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Body composition of extreme performers in the US Marine Corps

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ABSTRACT

Background The creation of highly muscled and strong fighters is a recurring theme in human performance enhancement concepts. Physical readiness standards, intended to prevent obesity in the military, produce contradictory objectives, hounding large individuals to lose weight because of confusion between body size and body composition. Through selection, specialised training and policy exceptions the US Marine Corps has successfully developed a unique group of large (body mass index (BMI) >30 kg/m^2) and strong individuals, the body bearers (BB) who carry coffins of Marines to their final resting place.

Methods We examined the relationship between adiposity and body size from nine male BB (age 25.0±2.1, height: 1.84±0.04 (1.80–1.92) m, BMI: 33.0±2.1 (30–37) kg/m^2). Body composition was assessed by dual-energy X-ray absorptiometry (DXA), bioelectrical impedance (BIA) and tape measured abdominal circumference (AC)-based equations and from three-dimensional scanning (3DS).

Results Measures were made of fat-free mass (FFM): 90.5±7.0 (82.0–106.7) kg, where FFM included total body water: 62.8±5.0 (55.8–71.8) L, representing 69±2 (67–73) % of FFM, along with calculated FFM index: 26.8±2.4 (24.4–32.9) kg/m^2). DXA measures were made for bone mineral content 4.1±0.4 (3.5–4.9) kg, bone mineral density (BMD) 1.56±0.10 (1.37–1.76) g/cm^2 and %BF 19.5±6.6 (9.0–27.8). Additional measures of percent body fat (%BF) were made by AC: 20.3±2.9 (15.2–24.6), BIA: 23.7±6.4 (9.8–29.2) and 3DS: 25.5±4.7 (18.9–32.2). AC %BF reasonably matched DXA %BF, with expected overprediction and underprediction at low and high DXA %BF. BIA %BF was affected by deviations from assumed FFM hydration (72%–73%).

Conclusion These men are classified as obese by BMI but carried massive amounts of muscle and bone on their large frames, while presenting a range of %BF irrelevant to strength performance. BMI did not predict obesity and adiposity had no association with muscle mass and strength performance.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ 'Large and strong' are generally desirable characteristics for soldiers but military standards that use weight tables drive large individuals to try to become smaller.

⇒ The US Marines maintain an elite team of strong performers that serve as ceremonial body bearers; these individuals are large (body mass index (BMI) >30 kg/m^2) and carry a massive fat-free mass (>80 kg), based on dual-energy X-ray absorptiometry assessments.

WHAT THIS STUDY ADDS

⇒ Adiposity in this group was variable (9%–28% body fat) and unrelated to lean mass, or to strength performance and military appearance.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These data highlight a fundamental fallacy in using BMI to draw conclusions about obesity or physical readiness, where high BMI was actually associated with optimal performance for this job specialty.

INTRODUCTION

Concepts of body size and body composition are commonly confused in readiness standards and policies, as is the association of these characteristics to various aspects of military performance. Much of this confusion comes from the common use of body mass index (BMI) as a surrogate marker of obesity and increased health risk. In fact, BMI is a poor predictor of excess body fat or increased health risk in highly trained individuals. Previous studies such as the one by Matsuzawa *et al*[1] demonstrated normal markers of cardiovascular health risks in a group of very large physically fit sumo wrestlers. We report here the relationship between body size and several different estimates of body composition in another group of very large physically fit men.

Body composition standards have been enforced in the US Department of Defense since the 1980s. The US Marine Corps has traditionally led the military in fitness initiatives and policies, in part because of their focused mission where '*every Marine is a basic rifleman*'. In the 1980s, the military services were directed to follow the Marine Corps example and adopt abdominal circumference-based percent body fat (AC %BF) standards. This was to address the problem of obesity and physical readiness in a post-Vietnam era sedentary force. The Marines currently use weight-for-height tables to determine who may be overfat and need to be assessed against AC %BF standards; male screening weights are BMI 27.5 kg/m^2 and male BF limits are age 20–25 years, 18%; age 26–30 years, 19%. Although only a screening test to determine who may need to be assessed for the BF standard, the weight tables become a de facto standard to avoid the stigma of an '*overweight*' label, even if the individual meets BF standards.

It has become apparent that some very good physical performers are put in jeopardy with standards that inadvertently place the focus on weight (or BMI) and that set absolute %BF limits where the physiological impacts may be more variable than previously recognised. Comparison of military standards with the characteristics of strength athletes such as American football players highlights the conundrum between preventing obesity and degraded physical readiness, and the cultivation of superior strength performance. Behnke first called attention to this in 1945, reporting an early application of BF assessment to a group of professional football players who would have been rejected from military service for being overweight but had a mean body density of 1.080 gm/cm^3 (~8%–10%BF).[2] Development of the first military AC %BF methods by the US Marine Corps was a direct result of these early experiments.

A secondary issue that has not been evaluated is how body physique of very strong men influences the prediction of AC %BF; a larger midsection of powerlifters and the effect of the neck circumference in the predictive equation are relevant parts of this question. Previously, a neck strengthening study demonstrated that there was minimal hypertrophy of neck muscles in response to a 24-week training programme that produced strength gains.[3] This suggests that resistance training, even specifically targeting the neck, might not change body dimensions in a proportionate manner that will produce correct AC %BF estimates. We had a unique opportunity to evaluate the performance of the male AC %BF predictive equation in a select group of large and strong Marines (BMI >30 kg/m^2).

METHODS

Nine members of the select Marine Corps body bearers (BB) unit were studied in a single test session (age: 25.0±2.1 years, range 21–28 years). The group was not fasted as they eat approximately every 3 hours when not sleeping. Marines are competitively selected to serve in the BB and must meet height (177.8–193.0 cm), initial strength requirements (bench 10×102 kg; shoulder press 10×61.2 kg; curl 10×52.2 kg; squat 10×142 kg), achieve and maintain excellent performance on the physical fitness test (PFT) and combat fitness test (CFT) ('*first class*' scores, ≥235) and successfully complete Ceremonial Drill School. As a member of the team, they are provided with personalised training, nutrition guidance and conduct physical training (PT) several times per day.

Height (cm) and body mass (kg) were collected using a stadiometer and calibrated scale, respectively, while in standardised PT uniforms (athletic shorts and t-shirt) and without shoes. BMI (kg/m^2) was calculated from this information. Body circumference measurements were made in accordance with the Marine Corps Order 6110.3A CH-3, as previously described.[4] Briefly, circumferences were measured with an approved US Marine Corps tape measure that holds the tape flat against the skin to measure neck and abdomen (at the level of the umbilicus). Percent BF was calculated by: AC %BF=86.010×log10(abdomen−neck)−70.041×log10(height)+36.76.[5] Reproducibility of this estimate between experienced observers is±1% BF units.[5]

Body composition was assessed by dual-energy X-ray absorptiometry (DXA) (iDXA, GE Healthcare, Madison, Wisconsin, USA) and data analysis relied on manufacturer-supplied algorithms (enCORE, V.13.5, Lunar, Madison,Wisconsin, USA).[6 7] DXA-determined mass matched gravimetric measures for participants with the highest DXA %BF and overestimated scale weight by 2 kg for the two lowest DXA %BF men, not explained by deviations in hydration of the assumed fat-free mass (FFM). At the end of the DXA scan each volunteer remained in a relaxed prone position and total body resistance was measured at 50 kHz between left hand and left foot (Quantum IV, RJL Systems, Clinton Township, Wisconsin, USA) and total body water (TBW) and BF were calculated using the equations of Sun *et al*.[8] Full body surface scans (2 million data points) were obtained with volunteers in a standardised standing pose in booth scanner wearing only compression shorts (SS20, Size Stream, Cary, North Carolina, USA) and %BF was calculated using the Harty *et al* equation using machine determined biceps, waist, thigh and calf circumferences.[9] Percent BF was also calculated from BMI using the Deurenberg *et al* equation.[10]

Statistical analyses were performed using SPSS for Windows V.24 (IBM, Armonk, New York, USA). Descriptive statistics were calculated and reported as mean±SD for each group.

Table 1 Body composition values and ranges of USMC BB group (n=9)

Value	Mean±SD	Range
FFM (kg)	90.5±7.0	82.0–106.7
FFMI (kg/m^2)	26.8±2.4	24.4–32.9
BMC (kg)	4.1±0.4	3.5–4.9
TBW (L)	62.8±5.0	55.8–71.8
TBW/FFM	0.69±0.02	0.67–0.73

BMC, bone mineral content; FFM, fat-free mass; FFMI, fat-free mass index; TBW, total body water; TBW/FFM, proportion of water in the FFM; USMC, US Marine Corps.

RESULTS

Basic characteristics from the group (age, height, body mass, BMI) were: age 25±2.1 (21–28) years, height 1.84±0.04 (1.80–1.92) m, body mass 111.5±6.8 (103–124) kg, BMI 33.0±2.1 (30–37) kg/m^2. Measured body composition values (mean±SD, ranges) are shown in Table 1. The men averaged PFT, CFT scores of 268 and 264, repectively, and all the men demonstrated maximal or near-maximal performance in pull-ups (count of 23) and crunches (count of 110 or 115, depending on age).

Body composition data from DXA and bioelectrical impedance (BIA) are shown in Table 1. These large men based on body mass and BMI had relatively low DXA %BF (19.5±6.6) compared with Deurenberg *et al*[10] equation BMI-based predictions for the general population predictions (29.1±2.7%) (Table 2). All of the men exceeded BMI 30 kg/m^2 which classifies them as '*obese*' by conventional BMI categories, yet these men were remarkable for their very high FFM and FFMI, including a high bone mineral content (BMC) and bone mineral density (BMD) (1.55±0.10 g/cm^2). TBW fraction of FFM was below assumed normal values

Table 2 Measured and estimated values of body fat percentage (% BF)

Measure	Mean±SD	Range
DXA	19.5±6.6	9.0–27.8
AC	20.3±2.9	15.2–24.6
BIA	23.7±6.4	9.8–29.2
3DS	25.5±4.7	18.9–32.2
BMI-D	29.1±2.7	25.1–33.8

%BF methods: DXA, AC-based estimate,[5] BIA and Sun *et al*[8] equation, BMI-D, 3DS and Harty *et al*[9] equation.
AC, abdominal circumference; %BF, per cent body fat; BIA, bioelectrical impedance; BMI-D, BMI-based estimate Deurenberg *et al* equation; 3DS, 3D full body scan; DXA, dual-energy X-ray absorptiometry.

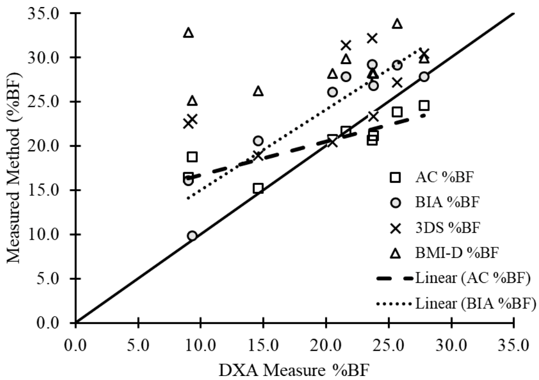

Figure 1 Comparison of dual-energy X-ray absorptiometry (DXA) measured to estimated body fat percentage (%BF). %BF methods: DXA scan, abdominal circumference (AC)-based estimate,[5] bioelectrical impedance (BIA) and Sun *et al*[8] equation, best fit lines are shown for AC %BF (dashed) and BIA %BF (dotted).

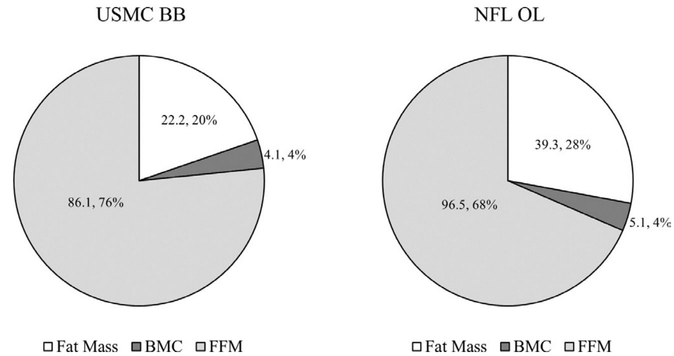

Figure 2 Comparison of body composition components of US Marine body bearers (BB) with a sample of National Football League (NFL) offensive linemen (OL). Data from Dengel *et al*[16] represent the bone mineral content (BMC) for a group of 65 OL from this sample. FFM, fat-free mass; USMC, US Marine Corps.

(0.72–0.74), averaging 0.69±0.02, based on BIA-assessed TBW and DXA-assessed FFM.

Percent BF assessed using four different predictive equations overestimated DXA %BF (Table 2). The male AC %BF equation overestimated the leanest men and underestimated the fattest men (Figure 1). BIA %BF matched or overestimated all of the men (Figure 1). The 3DS %BF from a new predictive equation and the Deurenberg *et al*[10] equation estimating %BF from BMI produced substantial overpredictions (Table 2).

Scale weight (115.5±6.8, 102.5–124.1 kg) was underestimated by DXA (112.7±6.6, 104.2–124.9 kg). This artefact in the interpretation of tissue attenuation values was largest (+2 kg) in the two leanest (~9% BF) volunteers and the best agreement between scale-assessed and DXA-assessed body mass was in men with the highest %BF.

DISCUSSION

The men in this study represented a group of elite performers selected to serve in their current job specialty on the basis of strength. They were characterised by extraordinarily high FFM, including muscle and bone, yet demonstrated a wide variation in relative BF (9 to nearly 29 %BF). Based on fat-free mass index (FFMI), these men are above the 99th percentile for FFMI of US men (National Health and Nutrition Examination Survey (NHANES), age 25 years).[11] These data are comparable to 53 young collegiate Division 1 American football defensive linemen reported in the consortium study by Bosch *et al*, averaging BMI 33.7 kg/m^2, FFM 87.6 kg and %BF 23.5.[12] These data also closely matched a cohort of 23 young professional sumo athletes averaging BMI 36.0 kg/m^2, FFM 83.2 kg and %BF 27 (based on underwater weighing).[13] However, they did not reach the upper human limits of lean mass described by Kraemer *et al* in the '*strongest man*' competitors.[14] This high FFM was attained despite the generalised training required of these Marines to maintain high standards on the Marine Corps CFT and the PFT. Run training compromises maximal resistance training gains in FFM, as demonstrated in Finnish conscript training studies.[15]

These select US Marine BB have relatively high BMC (kg) and BMD (g/cm^2), comparable to previously published data on professional American football players from Dengel *et al*.[16] Proportion of BMC is the same between these two groups (~4%) but the US Marine Corps BB had a lower relative fat mass (20%–28%) (Figure 2). Bone density of the US Marine Corps BB was higher than mean values reported for weight lifters by Karlsson *et al*[17] (Table 3).

The wide range of %BF confirms many other studies including military studies that demonstrate little to no association between fat and strength performance.[18] The general companionship of fat and lean has been well recognised and is nowhere more evident than in the large abdominal girth of many world class powerlifters.[19] Vasily Alekseyev, the 1970s Olympic powerlifting champion provides a stereotypical image the physique of a world class powerlifter; he reputedly ate massive amounts of protein-rich foods to maintain muscle mass and had BMI 46.2 kg/m^2 with a 48" waist and 21" biceps.[20] In contrast to strong men, body builders engage in extreme nutrition practices to separate the normal increases of both fat and lean, and their impressive appearance may not be consistent with physical readiness and performance.[21]

A strong association between resistance trained athletes and bone mass and BMD has been previously reported.[11 12] In this study, we also noted extraordinarily high BMC and BMD. It is important to distinguish the DXA device when comparing values between studies as Hologics systems provide lower values than the Lunar systems and the newer fan beam technologies may produce artefacts related to the overlying soft tissue.[22] Nevertheless, comparisons between studies using similar systems confirmed that the men in this study have extraordinarily high bone density and BMD. Further research is needed to discern the relative contributions of genetics and strength training to these upper limits of bone and muscle mass.[23]

Body shape and size can affect all of the DXA measurements and in our study it was evident that the two leanest men had the greatest deviation in estimated TBM from the DXA compared

Table 3 Total bone mineral density (BMD, g/cm^2) comparison of USMC BB group with weight lifters

Group	Mean±SD	Age group
USMC BB (n=9)	1.55±0.10	25±2.1
Lifters (n=40)	1.36±0.19	33.2±10.7
Lifter control (n=52)	1.24±0.09	32.5±9.0
Active lifters (n=21)	1.38±0.25	26.0±8.7
Active lifter control group (n=37)	1.26±0.09	27.8±4.7

Data from Karlsson *et al*[17] represent BMD for weight lifters and age-matched control groups.
BB, body bearers; USMC, US Marine Corps.

with calibrated scale weights (~2 kg overestimation) while the two fattest men were correctly estimated. In a much earlier study with 1990 DXA technology, we noted that chronic semi-starvation in the US Army Ranger Course produced significant overestimations of body mass at the end of the course that were not present at the start of the course; we attributed this to a major effect of semi-starvation confirmed in that study with water isotopes but those men had also been reduced to unusually low relative fat.[24] In the current study, the artefact does not appear to be explained by noted differences in hydration of the FFM.

An important observation in this study was that the body circumference-based %BF prediction used by the US military is a reasonable predictor of %BF even in massive strength trained men; this has been a persistent unanswered question. The '*tape test*' performance (ie, AC %BF) in this group provides a good illustration of what is being assessed in men with an AC. The male prediction equation uses height, neck and abdominal (at the umbilicus) circumferences. The abdominal measurement targets the primary site of male fat deposition, but underestimates low %BF individuals as the measure cannot detect the difference in intra-abdominal fat at the low end and it overestimates high %BF individuals by missing fat that begins to deposit elsewhere in the body as BF increases.[4 25] This trend held true in this study as well, with the lowest %BF Marines overestimated by AC %BF compared with DXA %BF and the highest %BF Marines underestimated. The neck circumference represents a lean mass and/or frame size correction to abdomen in the equation; the equation uses a factor from AC minus neck circumference. Military strength athletes have asked if there is a bias against strength athletes with this equation and wondered if neck size has a stronger genetic basis than the influence of training. Several neck strengthening studies, including one by the Naval Health Research Center specifically intended to address this question, found relatively smallchanges with a 24-week neck training programme.[3] Neck circumference follows a linear relationship with BMI; because of this relationship, neck circumference has been proposed as an indicator of obesity.[26] One threshold proposed (neck circumference >37 cm) would indeed identify all of the men in this study as BMI >30 kg/m^2, correctly providing a size factor but not useful without the AC in estimating body composition. The necks of these men were proportionately large to match their large lean mass. Height is important in the equation as it provides a proportional adjustment that prevents overestimation of %BF in taller men.[27]

The estimation of %BF using BMI is inappropriate in heavily muscled men. The Deurenberg *et al*[10] equation to estimate %BF from BMI works reasonably well for a population of normal aerobically fit (bicycling) men and women from which it was derived, but cannot distinguish the high FFM component of these men who all exceeded BMI 30 kg/m^2. This is highlighted in Figure 3, where three Marines of similar age and %BF (8%–9%) with differing lean mass would be interpreted by BMI as being '*healthy*', '*overweight*' or '*obese*' In fact, the heaviest lean Marine in these images is one of the elite performers from this study.

Estimation of %BF using single frequency BIA was accurate only when the normal assumptions of hydration of 72%–73% of FFM held true.[28] This was the case for only two of these men, where the rest of the group may have had an osmoregulatory shift produced from their daily intensive PT regimens and despite the fact that they practised good water discipline and did not consider themselves underhydrated. The high BMC may also contribute to an altered water fraction of the normal FFM. Regardless of the cause, the lower than assumed FFM hydration results in overestimates of %BF; in the case of these men, by an average of >+4% BF.

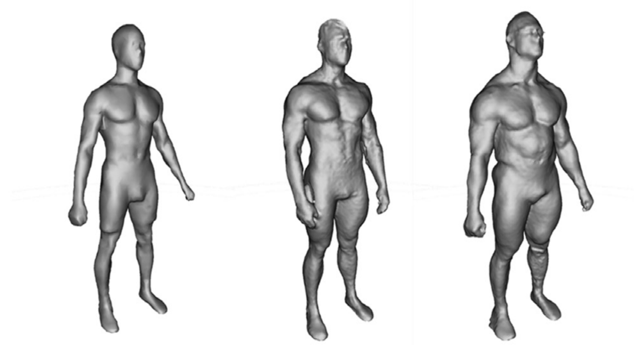

Figure 3 Three age-matched male US Marines with similar body fat percentages (8%–9%BF) with progressively higher body mass index (BMI).

Predictive algorithms from the 3D scanner technology are still in development but with great promise including the possibility of meaningful assessment of muscle mass and body physique, as articulated by Harty *et al*.[29] Harty *et al* has developed an initial %BF equation, using modern machine learning analytic tools applied to the large number of body measurements that can be obtained in these scans.[9] This current equation, developed from a large dataset and using a novel algorithm that takes advantage of body circumferences defined by the machine, overestimated %BF of the men in this study who had physiques that were unlikely to be well represented in the original test sample.

This study quantified the extraordinary FFM of this special group of Marines and verified for the first time that the AC %BF for men does not grossly misclassify very muscular strength trained men. The results also highlight the larger range of %BF that might be tolerated in body composition standards if strength performance is valued in military performance. It may be a useful point of reference in resetting body composition perceptions to realise that most men have higher relative BF than the ~10 %BF of the typical Asian elephant.[30] Further inquiries into accurate prediction and relevant thresholds of lean mass will be important to improved screening and standards for a modern ground force still faced with a preponderance of lifting and carrying tasks and with a new influx of '*skinny fat*' (metabolically obese normal weight) digital age recruits.

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Competing interests None declared.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study was approved by the US Army Medical Research and Materiel Command Institutional Review Board and by the US Marine Corps Institutional Review Board. All participants were briefed on the purpose, risks and benefits of the study and provided written informed consent before testing.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy and associated regulatory constraints.

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