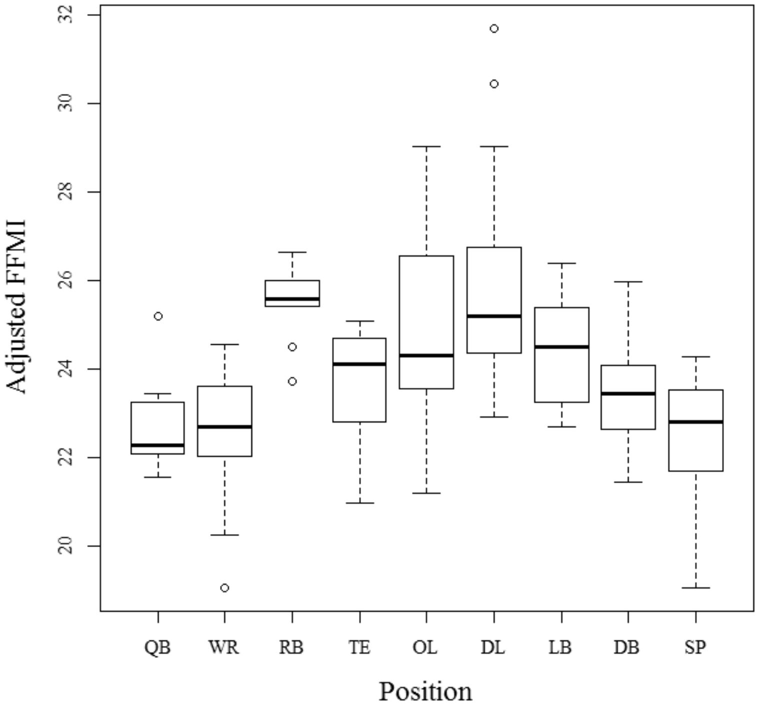

Figure 4.

Boxplots of $FFMI_{Adj}$ values ($kg \cdot m^{-2}$) by position in Division I football players (n=147). QB = quarterback; WR = wide receiver; RB = running back; TE = tight end; OL = offensive line; DL = defensive line; LB = linebacker; DB = defensive back; SP = special teams.

Table 1

FFMI_{Adj} values among position groups. Values are mean ± SD.

Position	**FFMI_{Adj} ($\text{kg}\cdot\text{m}^{-2}$)**
Offensive Line (OL)	25.1 ± 2.0 *†
Defensive Line (DL)	25.2 ± 2.3 *†
Offensive Back (OB)	22.8 ± 1.8
Defensive Back (DB)	22.9 ± 1.4
Tight End/Linebacker (TE/LB)	23.8 ± 1.4 *

FFMI_{Adj} = Height-normalized fat-free mass index values.

[*] Significantly greater than OB and DB ($p < 0.05$)

[†] Significantly greater than TE/LB ($p < 0.05$)

Table 2

$\mathrm{FFMI_{Adj}}$ values among age groups. Values are mean ± SD.

Age (years)	**$\mathrm{FFMI_{Adj}}$ ($\mathrm{kg{\cdot}m^{-2}}$)**	**$\mathrm{FFMI_{Adj}}$ ($\mathrm{kg{\cdot}m^{-2}}$), corrected for position makeup**
≤ 18 (n=23)	24.0 ± 2.4	24.0 ± 1.8
19 (n=68)	23.5 ± 1.8	23.8 ± 1.8
20 (n=63)	23.6 ± 2.1	23.9 ± 1.8
21 (n=55)	24.2 ± 2.3	24.3 ± 1.8
≥ 22 (n=26)	23.5 ± 1.7	23.6 ± 1.8

$\mathrm{FFMI_{Adj}}$ = Height-normalized fat-free mass index values.

No significant differences between age groups ($p > 0.05$)