Assessing Body Composition Among Male Collegiate Runners and Swimmers Using Dual-Energy X-ray Absorptiometry (DXA)

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Abstract

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This observational study investigated whole body and regional differences in bone mineral density and soft tissue amounts (fat mass versus lean mass) among collegiate runners and swimmers using dual energy X-ray absorptiometry (DXA) for body composition measurement. A data subset was gathered for post-hoc analysis on a group of Caucasian male Cal Poly swimmers (n=20) and Cal Poly track and field runners (n=20) of similar age (18-25 years) and race. In addition to their sport-specific training, both teams had engaged in free weight training and running for approximately 12 weeks prior to their DXA scans. Group mean values for total body and regional bone mineral density (BMD) and percent body fat (% BF) were then compared, as were ratios for soft tissue distribution among the athletes. Multiple correlations between BMD, age, body weight (BW), fat mass (FM), lean tissue mass (LTM) and sport grouping were also determined.

Results for bone mineral differences between the two groups were consistent with past literature, as the runners had significantly greater total body BMD (p=0.000), and regional BMD of the legs (p=0.000). Swimmers possessed significantly greater total % BF (p=0.004), and legs % BF (p=0.004), despite having a greater lean torso-to-legs (LTL) ratio than the runners (p=0.000). However, even though the swimmers exhibited the greater average BW of the two groups, the runners actually had more measured LTM (in kg) located in the legs than the swimmers. The track

runners had a greater FFM/FM ratio, but this value narrowly missed significance ($p=0.012$) after Bonferroni correction for multiple test comparisons lowered the level of significance ($p<0.0083$). The FFM/FM ratio was not correlated to the BMD among all subjects.

Several significant correlations were found among the body composition and group descriptive variables. Total BMD was predicted by BW (Pearson $r=0.421$, $p=0.007$) and whole-body LTM ($r=0.468$, $p=0.002$) among both groups. The strongest correlation was displayed between LTM and BW for both groups ($r=0.932$, $p=0.000$). While much is known in the research about the relationship between BW and load-bearing forces among weight-bearing and non-weight-bearing athletes, these data findings suggest that soft tissue distribution differences among such athletes should be further evaluated. Future research conducted with larger athlete sample sizes may possibly be able to determine what other physiological factors (age, hormonal and metabolic variations, muscular contractions, etc.) have the most influence on such differences in body composition.

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Chapter 1

Introduction

Background of the Study

Body composition testing among athletes has been performed using a variety of different methods such as skinfold testing (SKF), hydrostatic weighing (HW), and bioelectrical impedance (BIA) (Lohman & Chen, 2005). Perhaps the most promising and practical means of testing body composition is dual energy X-ray absorptiometry (DXA). A DXA scan uses two low-radiation energy beams of differing energies that pass through a subject lying on a table. Total-body and regional amounts of both bone mineral and soft tissue mass can then be estimated based on the different attenuation rates of these beams. Many DXA machines can scan the entire body in about five minutes, and expose the subject to a much smaller radiation dose than that used during computed tomography (CT) or magnetic resonance image (MRI) scans. The DXA scan is a two-dimensional, pixilated image that distinguishes between bone, fat mass and lean soft tissue mass within the body. Bone mineral content (BMC) is the most basic unit of measuring bone amounts (in grams) using DXA. Bone quantities can also be expressed as bone mineral density (BMD) and quantified in units of g/cm^2 across the body. While DXA is used as a preferable "gold standard" method for measuring BMD, its potential to assess fat and fat-free mass continues to improve.

Many studies using DXA have compared BMD between athletes involved in weight-bearing sports to those in non-weight-bearing sports to investigate risk of fracture injuries or correlation to lifelong health (Taafe, Snow-Harter, Connolly, Robinson, Brown, and Marcus, 1995, Bennell, Malcolm, Khan, Thomas, Reid, Brukner, Ebeling, and Wark, 1997, Calbet, Dorado, Diaz-Herrera, and Rodriguez-Rodriguez, 2001, and Mudd, Fornetti, and Pivarnik, 2007). Several studies of this nature have used runners and swimmers as their representative weight-bearing and non-weight-bearing subjects, respectively (Kemmler, Engelke, Baumann, Beeskow, von Stengel, Weineck, Kalender, 2006, Brahm, Strom, Piehl-Aulin, Mallmin, and Ljunghall, 1997, Hind, Truscott, and Evans, 2006, Avlonituou, Georgiou, Douskas, and Louizi, 1997, Taaffe & Marcus, 1999, and Emslander, Sinaki, Muhs, Chao, Wahner, Bryant, Riggs, and Eastell, 1998). Male and female swimmers from a wide variety of age groups were found to have BMD values not significantly different than age-matched, non-athlete controls, while they displayed significantly lower BMD than runners and weight-bearing athletes across most studies (Taaffe et al., 1995, Avlonitiou et al., 1997, and Creighton, Morgan, Boardley, and Brolinson, 2001). This research suggests that forceful muscle contractions alone (such as those taking place in swimming, rowing, or water polo) confer no significant BMD enhancements without weight-bearing exercise (Taaffe et al., 1995, Avlonitiou et al., 1997, Taaffe et al., 1999, and Emslander et al., 1998). Studies on weight-bearing athletes have shown the greatest BMD values among sports with high impact ground forces (ex. track), with the larger differences observed at loaded sites (i.e., legs) only (Kemmler, 2006, Bennell et al., 1997, and Creighton, 2001). One possibility to be considered may be that if swimmers added more cross-training (i.e., running and lifting weights) to their workout regimen, then the marked differences in their BMD as compared to runner's BMD might then disappear.

While a great deal is known about bone density from DXA studies, research comparing fat mass and lean mass among athletes is generally more scarce when DXA is the research tool. Some research articles studying athletes suggest total body mass or lean mass to be superior predictors of BMD (Andreoli, Monteleone, Van Loan, Promenzio, Tarantino, and De Lorenzo, 2001, and Nevill, Holder, and Stewart, 2003, Taaffe et al., 1999, and Mudd et al., 2007), but more research is needed to examine correlations between BMD and fat-free mass/fat mass ratios.

Before such correlations can be determined, additional studies comparing soft-tissue mass differences between runners and swimmers are required. The studies that have assessed the soft tissue mass among weight-bearing and non-weight-bearing athletes have found that percent fat and percent lean muscle were sufficient values for correlating soft tissue mass to BMD (Stewart & Hannan, 2000c, Taaffe et al., 1995 and Silvestre, West, Maresh, and Kraemer, 2006). Ratios of fat free mass/fat mass (FFM/FM) among athletes have been commonly used in the research, but differ slightly from estimates of percent body fat (% BF), which is calculated by dividing fat mass by an individual's total body mass (Fornetti, Pivarnik, Foley, and Fiechtner, 1999). In addition, regional intra-person ratios that do not require a correction for total body mass - such as lean mass *torso* to lean mass *legs* - are also great comparative values that could lead to additional discoveries when looking at the body composition in different athletes (Stewart & Hannan, 2000c and Taaffe et al., 1995).

It is commonly known that activities like running and total body resistive weight training (both of which involve large muscle groups) can result in hormonal and metabolic variations within the body. These are two of four key factors (along with biomechanical loading and genetics) known to influence bone mineral content or BMD (Andreoli et al., 2001, and Taaffe et al., 1999). Further comparative studies could lead to a wide realm of new information. For example, new DXA software programs are now able to correlate lean tissue mass (LTM) to resting energy expenditure (REE), as one study found that 90% of variations in the REE of subjects could be explained by LTM and fat mass amounts (Kistorp, Toubro, Astrup, and Svendsen, 2000). Research on how different training modes could affect these physiological variables in athletes is possible with DXA, and could extend well beyond simply measuring bone mineral content.

Statement of the Problem

Several research studies have evaluated the BMD of runners and swimmers, but fewer studies have looked at a correlation between BMD and the fat-free mass to fat mass ratio (FFM/FM), as well as regional distribution of soft tissue. A limited amount of research using DXA has suggested runners to be significantly leaner than swimmers (see Table 1), but no known studies have investigated swimmers who were regularly engaged in weight-bearing cross training. To date, more reports of soft tissue mass comparisons are presently needed between these athletes.

Statement of the Purpose

The purpose of this study was two-fold; first, to assess and contrast whole body and regional differences in bone mineral density, fat mass, and lean mass amounts among male, NCAA Division-I collegiate runners and swimmers engaged in cross-training techniques (i.e., running and lifting weights) over the same amount of time. The second purpose of this study was to strengthen the literature support for using DXA as a valuable and practical body composition measurement tool with such assessments among athletes.

Research Questions

While many studies using DXA have assessed the BMD of runners and swimmers, more research is needed to better investigate body composition differences between these weight-bearing and non-weight-bearing athletes. Will swimmers regularly cross-training still exhibit a significantly lower BMD of the legs than runners? Would such BMD differences also be seen across the total body? Are there significant differences in the average total body or leg percent fat values between runners and swimmers in the current study? Does lean mass distribution differ substantially between these athletes, as evident by an average LTL ratio of percent lean *torso* to percent lean *legs*? Will runners and swimmers display significantly different ratios of fat-free mass to fat mass (FFM/FM), and might these values be correlated to their BMD?

Research Hypotheses

It was hypothesized that:

1. Despite the cross-training methods of the swimmers, they will exhibit a significantly lower average total bone mineral density as compared to the runners.

2. Despite the cross-training methods of the swimmers, they will exhibit a significantly lower average bone mineral density of the legs as compared to the runners.

3. There will be a significant difference in the average total body percent fat between the runners and swimmers, with the latter group having the higher values.

4. There will be a significant difference in the average percent fat (legs) between the runners and swimmers, with the latter group having the higher values.

5. There will be a significant difference in the average ratios of percent lean *torso* to percent lean *legs* between runners and swimmers, with the latter group also having a higher LTL ratio.

6. Runners will have a higher average ratio of fat-free mass to fat mass as compared to swimmers, and these values will be correlated to the average BMD values for all subjects.

Assumptions

The study was based on the following assumptions:

1. Some modes of weight-bearing cross-training between groups were similar, as weight training was performed with nearly identical volumes, while runners did perform more running as required by their sport (accounts based on interviews with coaches).

2. That DXA testing took place as athletes from both sports had been lifting weights and running during nearly identical time periods prior to their respective test dates.

3. That no athlete tested deviated grossly from the team training regimen, given the rigorous demands of daily sport specific training.

Delimitations

The study was delimited as follows:

1. Two groups of male collegiate athletes of identical sample sizes (n=20, age 18-25 years, Caucasian ethnicity) were test subjects in the study.

2. Coaches were interviewed and asked to confirm modes and volumes of weight-bearing exercise that took place prior to the time of testing.

3. DXA scans were performed using the same machine on different dates, with good intra-tester precision and the same test technician.

Limitations

The study was limited as follows:

1. All subjects were Caucasian male runners or swimmers, age 18-25 years, who were competing in an NCAA Division-I athletic program.

2. Some track and field athletes were excluded from the runner subject group based on event or training routines (i.e., throwers, jumpers, short sprinters and pole vaulters).

3. All training modes and volumes taking place during offseason competition periods and at the time of testing were generalized by coaches' accounts and not controlled for in this study.

4. No examinations of genetic information, hormonal status, or nutritional intake of the subjects were conducted.

Definition of Terms

The following terms or abbreviations are defined as used in the study:

BMC. (Bone mineral content). A measurement of bone mineral found in the region of interest. BMC is measured in grams (g).

BMD. (Bone mineral density). A measurement of bone mineral in a region, measured in grams per centimeters squared (g/cm^2). BMD is derived using BMC divided by area.

Cross-training. Mixed modes of training outside of the requirements of one's own sport. In the case of this study, cross-training describes the running and free weight training of the swim group; while all runners performed free weight training, only a few incorporated short-term swim training during periods of injury.

CT. (Computed tomography). Method of producing an image that quantifies components of tissues, organs, and bone within the body by using ionizing radiation.

DXA. (Dual-energy x-ray absorptiometry). Method of producing an image that quantifies components of bone mineral content and soft tissue amounts within the body by using attenuated radiation.

FFM. (Fat-free mass). Mass within the body to include bone plus lean soft tissue.

FM. (Fat mass). Mass within the body that is composed of adipose tissue.

LTL. (Lean torso-to-leg). Ratio of lean tissue mass *torso* to lean tissue mass *legs*, as measured in grams (g).

LTM. (Lean tissue mass). Non-adipose soft tissue; primarily muscle mass.

MRI. (Magnetic resonance image). Method of producing an image that quantifies components of tissue within the body by using the magnetic field interaction by hydrogen protons.

REE. (Resting energy expenditure). The body's caloric expenditure before factoring in exercise and food intake in a 24 hour period.

Runners. For purposes of this study, runners group includes any NCAA D-I track or cross country athlete who routinely incorporated repeatedly running distances of at least 400 meters (excludes pole vaulters, throwers, jumpers, and short sprinters).

Swimmers. For purposes of this study, swimmers group includes any Caucasian male NCAA D-I swimmer (age 18-25 years), regardless of distance specialty.

TBM. (Total body mass). Includes all of the bone, tissues, and organs in the body.

Torso. A combination of the trunk and arm regions. The DXA-measured body region for the trunk is a rectangular region of interest with its inferior and superior borders just on top of the iliac crests but just below the chin, respectively, and its lateral borders placed just wide enough to include all soft tissue surrounding the rib cage.

Weight-bearing. Defined as a kinetic activity where an external load or ground reaction force is applied to the body.

Chapter 2

Review of the Literature

Assessing body composition in living humans has traditionally been done relying on two-compartment (2C) assessment models. The 2C models (or methods) are limited by the fact that they strive to distinguish between only two components in the body: fat mass and fat-free mass (DeLorenzo, Bertini, Iacopino, Pagliato, Testolin, Testolin, 2000). These popular methods, such as skinfold testing (SKF), hydrostatic weighing (HW), and bioelectrical impedance (BIA) are becoming less preferred because of their limitations, as more technologically advanced methods are now being introduced (Ball, Altena, and Swan, 2004, and Stewart & Hannan, 2000a). The primary problem with these 2C methods is that until recently, they have relied on prediction equations developed back in the 1970's and 1980's which estimate the density of bone and hydration status of the fat-free mass (bone + muscle tissues) in different non-athlete reference populations (Stewart & Hannan, 2000a). Since that time, more recently introduced methods are able to directly measure these body components, which previously were only estimated by older 2C models (Ball et al., 2004).

Perhaps the most promising and practical means of measuring body composition is dual energy X-ray absorptiometry (DXA). A DXA scan is considered a three-compartment (3C) model, as it can differentiate between bone, fat mass and lean soft tissue mass without having to make assumptions regarding their densities (Ball et al., 2004). The purpose of this review is to evaluate the findings of research that used DXA bone density, fat and lean soft tissue mass measurements among male athletes in weight-bearing and non-weight-bearing sports. The overall potential of DXA as a total body composition method (as it compares to other test methods) is also discussed.

Comparisons Among Methods of Body Composition Testing

Underwater hydrostatic weighing (HW) - formerly known as the 2C “gold standard” of assessing body composition - is likely the most widespread reference method used for estimating fat mass in athletes (DeLorenzo et al., 2000). However, hydrostatic weighing may not be an accurate measure because the density of the fat-free mass (bone and muscle tissue) varies greatly, especially among athletes (Stewart & Hannan, 2000a). Therefore, the prediction equations - which rely on estimated bone density or muscle density norms - may be inappropriate when used to convert their underwater weight (body density) to a percent body fat. A research review by Stewart & Hannan (2000a) found DXA to have a lower standard error estimate (SEE) than HW, thus amounting to an approximate one percent difference in measured percent body fat of 172 young men and women. In this study, DXA % fat values were slightly higher, due to the HW test’s reliance on inexact body density norms. In his review, Stewart also suggests that some of this error with HW could likely come as a result of the varying levels of confidence of the subjects when immersed in water. For example, those subjects who are not comfortable exhaling all of their air underwater would appear to have more body fat (and a lower body density) due to the remaining air in the lungs.

In addition to relying on popular prediction equations - such as Jackson and Pollock’s three site equation (Stewart & Hannan, 2000a) - skinfold caliper testing (SKF) holds the greatest potential for human tester error among all methods, and is limited in its ability to measure more than just subcutaneous fat (directly underlying skin). Tester error is also a limiting factor in the accuracy of SKF predictions, as even experienced testers are subject to a SEE of 3.5% body fat (Adams and Beam, 2007). In a study comparing similar anthropometric measures conducted on 82 male athletes, skinfold equations displayed a larger standard error in their predictions of percent fat than did DXA methods, with a SEE of ~3.5% for SKF and ~2.8% for DXA (Stewart & Hannan, 2000a). Additionally, skinfold caliper testing has frequently been proven to underestimate total fat mass in comparison with DXA (Ball et al., 2004, Oates, Puhl, and Wacker, 2006, DeLorenzo et al., 2000, and Avlonitou et al., 1997). Indeed, DXA % fat was about 4.6 percent higher than skinfold values in two separate studies of over 200 male athletes combined (Ball et al., 2004, and DeLorenzo et al., 2000). Skinfold testing, however, remains as one of the quickest and most convenient 2C methods of body composition field testing.

Bioelectrical Impedance Analysis (BIA) is also a quick and easy means of assessing body composition across two compartments. BIA works by sending a current through the body, whereby the measured resistance that the current encounters is dependent on the ratio of intracellular water to extracellular water in various body tissues. Unfortunately, until very recently, the prediction equations that BIA methods have used for distinguishing fat mass from lean mass have been very dependent on the subject's hydration status, making BIA equally susceptible to estimation error, much like the aforementioned test methods (Stewart & Hannan, 2000a, and Oates et al., 2006). Recent equations developed in 2009 show promise that the accuracy of BIA is improving in its measurement of some specific populations (Kanellakis, Kourlaba, Moschonis, Vandorou, and Manios, 2010). Future research will determine the effectiveness of these changes.

Another technological two-compartment method of testing body composition is through air displacement plethysmography. The BODPOD (Life Measurement Instruments Inc., Concord, CA) is the primary test instrument: an egg-shaped capsule with two chambers, one of which the swimwear-clad subject climbs into before it is sealed. Air pressure then increases through a port in the machine, allowing the new volume of air (surrounding subject) to be subtracted from the previous total volume (measured before the subject entered). For best accuracy, the subject is then instructed to follow a breathing pattern using a tube to measure lung volume. Much like HW, the difference in air volumes (represents body density) is then plugged into the Siri equation to determine body fat. Many studies have found the reliability and validity of the BODPOD to be very good, and nearly identical to HW, but with similar limitations if lung volume is estimated and not directly measured. The BODPOD may still introduce the possibility of human error with uncomfortable or confused subjects who may have difficulty following the tube breathing protocol. Since plethysmography is a 2C model, it remains inferior to DXA, and is likewise affected by technical and model error, unlike four compartment (4C) methods, which are actually able to measure water and mineral fractions of the FFM (Going, 2005).

DXA body composition measurements show a strong correlation to popular two-compartment methods across multiple quantitative research studies (Lohman & Chen, 2000, Ball et al., 2004, and Oates et al., 2006). While DXA soft tissue measures correlate well with other methods, DXA has often yielded significantly higher % fat values (DeLorenzo et al., 2000, Oates et al., 2006, and McLauglin, Lail, Morrill, Viola, Wygand, and Otto, 2003), partly as a result of the machine's calibration and software algorithms. In comparison to DXA, the 2C methods (SKF, UW and BIA) all have a tendency to underestimate body fat (by at least three percent) and to equally overestimate lean soft tissue mass, with the respective difference sizes being listed in ascending order, starting with the latter method (Ball et al., 2004, Oates et al., 2006, and DeLorenzo et al., 2000). Despite some good correlations, multiple regression studies demonstrate that it is not advisable to compare percent body fat values across the various methods, all of which use completely different prediction equations to arrive at their final product in predicting fatness (DeLorenzo et al., 2000, and Oates et al., 2006).

<u>DXA and Ideal Reference Methods for Body Composition Testing</u>

Hydration levels within the fat-free mass can vary significantly, being composed of between 71-75% water (Lohman et al., 2000). Hydration status can therefore affect body density values given by 2C tests, and any body composition method that assumes a constant density of the fat-free mass must be considered inferior as a reference. The variations in water content within both muscle and bone are greatest among athletes of different sports, who also contain higher water, mineral and protein constituents than the non-athlete population (DeLorenzo et al., 2000). A few studies on collegiate athletes have found that gymnasts, for example, have exhibited an extremely high density of the fat-free mass (D_{FFM}), even higher than other collegiate athletes (such as football players) who possessed more total lean mass (Prior, Modlesky, Evans, Sloniger, Saunders, Lewis and Cureton, 2001, and Taaffe et al., 1995). This was explained by the fact that bone mineral has a greater density than lean muscle. Therefore, since the football players abundance of muscle mass contained more water, their D_{FFM} was actually less than that of the gymnasts, whose D_{FFM} had a greater proportion of dense bone (Prior et al., 2001). A group of swimmers from one study (n=111 athletes total) exhibited the lowest D_{FFM} (Kohrt, 1998 and Prior et al., 2001). Such findings were well summarized by Prior (2001), who stated that, "Any prediction equations that assume constant FFM proportions can be inaccurate when applied to certain groups of athletes." In the case of the longstanding Siri equation for body density (which generally assumes a D_{FFM} value of 1.1 g/cm^3), a mean percent body fat estimation error of 2-5% of total body mass could occur (Prior et al., 2001).

Ideally, four-compartment (4C) assessment models - which are able to directly measure body water fractions by isotope dilution - stand as the true "gold standard" when measuring body composition (Ball et al., 2004). However, these 4C test methods remain too costly and time consuming for widespread testing in the field (Stewart & Hannan, 2000a). Special equipment is required to perform such tests, and these resources are still largely unavailable or limited to major research institutions. Therefore, until such practical testing methods and prediction criteria are established for athletes, DXA may be the preferred choice (Stewart & Hannan, 2000a). While DXA calibration methods do assume a standard 73% water composition for the fat-free mass (FFM), they are only slightly affected by extreme hydration variations within the FFM, which lends to good precision (Plank, 2005, Kohrt, 1995, Kelly, Berger, and Richardson, 1998, Lohman et al., 2000, Ball et al., 2004, and DeLorenzo et al., 2000). Furthermore, in Lohman et al.'s (2000) review, which investigated reports of how hydration changes of FFM affected DXA % BF values, the author suggested that "a 5% change in the water content of FFM affects DXA estimates of body fatness between 1-2.5%." Overall estimates of body fat using DXA have shown to measure within 1-3% of four-compartment body fat values, an acceptable standard error of comparison (within 3%) according to leading researchers (Lohman et al., 2000).

While DXA is the primary means of accurately assessing bone mineral content, some researchers may be hesitant to define it as a new "gold standard" for assessing total body composition (Stewart & Hannan, 2000a, and DeLorenzo et al., 2000). Multi-slice computerized axial tomography (CT) and magnetic resonance imagery (MRI) scans remain the superior diagnostic tools in terms of measuring soft tissue with highest absolute accuracy, although radiation exposure is higher, and access to this technology is limited and much more costly. By comparison, DXA scans also operate using negligible levels of radiation for all adult groups aside from pregnant women, who are more susceptible to lower radiation doses due to the developing embryo or fetus. It must be remembered, however, that while DXA can measure total body fat, it does not have the resolution properties needed to distinguish between subcutaneous and visceral adipose tissue. MRI and multi-slice CT scans, on the other hand, do have this capability (Stewart & Hannan, 2000a). As for lean muscle, one study measuring three different body regions among 27 male athletes demonstrated that multi-slice CT scan defined skeletal muscle mass more accurately than DXA (Wang, Wang, Faith, Kotler, Shih, and Heymsfield, 1999). A similar study did report an excellent correlation between DXA measured FFM as compared to multi-slice CT scan, but also noted a consistent overestimation of leg muscle mass by DXA (Levine, Abboud, Barry, Reed, Sheedy, and Jensen, 2000). These researchers hypothesized that "since adipose tissue is composed of about only 85% lipid, the nonfat components of adipose tissue might be included" in the DXA measured pixels.

Past studies have also cited DXA's difficulty in accurately quantifying soft tissue areas that directly overlay bone, (Kohrt, 1995, Stewart & Hannan, 2000a, and Genton, Hans, Kyle, and Pichard, 2002). Ball et al., (2004) warned that the area around the rib cage may be of greatest concern, stating that "The pixels directly over bone must be extrapolated from the nearby non-bone containing pixels." One study claimed that DXA failed to record any significant fat in the torso region of three of its leanest subjects (Stewart & Hannan, 2000a). Additional studies observed that early DXA scans underestimated fat content in the central torso, while producing no such discrepancies in peripheral body regions. However, these same researchers now acknowledge that these measurement errors have been corrected by updated DXA software versions (Kohrt, 1998). Furthermore, the ever-improving precision of DXA technology has been praised by many researchers. Kohrt (1998) and Lohman et al., (2000) both found that DXA estimates of body fat were within 1-3% of 4C methods measuring total body water, and that DXA is capable of accurately assessing fat mass changes down to 1.5 kg.

Despite its limitations, DXA remains superior to any two compartment body composition testing techniques because of its ability to directly measure the density of bone as a third compartment (Ball et al., 2004). DXA software is becoming more and more accurate with each version introduced, with new calibration modes to increase precision and accuracy, plus improved x-ray tube and detectors for improved image resolution (O'Connor, 2006a). Therefore, the margin for human tester error is rapidly decreasing with each advance in technology. Factor in the machine's precision, time efficiency (most fan beam scans last between 5-10 minutes) and growing availability as an anthropometric tool, and it is easy to envision DXA becoming the preferred body composition reference standard in the future.

Relationships between athletes' bone mineral density, soft tissue amounts

Some research studies using DXA go beyond simply reporting findings of just bone mineral density, and are now examining soft tissue (fat and lean mass) content amongst athletes as well. Bone mineral density (BMD) among athletes has repeatedly been proven to have a very high correlation to anthropometric measures of total body mass (TBM), LTM, or even FM. Body size (along with variables such as age, sex, ethnicity, diet and exercise habits) is known to greatly influence bone mineral density (Lohman & Chen, 2005). Total body mass alone has shown a positive correlation to the variables of both bone mineral content (BMC) and BMD (Nevill et al., 2003, Taaffe & Marcus, 1999, and Mudd et al., 2007). In his research, Taafe (1995) claimed that "several studies report an association of muscle strength and muscle mass with bone mineral." Related studies on different groups of athletes have reported that BMC of limbs increased in proportion to subjects' whole-body fat-free mass (Nevill et al., 2003, and Taaffe & Marcus, 1999).

Furthermore, muscle mass has shown to be an independent predictor of both regional and total BMD in studies of gymnasts, controls, and non-weight-bearing elite swimmers (Taaffe et al., 1995, Andreoli et al., 2001, and Taaffe & Marcus, 1999). A study of 33 right-leg dominant male soccer players showed a high correlation between the BMD and the muscle mass in the left (plant) leg (Calbet, Dorado, Diaz-Herrera, and Rodriguez-Rodriguez, 2001). One DXA study, however, found that although water polo players had significantly higher muscle mass than martial arts athletes, they also displayed a significantly lower total body BMD value. This led researchers to speculate that appendicular muscle mass alone is not entirely responsible for increased BMD. The fat mass of the water polo players also was not correlated to BMD (Andreoli et al., 2001). Research by (Kemmler et al., (2006) similarly found body fat to be a negligible determinant of BMD among 20 elite male distance runners (mean age=26.6 years).

Other findings, however, have indeed suggested a relationship of fat mass (FM) to BMD among athletes of both genders (Creighton, et al., 2001 and Taaffe, 1999). Creighton et al.'s (2001) study, in particular, discovered an intriguing trend when categorizing 41 female collegiate athletes, grouping them by the differing impact forces their training produced. Among high, medium, and non-impact groups (plus controls), measured bone mineral density values descended in that order, respectively; while percent body fat increased with nearly identical proportions. Along these lines, studies of elite male distance runners have reported that those runners who resistance trained more than twice per week exhibited a lower percent body fat (10.1% versus 11.4%) and a higher bone mineral T-score (0.4 to -1.1) at the lumbar spine (Hind et al., 2006). A T-score is the difference between the subject's BMD and the mean young adult value of the reference population, divided by the reference standard deviation; these scores are most often used to assess fracture risk. In terms of fat distribution alone, weight-bearing activities like running that involve multiple large muscle groups may have a lipolytic effect similar to resistance training. One study found the amount of body fat in the legs and abdomen to be associated with running volume (defined here as a combination of frequency and intensity of training), as elite runners had a lower fat percentage than recreational runners, particularly with abdominal adipose tissue (Hetland, Haarbo, and Christiansen, 1998).

Body composition findings among runners and swimmers

A multitude of research has been performed with the purpose of assessing the bone mineral density of athletes in weight-bearing and non-weight-bearing sports, and some of these articles have reported soft-tissue mass differences as well (Table 1). Many of these BMD studies have highlighted swimmers and endurance runners, with a particular focus on females because of their susceptibility to reduced BMD related to the female athlete triad, or the link between osteoporosis, disordered eating, and menstrual disorders (Mudd et al., 2007). Yet several research articles have looked at the BMD of male runners as well (Bennell et al., 1997, Brahm et al., 1997, Hetland et al., 1998, Kemmler et al., 2006, and Stewart & Hannan, 2000b). As previously established, it has been proven that weight-bearing athletes such as runners, gymnasts, and weight lifters exhibit higher bone mineral content than non-weight-bearing athletes like swimmers, cyclists, water polo players or non-athlete controls (Taaffe et al., 1995, Bennell et al., 1997, Brahm et al., 1997, Calbet et al., 2001, and Taaffe & Marcus, 1999). One particular study revealed male endurance runners to possess a significantly higher total body BMD (1.32 g/cm^2, $p<0.05$) than both cyclists (1.21g/cm^2) and controls (1.24 g/cm^2). According to the research of Stewart & Hannan (2000b), the fact that the elite cyclists had an even lower BMD than the controls could be attributed to a significant amount of time (~11 hours per week) spent training in a non-weight-bearing position.

Endurance runners do not typically exhibit the incredibly high total-body BMD values often seen with strength and power athletes, although similar regional values have been reported. One study found runners to have an even higher leg BMD than rugby players when values were corrected for body weight (Nevill et al., 2003). Indeed, the BMD of the legs measured amongst 20 elite male distance runners (mean age=26.6 yrs) was found to be 1.47 g/cm^2 while their total body BMD was an average 1.25 g/cm^2 (Kemmler et al., 2006). This is not surprising when considering that jump training (ex. basketball, Olympic weightlifting) produces impacts of six times body weight, while merely jogging produces impact forces of three-to-four fold (Stewart & Hannan, 2000b). Much debate continues as to whether or not extreme running volumes can be detrimental to bone density beyond a certain point, as the research on this issue is conflicting (McClanahan, Ward, Vukadinovich, Klesges, Chitwood, Kinzey, Brown, and Frate, 2002, Brahm et al., 1997, and Hind et al., 2006). One such study on male runners which states that very high volumes of endurance training can decrease BMD suggests hypogonadism and reduced androgens as a possible cause (Taaffe & Marcus, 1999).

Bone mineral density appears highest in regions most immediately loaded, as runners usually have a very high femoral BMD, an above average BMD at the lumbar spine, but similar arm BMD as compared to controls (Bennell et al., 1997, and Brahm et al., 1997). Research studies comparing cross country runners to non-weight-bearing athletes like swimmers have proven that forceful muscle contractions alone are unable to confer positive BMD enhancements at any anatomical sites unless the exercise is weight-bearing (Avlonitou et al., 1997, Taaffe & Marcus, 1999, and Emslander et al., 1998). In fact, the same researchers discovered that the BMD of swimmers does not significantly differ from that of age and size-matched controls – in some cases being even lower. One small study on nationally ranked college swimmers (n=11)

Table 1.

Previously Reported Bone Mineral Density (BMD) and Percent Body Fat (% BF) Group Mean (±SD) Values Among Young Adult Male Swimmers and Runners Using DXA.

Sport/Activity	Sample size	Mean Age (yrs)	BMD (g/cm^2)	% BF (DXA)
Swim[1]	11	19.9 ± 1.2	1.15 ± 0.02	9.5 ± 1.5
Swim[2]	16	20.8 ± 3.7	1.06 ± 0.11	11.8 ± 3.1
Water Polo[3]	24	22.4 ± 3.2	1.31 ± 0.09	15.2 ± 5.7
Run (mid.)[4]	31	20.7 ± 2.1	1.14 ± 0.09	8.3 ± 2.5
Run (unknown)[5]	12	27.6 ± 6.0	1.32 ± 0.07	7.6 ± 3.5
Run (distance)[6]	44	27.0 ± 6.5	1.14 ± 0.10	11.2 ± 4.6
Run (distance)[7]	17	26.6 ± 5.5	1.25 ± 0.10	10.9 ± 1.8
Run (mid.)[8]	22	32.0 ± 8.1	________	8.4 ± 0.8
Run (unknown)[9]	12	26.6 ± 6.5	________	7.8 ± 3.5

[1]Taaffe & Marcus (1999); [2]Avlonitou et al. (1997); [3]Andreoli et al. (2001)
[4]Bennell et al. (1997); [5]Stewart & Hannan (2000b); [6]Hind et al. (2006);
[7]Kemmler et al. (2006); [8]Hetland et al. (1998); [9]Stewart & Hannan (2000c)

found the total-body BMD to be as low as 1.16 g/cm^2 versus 1.20 g/cm^2 for controls, failing to display significance with a p value of 0.11 (Taaffe & Marcus, 1999). Despite this fact, some of these studies measured swimmers (n=32) and water polo players (n=24) to have greater lean mass than controls (n=12) and martial arts athletes (n=35), respectively, being especially lean in the arms and trunk (Andreoli et al., 2003, Avlonitou et al., 1997, and Taaffe & Marcus, 1999). Yet once again, even the BMD of the water polo players (1.31 g/cm^2) did not differ significantly from that of controls (1.27 g/cm^2), despite being substantially lower than the karate and judo athletes (1.38 g/cm^2), who also possessed the lowest percent body fat (10.7% - martial arts; 15.2% - water polo; 16.6% - controls).

In contrast, many studies have at least proven swimmers and water polo players to be leaner than controls. While male control subjects in their early 20's tend to range between 17-24% body fat as assessed with DXA (Wittich, Oliveri, Rotemberg, and Mautalen, 2001, and Oates et al., 2006), two different studies with 32 combined elite male swimmers of this age group were found to average 9.5% and 11.8% body fat as compared to 16.2% and 21% fat mass with their respective control groups (Avlonitou et al., 1997, and Taaffe & Marcus, 1999). In Avlontiou et al.'s findings, swimmers displayed a ratio of % lean *torso* to % lean *legs* of 2.02 and a % body fat *torso* to % body fat *legs* ratio of 0.77, being significantly leaner than controls in the arms and trunk. In a similar study, other elite swimmers possessed a trunk fat-to-limb fat ratio of 0.62, indicating significantly lower ($p<0.05$) amounts of fat distributed in the trunk than the controls, whose ratio was 0.76 (Taaffe & Marcus, 1999).

In comparison, runners have often been found to have an even lower fat mass constituent than their non-weight-bearing athlete counterparts across much of the literature. Examining three studies with a combined total of 86 elite male distance runners (mean ages=25-32 years;

average BMI=21.3 kg/m^2) revealed total body fat percentages (% BF) of 10.9%, 11.2%, and 8.4% (Hetland et al., 1998, Kemmler et al., 2006, and Hind et al., 2006). Remarkably, one research article involving twelve male running subjects (mean age=26.6 years) found the average % BF to be as low as 7.8%, although this is atypical among DXA measures (Nevill et al., 2003). Another study contrasted the total and regional body fat percentages of 22 elite male distance runners with 86 recreational runners, presenting 8.4% and 10.6% total BF as the respective values (Hetland et al., 1998). These results regarding soft tissue composition of the elite runners should not be surprising when considering the metabolic adaptations produced by weight-bearing exercise, which can maintain lean muscle mass while decreasing fat stores in conjunction with consistent endurance training.

The history and future of DXA and its applications with athletes

One of the main criticisms of DXA is that there has never been standardization between machines and software produced by different manufacturers. This is likely a major reason why DXA still has not been unanimously deemed a "gold standard" reference method, even though modern absorptiometry technology has been in place since the late 1980's. Consistency of scan results has even been a noted problem between machines from the same manufacturer, and constantly changing software upgrades often include changes in calculation algorithms used for body composition detection (Plank, 2005).

In the past, differences between DXA instruments from the main three manufacturers (Hologic, Lunar, and Norland) have been observed as high as 7% for body fat and up to 15% for bone mineral content (Tothill, Avenell, and Reid, 1994, Van Loan, Keim, Berg, and Mayclin, 1995, and Lohman & Chen, 2005). However, the recently produced iDXA (made by Lunar) showcased regional BMD measurements that were nearly identical to values assessed by the

Lunar Prodigy, its slightly older fan-beam model predecessor (Faulkner, 2006). Yet the same study also found the iDXA to have slightly better total-body precision than the Prodigy. Other studies with up to 245 subjects displayed a high correlation in BMD measurements between the two systems, with nearly identical values in precision at measured sites (lumbar spine, femoral neck, trochanter, and total femur) using the iDXA and the Prodigy (Kraeger, 2006, and Cole, 2006). The iDXA has been noted to possess a better image scan quality as well as improved spatial resolution over the Prodigy and other similar machines. It is also unique with its higher table weight limit (450 lbs.) and a longer, wider patient portal (measurement space) that allow it to assess persons up to 6’5” tall and large subjects such as NFL linemen (O’Connor, 2006a).

Another obstacle posed to DXA methodology is that varying thicknesses in different body regions and individual body shapes have led to large variations in percent fat in several DXA studies (Lohman & Chen, 2005, Kohrt, 1995, Kohrt, 1998, Stewart & Hannan, 2000a, and Genton et al., 2002). This limitation is known as beam hardening. As the dual-energy X-rays pass through increasing amounts of soft tissue, the average effective energy of the low energy beam comes closer to that of the high energy beam, which reduces the contrast in attenuation rates (Kelly, 1998). In the past, accurately predicting soft tissue amounts in the central trunk region has been particularly problematic at tissue depths above 25 cm (Lohman, 2005, Stewart & Hannan, 2000a, and Genton et al., 2002). Similar limitations with accuracy have been seen with BMD values resulting from scans of subjects with higher abdominal thicknesses (O’Connor, 2006b). Fortunately, research has suggested the newer Lunar iDXA to be capable of imaging patients with abdominal thicknesses up to 35 cm (14 in). This is made possible by the iDXA software’s optional scan settings to thick, normal, or thin mode. At thicknesses outside the normal limit of each mode, BMD values appear to increase drastically (O’Connor, 2006b).

Findings on the latest capabilities of DXA machines have been very intriguing. Recent DXA software programs are able to correlate LTM to resting energy expenditure (REE). One study found that 90% of variations in the REE of subjects could be explained by LTM and FM amounts (Kistorp, Toubro, Astrup, and Svendsen, 2000). This type of software could be of an enormous benefit to athletes trying to lose fat mass or gain/maintain lean muscle, thereby giving them a basis for adjusting their caloric intake at the training table. This type of metabolic information could be of unprecedented benefit for female athletes struggling with the female athlete triad if used in combination with their BMD results. For example, by comparing DXA measurements, a female mid-distance runner restricting her caloric intake might be persuaded that after a period of initial strength training, her gains in lean muscle are leading to a higher basal metabolic rate and total calories expended each day. Such an athlete could also be helped to realize that an insufficient energy intake would be detrimental to building bone mass or lean mass within the body, and could also negatively affect her performance.

Detailed research explains how DXA machines such as the Hologic QDR-1000W have been able to further section body regions, such as the partitioning of the legs into subdivided regions for measurement of body composition (Bennell et al., 1997). Most machines have this capability to set up custom region-of-interest (ROI) lines for scan boundaries. This studies illustrate how DXA measurements are expanding into not only clinical medicine and research fields (like examining the effects of wasting diseases such as AIDS (McDermott, Terrin, Wanke, Skinner, Tchetgen, and Shevitz, 2005), but are also bringing great scientific potential into the fields of athletic training and sports medicine (Kelly et al., 1998). It is practical to assume that additional possibilities for DXA's use would be to measure structural changes by assessing regional muscular atrophy or restoration following post-surgery rehabilitation. DXA can allow strength and conditioning coaches to accurately track regional lean muscle hypertrophy during and after training periods, or to assess fat mass when players report back for preseason camps (and again periodically throughout the season). The technological advances listed above suggest that the DXA may be the optimal body composition measurement tool for athletes.

Chapter 3

Methods and Procedures

The purpose of this ex post facto study was two-fold; first, to assess whole body and regional differences in bone mineral density and soft tissue amounts (fat mass versus lean mass) among collegiate runners and swimmers engaged in cross training techniques. The second purpose of this study was to strengthen the literature support for using DXA as a practical body composition measurement tool of choice among athletes. Estimates of training modalities and frequencies were generalized by coaches' accounts. DXA testing occurred at a point when athletes from both sports had been lifting weights and running for similar time periods.

Participants

Initial data were gathered from consented volunteers through the Marian Medical Center Institutional Review Board (Santa Maria, CA), which was approved for the medical research of Mary Oates, M.D., and David Oates, M.D., who specialize in the diagnosis, prevention, and treatment of osteoporosis within their practice. One objective of Dr. Mary Oates' Lean Research data collection was to contribute to a larger database for DXA body composition reference norms among collegiate and elite athletes, as part of an ongoing observational study to establish reference ranges for healthy, physically active adults. Thirty-eight members of the Cal Poly (San Luis Obispo, CA) track and field teams (31 men, 7 women) and 21 members of the Cal Poly men's swim team were examined to be included in a reference data base, but not all were included in the data subset taken for purposes of Dr. Oates' study. Members of either Cal Poly team were initially eligible to be included in this study (regardless of event or competition), provided none had medical conditions or fluctuating weight changes that excluded them from participation in the analysis (see Appendix A). From this group of consented subjects, a smaller subset of male swimmers (n=20) and male track & field runners (n=20) competing for Cal Poly were selected and designated for analysis of whole-body DXA scan results. After reviewing the sampling stratification of past research, and also based on coaches' information regarding sport events, the author determined the following criteria necessary for inclusion in the current study of runners and swimmers:

- All participants were male
- All participants ranged in age from 18-25 years
- All participants were Caucasian
- All participants were current members of the swim or track and field teams at Cal Poly
- Any track and field athlete included in the "runners" classification had to repeatedly perform running distances of $\geq$ 400 meters on a weekly basis as part of their training

As a result of the inclusion criteria, throwers, pole vaulters, jumpers, and short sprinters were excluded from this subset study, as their training did not routinely incorporate repeatedly running intervals of at least 400 meters on a weekly basis. However, decathletes and heptathletes did meet the subset inclusion criteria, since they compete in and train for numerous running events in addition to field events. With the swimmers, coaches confirmed that the training distances between short distance and long distance swimmers typically do not vary as widely as do runners when compared by event. These variations in swim distance were usually between 1,000 – 2,000 yards at most, with many training days where the entire team swam identical distances. This is likely why past research has not segregated swimmers by distance for their assessments. Therefore none of the swimmers in this study were excluded based on event, although one was excluded from the subset based on race, and no divers were included. All subjects included in the subset were Caucasian, in an attempt to control for the known variations in BMD among different races (Lohman & Chen, 2005). Coaches confirmed that athletes from both sports had engaged in team sessions of free weight training and running at least three times per week ($\geq$40 minutes each session) over the 12 weeks immediately prior to their DXA measurements.

Methods

All athletes involved as subjects in data collection were volunteer participants. Head coaches for both groups were informed of the data collection process, and were given an overview of the DXA technology. The Cal Poly athletic training staff members were also given advance notice to ensure that NCAA recommendations on body composition testing would be followed; subjects were given two copies of their scan results and informed that the sharing of results with coaches or trainers was strictly voluntary, in order to ensure athletes' privacy. The author generated a sign-up sheet with appointment times, which was distributed to the athletes when the author addressed them during team meetings. On one day designated for each team following 12 weeks of cross-training (Dec. 13, 2008 for swimmers; Jan. 24, 2009 for track runners), the subjects arranged their own transportation to the site where the DXA machine was located. Lean Research consent forms (see Appendix B) and health screening forms (Appendix C) were first reviewed by Dr. Oates' research team to ensure that inclusion criteria were met. Subjects were then directed to void urine and subsequently change into medical scrubs in preparation for testing. A body mass index (BMI) value was calculated (kg/m^2) measuring body weight to the nearest pound with a standard balance scale (General Medical Corporation, Richmond, VA) and obtaining height to the nearest quarter-inch using a wall mounted stadiometer (Seca Corporation, Hanover, MD). Each supine scan using the iDXA system (GE Lunar, Madison, WI) required an average of 4-7 minutes and was performed by the same licensed tester (David Oates, M.D.). Subjects then privately consulted with Mary Oates, M.D., who reviewed their test results to conclude the testing process. Test procedures are also outlined in Appendix B.

Data analysis

Permission for post-hoc data subset data analysis was granted to the author by Mary Oates, M.D. Prior to data analysis, all test results for the subset were transferred onto paper print-out that included each subject's I.D. number (coded for sport event), date of birth, sex, and ethnicity. Total-body and regional BMD values were computed by Lunar iDXA system software (analysis version 11.30; GE Lunar, Madison, WI), as were total body and regional BF and LTM percentages (including arms, trunk, and legs). For total % BF values, the regional computation was used (fat/fat+lean+bone). Mean age, height, weight, waist and hip circumference values, plus waist-to-hip ratios (W/H) were entered into iDXA software. Group mean descriptive and anthropometric measures of the two groups are displayed in Table 2. Values for each of the following six dependant variables were entered into a Microsoft Excel spreadsheet (2007 version) before transfer into MINITAB statistical software (version 15):

- Individual ratios for percent lean *torso* to percent lean *legs* using kilograms
- Individual ratios for fat-free mass to fat mass (FFM/FM) using kilograms
- Average BMD (total body) in g/cm^2
- Average BMD (legs) in g/cm^2
- Average % BF (total body)
- Average % BF (legs)

A complete listing of soft tissue amount ratios and percentages by sport group can also be found in Table 3.

Primary statistical data analysis was performed using measures of central tendency in the form of group means. For each of the six dependant variables, two sample one-tailed T-tests were performed (one for each group/team sample) using the MINITAB software (regression and correlation functions) and applying a Bonferroni correction ($p<0.0083$) to find significance and avoid Type I research error (or incorrectly assuming significant differences between groups) that could possibly be caused by multiple tests. A correlation between the fat-free mass to fat mass ratio and the BMD of both groups was then examined using the Pearson correlation coefficient. Several correlations were also performed to examine the role of age (yrs) and body weight (BW) as possible predictors of several of the dependant variables (total % BF, FFM/FM ratio) as well as total lean tissue mass (LTM). BMD was also evaluated as a response variable to determine its relationship to various factors (age, BW, LTM, FM, and FFM/FM ratio).

Chapter 4

Results and Discussion

Analysis of the Data

From a larger group of consented subjects, the author selected a smaller subset of 18-25 year old Caucasian male swimmers (n=20) and track and field runners (n=20) competing for Cal Poly (San Luis Obispo, CA), and these individuals were designated for analysis of whole-body DXA scan results. All recorded anthropometric and descriptive group mean variables of the subject groups can be found in Tables 2 and 3.

For five of the six dependant variables, two sample one-tailed T-tests were performed on the two sample groups using Minitab's basic statistical software (regression and correlation functions) and then applying a Bonferroni correction ($p<0.0083$) to find significance between group means and avoid any Type I research error (wrongly assumed significant difference) that could possibly be caused by multiple tests. As a result, tests with a p value <0.0083 were deemed statistically significantly different. To determine significant group mean difference with FFM/FM ratio, the presence of two outliers dictated that the non-parametric Mann-Whitney statistical test be used for this comparison only. All other dependant variable data were normally distributed. Using MINITAB statistical software, multiple correlations were then performed by examining the Pearson correlation coefficients, and then linear regression was performed to determine if any significant correlations between variables were seen independently within each sport group. The slopes for all regression lines were not significantly different between sports, with the exception of lean tissue mass (LTM) as predicted by body weight (BW). In this case, stepwise regression was used to determine that the factors of BW and sport were most responsible for predicting LTM.

Table 2.

Summary of Raw Group Mean (±SD) Descriptive and Anthropometric Data for Male Collegiate Swimmers and Runners Using DXA.

Variable	Swimmers (n=20)	Runners (n=20)
Age (yrs)	19.6 ± 0.8	20.1 ± 1.8
Height (cm)	182.7 ± 6.2	183.0 ± 5.9
Weight (kg)	78.2 ± 7.4	74.4 ± 8.5
BMI (kg/m^2)	23.4 ± 1.9	22.2 ± 2.0
LTM (kg)	63.7 ± 5.7	62.2 ± 7.4
LTM (legs)	20.4 ± 2.3	21.0 ± 2.7
FFM (kg)	66.7 ± 6.0	65.5 ± 7.7
FM (kg)	11.5 ± 3.1	9.0 ± 2.1
BMD-total body* (g/cm^2)	1.216 ± 0.097	1.334 ± 0.086[a]
BMD-legs* (g/cm^2)	1.281 ± 0.142	1.495 ± 0.101[a]
BMD-arms (g/cm^2)	0.968 ± 0.071	1.015 ± 0.112
BMD-spine (g/cm^2)	1.098 ± 0.094	1.157 ± 0.132

BMI=body mass index
LTM=lean tissue mass
FFM=fat free mass
FM=fat mass
BMD=bone mineral density
* variable tested for statistical significance
[a] p=0.000 (to three significant digits)
p values adjusted for multiple comparisons: Bonferroni.

Table 3.

Summary of Group Mean (±SD) Soft Tissue Ratio/Percentage Data for Male Collegiate Swimmers and Runners Using DXA.

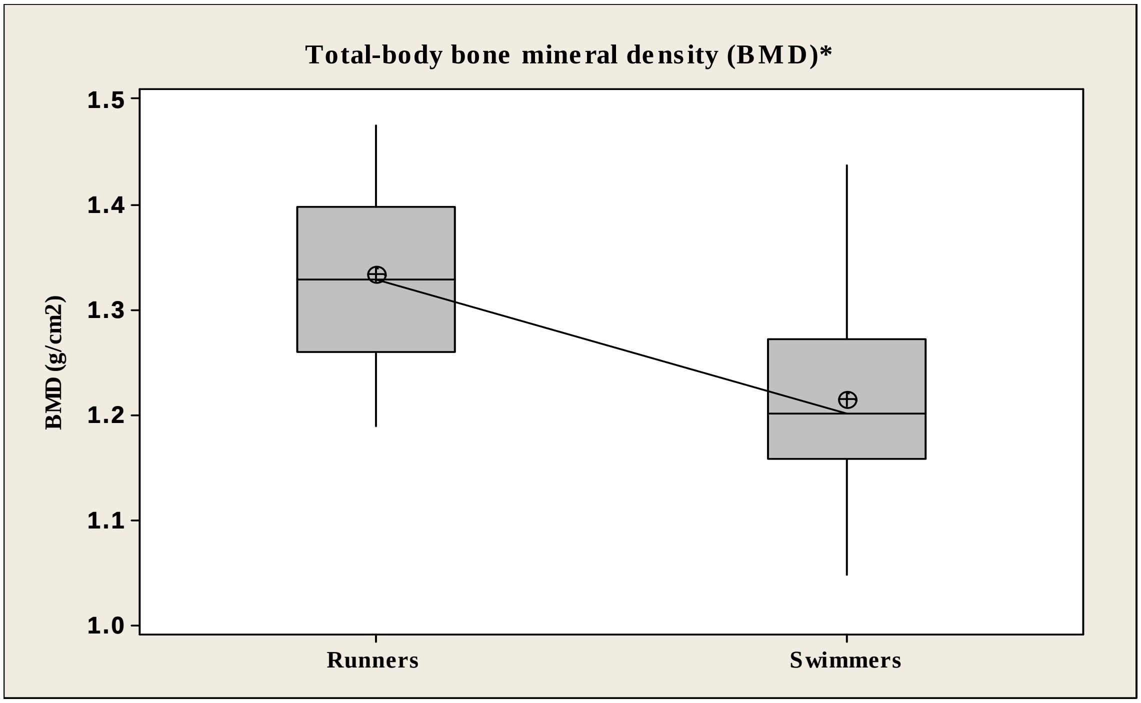
Variable	Swimmers (n=20)	Runners (n=20)
% BF (total body)*	14.6 ± 3.4	12.0 ± 2.4[b]
% BF (legs)*	17.6 ± 4.2	14.5 ± 2.9[b]
% BF (arms)	11.7 ± 2.7	10.9 ± 2.8
% BF (trunk)	13.9 ± 4.2	10.6 ± 3.0
FFM/FM ratio*	6.34 ± 1.85	7.65 ± 1.76[c]
LTL ratio*	1.95 ± 0.10	1.79 ± 0.09[a]

% BF=percent body fat; FFM/FM=fat free mass-to-fat mass ratio; LTL=lean torso-to-legs ratio
* variable tested for statistical significance
[a] p=0.000 (to three significant digits)
[b] p=0.004
[c] p=0.012
p values adjusted for multiple comparisons: Bonferroni.

Results

Group mean values (with standard deviation) for each of the above variables are displayed in Table 2 and Table 3. Of the six dependant variables of body composition, the group of swimmers were found to have significantly less total BMD ($p=0.000$; p values reported to three significant digits), as well as less regional leg BMD ($p=0.000$) than the runners. These group mean differences were evaluated using 2-sample T-tests and are illustrated with box plots in Figure 1. As displayed in Figure 2, swimmers had a greater total % BF than runners ($p=0.004$), while also possessing greater % BF in the legs ($p=0.004$). In conjunction, the swimmers were found to have a lower FFM/FM ratio, although this value was the only variable that did not quite reach significance ($p=0.012$; Mann Whitney) due to the adjusted p value for Bonferroni correction ($p<0.0083$). Despite having the greater % BF at all measured sites, swimmers had a significantly larger proportion of their lean mass concentrated above the waist as opposed to in the legs, as their lean torso-to-legs (LTL) ratio was markedly greater than runners ($p=0.000$; see Figure 3). Several correlations were performed to examine the role of age (years) and body weight (BW) as possible predictors of several of the dependant variables (total % BF, FFM/FM ratio) as well as total lean tissue mass (LTM). BMD was then evaluated as a response variable to determine its relationship to various factors (age, BW, LTM, FM, and FFM/FM ratio).

While no correlations were found with several of the above variables, some variables were positively correlated among all subjects. The regression lines and slopes for the runners and swimmers did not significantly differ by sport for the following correlated variables: The mean total BW (in kg) proved to be a significant predictor of total BMD (Pearson $r=0.421$, $p=0.007$). Lean tissue mass (LTM) was also correlated to BMD ($r=0.468$, $p=0.002$) but was



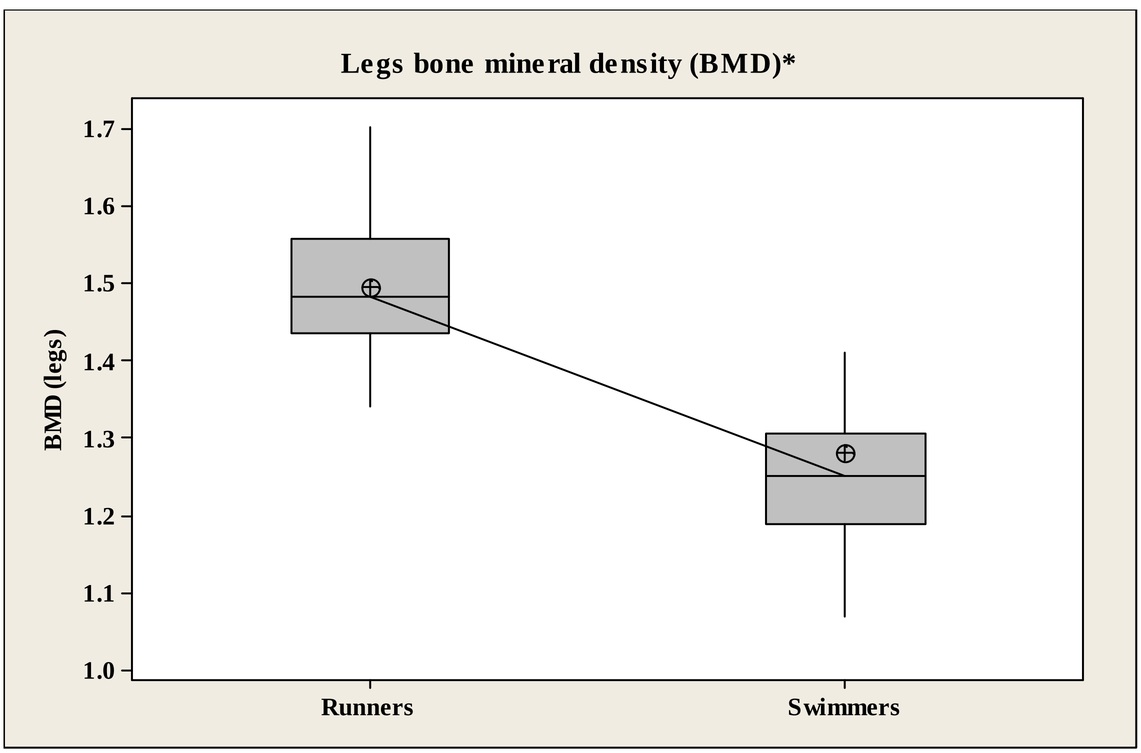
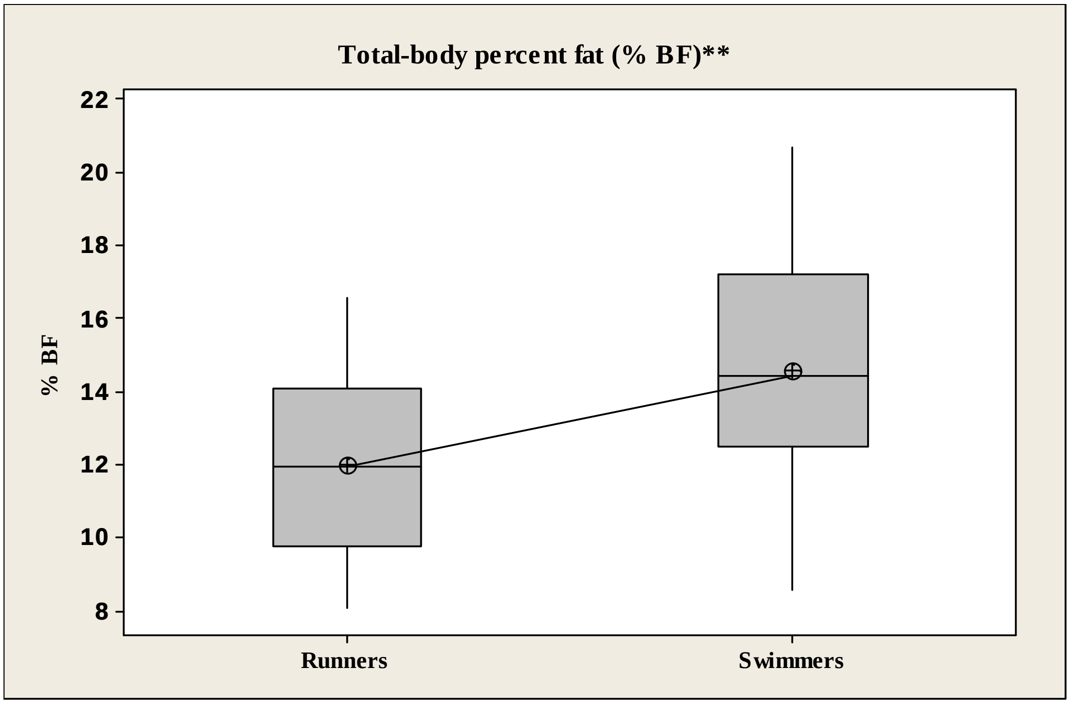


Figure 1. Boxplot Graphs for Bone Mineral Density (BMD) Two-Sample T Test Results of Male Collegiate Runners and Swimmers Using DXA.
*p=0.000



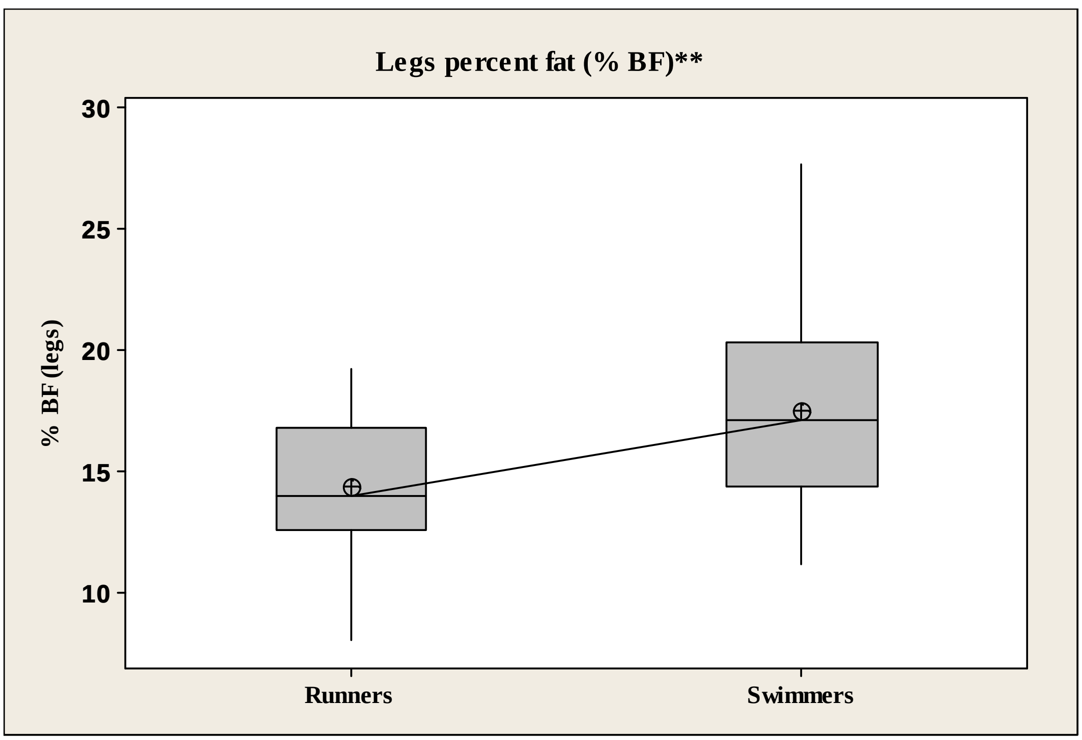


Figure 2. Boxplot Graphs for Percent Body Fat (% BF) Two-Sample T Test Results of Male Collegiate Runners and Swimmers Using DXA.
**p=0.004

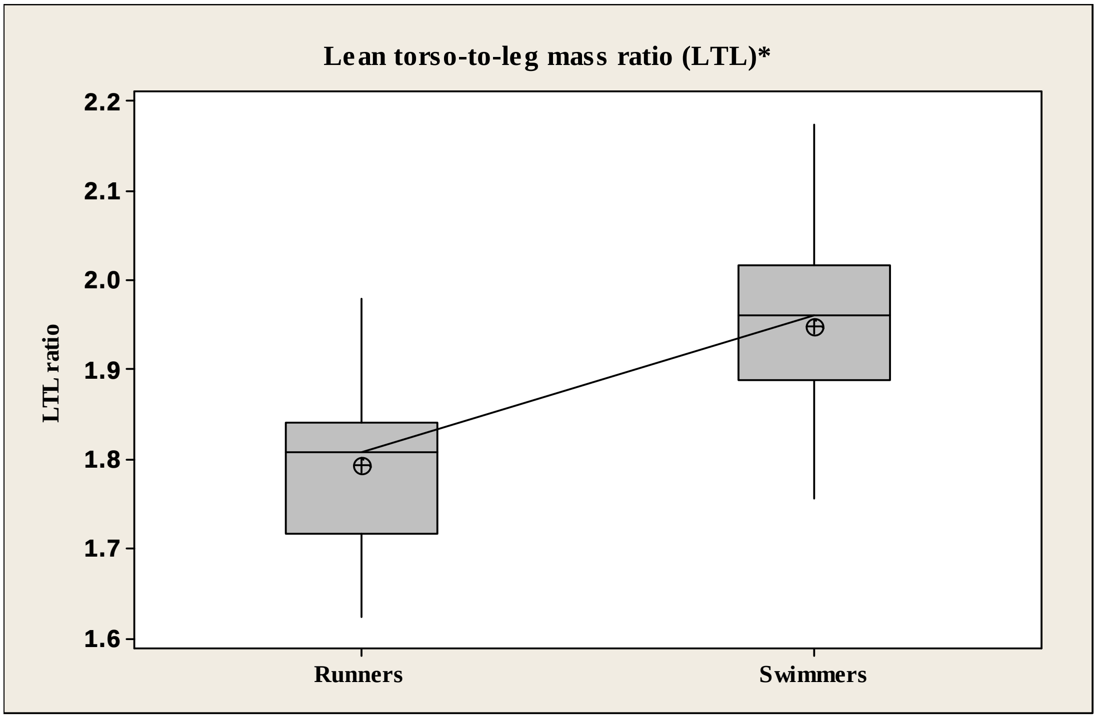


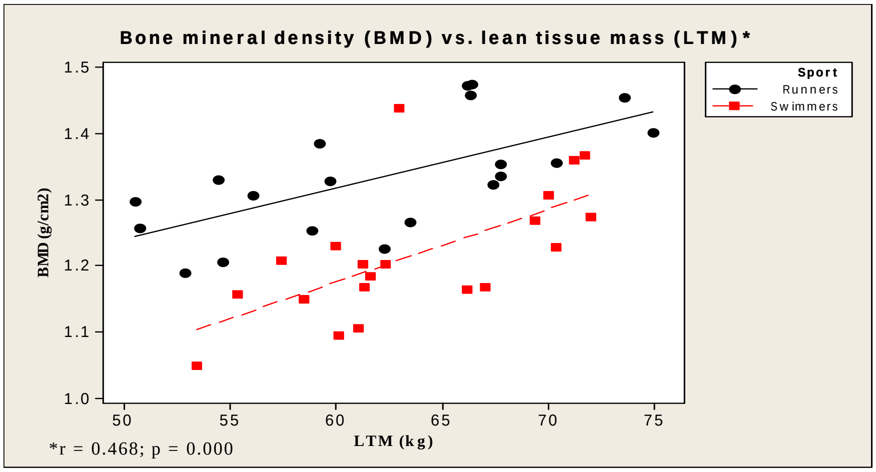
Figure 3. Boxplot Graph for Lean Torso-to-Leg Mass Ratio (LTL) Two-Sample T Test Results of Male Collegiate Runners and Swimmers Using DXA.
*p=0.000

most strongly correlated to total BW (r=0.932, p=0.000). These significant correlations are displayed on the following page using scatterplots in Figure 4. Body weight (BW) was not correlated to percent body fat (% BF). There were no significant correlations between the FFM/FM ratio and the BMD or age of the subjects. Furthermore, age was not associated with % BF or the lean torso-to-legs (LTL) ratio, nor was age a strong predictor of LTM. All MINITAB statistical text output is presented in Appendices D, E, and F.

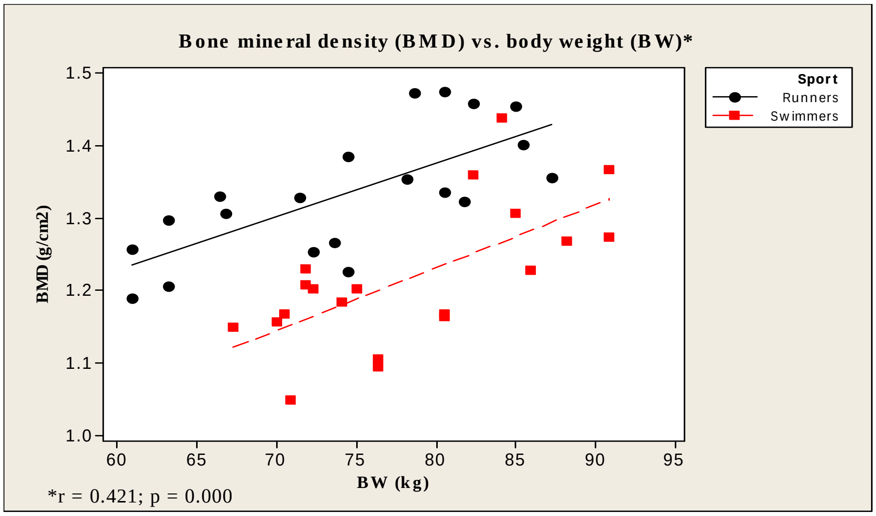
Discussion of the Findings

The current findings on the DXA-measured body composition differences between NCAA D-I collegiate male swimmers and runners reflected the research hypotheses, even after a lower statistical significance level was set (p=0.0083) due to the Bonferroni correction. In the current research, the group of male college swimmers was found to have significantly lower total and regional (legs) BMD values on average, and a lower (though not quite significant; p=0.012) FFM/FM ratio than the runners. The swimmers group also had significantly greater total and regional (legs) body fat percentages, although more of their lean weight was distributed above the waist. In contrast, the runners had a significantly lower lean torso-to-legs (LTL) ratio, proving that a greater percentage of their lean mass could be found in the legs. All of the variable outcomes listed above were in line with the current research hypotheses. The findings also reflected the results of past anthropometric research on groups of competitive swimmers and runners (Hetland et al., 1998, Kemmler et al., 2006, and Hind et al., 2006). However, (although hypothesized) there was no direct correlation shown between the BMD and the FFM/FM ratios of the groups, this once again implying that BMD and a measure of fat mass may not always be associated with one another.

(a)



(b)



(c)

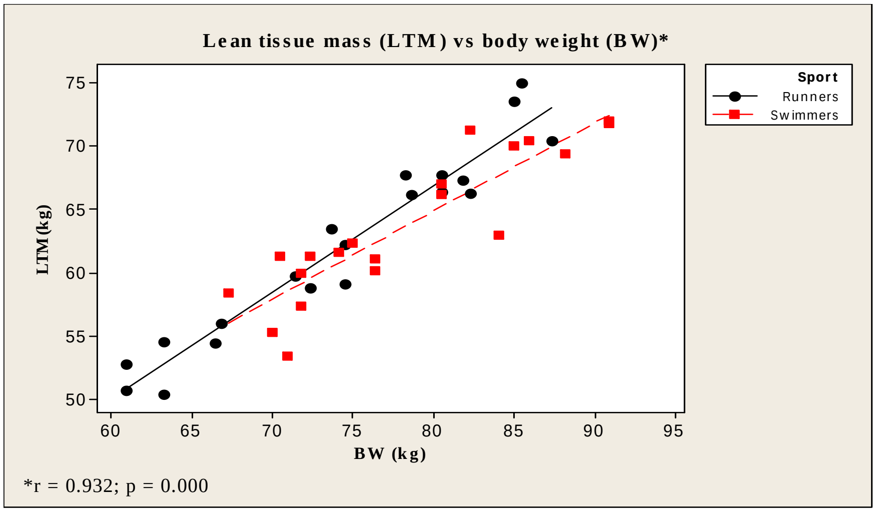


Figure 4. Scatterplot Graphs for Correlations Between Anthropometric Variables Of Male Collegiate Runners and Swimmers Using DXA. (a) Bone Mineral Density vs. Lean Tissue Mass (b) Bone Mineral Density vs. Body Weight (c) Lean Tissue Mass vs. Body Weight

As seen on Figure 4, total BMD was correlated with both BW and LTM, both of which were also strongly correlated with each other, although these findings were seen generally among both groups and were not sport-specific in their significance. However, a trend was seen with LTM as predicted by sport alone (p=0.057) and although this value narrowly missed significance, it did suggest that the heaviest runners were substantially more muscular than the heaviest swimmers, despite the latter group possessing a greater average body weight. The results of this study complement past research which suggests that body weight is one of the factors known to greatly influence bone mineral density (Lohman & Chen, 2005). In addition, lean tissue mass (LTM) has previously been reported to be an independent predictor of both regional and total bone mineral density in past studies of gymnasts, non-weight-bearing elite swimmers, and control populations (Taaffe et al., 1995, Andreoli et al., 2001, and Taaffe & Marcus, 1999).

In contrast, fat mass (FM) was not correlated with BMD. Age was not related to BMD, % BF, nor to the measured ratios of lean torso-to-leg (LTL) and fat-free mass-to-fat mass (FFM/FM). Body weight also was not correlated with % BF, among either team or in general. These findings are consistent with the past research of Andreoli (2001) and Stewart and Hannan (2000c), the latter of which suggested in their study that differences in tissue mass were largely a result of lean tissue distribution. In their assessments on athletes from a multitude of different weight-bearing and non-weight-bearing sports, these authors concluded that while lean and bone mineral content distributions indicated very specific adaptations to different sports, fat distribution is nonspecific in its response to training, with little variation present. When the wide range of athletic groups were all compared to one another, no pattern of fat distribution was significantly different amongst the athletes from different sports (p>0.05).

The current research also coincides with past studies which have suggested that forceful muscle contractions alone (such as those taking place in swimming, rowing, or water polo) confer no significant BMD enhancements without weight-bearing exercise (Taaffe et al., 1995, Avlonitiou et al., 1997, Taaffe & Marcus, 1999, and Emslander et al., 1998). However, when dealing with weight-bearing athletes, like track and field runners who have higher percentages of lean mass (and low associated fat mass percentages), the lean muscle mass correlation with BMD cannot be ignored. Possible explanations for this relationship will be discussed in more detail in Chapter 5.

Chapter 5

Summary, Conclusions, and Recommendations

Summary

This study assessed whole body and regional differences in bone mineral density and soft tissue amounts (fat mass versus lean mass) among collegiate runners and swimmers, utilizing a one-time DXA scan as the body composition assessment method. A number of past studies have already explored such differences among these athletes, findings which replicate those seen with the present study.

Previous related research has repeatedly found similar results with BMD differences between weight-bearing and non-weight-bearing athletes. While weight-bearing athletes typically exhibit higher BMD values at all sites, the differences in BMD are less pronounced in body regions that experience less ground-based mechanical loading (Bennell et al., 1997, & Brahm et al., 1997). For example, it would be expected that runners would have a much greater BMD in their legs compared to swimmers, while their BMD measured higher up at the lumbar spine may be only slightly greater than that of the swimmers group.

Many studies on athletes have also found BMD to be highly correlated to both body weight and lean mass (Andreoli et al., 2001, Nevill et al., 2003, Taaffe & Marcus, 1999, and Mudd et al., 2007). A study of endurance runners by Hind et al. (2007) noted that runners who engaged in resistance training at least twice a week had greater lumbar spine BMD than those who did not resistance train. Most research has discovered runners to have a lower fat mass constituent than their non-weight-bearing athlete counterparts (Hetland et al., 1998, Kemmler et al., 2006, and Hind et al., 2006). Very few studies have been able to find a direct correlation between BMD and fat mass among athletes in different weight-bearing sports and swimming (Creighton, et al., 2001 and Taaffe & Marcus, 1999).

In particular, the study by Stewart & Hannan (2000c) investigated bone mass and soft tissue differences between whole-body exercisers (such as swimmers) vs. strictly lower-body exercisers (such as runners). In their study, the authors determined regional fat and lean mass distribution among these athletes by using ratios that do not require a correction for total body mass. Whole body exercisers had significantly greater arm proportions of total lean mass than lower body athletes or non-athlete controls ($p<0.001$) and a greater lean arms-to-legs (LAL) ratio ($p<0.001$). Fat distribution results indicate that the whole body exercisers had a significantly greater fat torso-to-legs (FTL) ratio compared with lower body exercisers ($p<0.05$), and yet fat distribution was the least variable measure among all groups. The authors concluded that while lean and BMC distributions have very specific adaptations to different sports training stimuli, fat distribution is nonspecific in its response to exercise.

While the sample size in the current study was somewhat small (n=20 runners, n=20 swimmers), most of the similar studies referenced in the current literature review investigated comparable sample sizes. One of the strengths of the present study is that all athletes were of the same gender, race, competitive classification, and narrow age range. A common characteristic of the subjects was their engagement in cross training techniques, although chronicling of such training methods was briefly observed over just one competitive season. Since the swimmers regularly ran and performed free weight training, however, one may have expected some attenuation in body composition differences between these two groups.

Conclusions

Because of the precision of the DXA scan equipment used in this study, small differences in body composition were successfully detected between the sample groups. The male college swimmers were found to have significantly lower total and regional legs bone mineral density (BMD) on average. The swimmers also had the higher total and regional (legs) body fat percentages, although more of their lean weight was distributed above the waist. In contrast, the runners had a higher percentage of their lean mass found in the legs, resulting in a lower lean torso-to-legs (LTL) ratio. While the swimmers were the heavier group on average, with a greater overall lean tissue mass, the runners actually displayed the greater total lean tissue mass (LTM - in kg) at the legs. Furthermore, although the swimmers had the greater proportionate lean mass above the waist, the runners exhibited a lower % BF for total body, trunk, legs, and arms regions, with the % BF of the arms proving the most similar between the two groups. A trend was also seen with the runners having a higher fat-free mass-to-fat mass ratio (FFM/FM) than the swimmers, as this value barely missed significance (p=0.012) after Bonferroni correction. Using this ratio to detect soft-tissue differences among athletes may therefore be more difficult than comparing body fat percentages alone.

Differences in regional BMD between the two groups displayed less variation the further the proximity of the measured body region from the ground, although runners still possessed higher average BMD values at all sites, including the arms. This finding was consistent with past research, and suggests that the preseason cross-training methods of swimmers in this study seemingly had little effect on the BMD differences. It must be considered, however, that a 12 week period of cross training may be insufficient to reflect significant BMD changes, whereas knowledge of long-term training habits over a number of years will likely be a more significant factor. Other findings revealed that total bone mineral density (BMD) was correlated with both body weight (BW) and lean tissue mass (LTM), both of which also strongly correlated with each other. The above correlations were seen among both groups, however, and therefore were not sport-specific in significance. There were no significant correlations found between the variables of BMD and fat-free mass-to-fat mass ratio (FFM/FM), or between BMD and FM alone. Age was not correlated to neither BMD, % BF, nor to the measured ratios of lean torso-to-legs (LTL) and FFM/FM. The subjects' body weight also did not correlate with % BF, among either team or in general.

While BMD differences among runners and swimmers found in this study were not unexpected and aligned well with past research, the differences involving soft tissue amounts among the two groups may hold more potential value for future exercise physiology research. For example, the relationship between BMD, total body weight, and lean mass support past studies that list exercise (or biomechanical loading) as one of the key factors contributing to gains in bone mass (Andreoli et al., 2001, and Taaffe & Marcus, 1999). Andreoli et al., (2001) pointed out that bone is a calcified tissue sensitive to not just loading, but also muscular contractions. The role of muscle as a shock absorber to counteract stress on bones has also been discussed in the research (Beck, 1998). In her review article on tibial stress injuries, Beck cites research that observed decreased lower limb muscle mass among athletes with stress fractures as compared to athletes without fractures. As previously stated, the runners group in the current study displayed the greater lean tissue mass (LTM) at the legs, although they weighed substantially less than the swimmers. Greater leg muscle mass could possibly be attributed to more forceful muscular contractions that take place in the lower body as a result of the runners' ground-based training, with a subsequent hypertrophic increase in cross-sectional muscle fiber in their legs.

In their study of weight-bearing and non-weight-bearing athletes, Stewart and Hannan (2000c) acknowledge that differences in lean mass distribution imply differential metabolic activity. It is known that greater lean muscle mass located amongst larger muscle groups (i.e., the legs) typically yields a greater VO2 and thus a higher caloric expenditure (Adams and Beam, 2007). This proposed difference in metabolic activity and energy expenditure might help to explain the lower % BF exhibited by the runners in the current research. The fact that recent DXA software programs are now able to correlate lean tissue mass (LTM) to resting energy expenditure (Kistorp et al., 2000) will likely help to further explain some body composition differences among different types of athletes.

Recommendations

Before solid determinations can be made on the body composition variations between runners and swimmers, and whether these variations can be attributed to differential metabolic activity, future studies should attempt to control a wide range of physiological variables. As an observational study, one limitation of the current DXA research on the body composition of runners and swimmers is that the recent history of the athletes' sport-specific training and cross-training is only estimated, and was not tightly controlled. In addition, according to Andreoli et al., (2001) and Taaffe & Marcus (1999), the four key factors that contribute to BMD levels are genetics, exercise, hormonal status, and nutrition. While exercise was reported in the current study, neither the genetic information nor hormonal status of the athletes were examined, nor was their nutritional intake monitored. Hind et al., (2006) noted that bone catabolism and reduced bone formation may occur if energy intake is insufficient, and that prior research had evaluated a relationship between sex steroids (ex. hypogonadism) and low BMD in male athletes performing very high volumes of endurance training. Important future studies to be performed on weight-bearing and non-weight-bearing athletes may attempt to control all of these factors. Longitudinal studies chronicling athletes' long-term nutritional intake or lifestyle behaviors could help explain contributing causes of age-related body composition changes at different points in their careers.

Many of the aforementioned physiological factors also come into play when soft tissue amounts are being compared. Hetland et al., (1998) examined regional distribution of fat and lean tissue in long distance runners, and how these values were affected by different levels of training or sex hormones. A correlation was found between abdominal fat and the free testosterone index ($p<0.0001$; $r=0.39$). Additional research is needed to evaluate the effect of running and swimming on the release of other hormones that facilitate the breakdown of fat in the body, or act to stimulate and suppress appetite. Future body composition studies also could benefit by measuring energy expenditure through calorimetry, perhaps testing runners and swimmers who are performing equal volumes of race-pace training within their sport to determine whether caloric expenditure correlates to changes in lean mass over the course of a season. Similar studies might even use muscular biopsy to evaluate changes in lean muscle due to different training methods. The biggest obstacle to such studies is the difficulty in equating training modalities, intensities, and volumes between the two sports, as would be necessary to establish a causative factor of training on the difference in body composition responses.

The differences in bone density, lean muscle, and fat mass that were found by the current research examining male collegiate runners and swimmers should encourage future research on the physiological adaptations and metabolic variations that exist among such athletes. This is especially true since such differences and correlations were found among small sample sizes, using statistical correction factors that decreased the significance level. The current study, like others, suggests DXA as a great modern tool with software programs capable of precisely measuring total and regional musculoskeletal quantities. Indeed, DXA values and findings for BMD, LTM, and FM were very similar to past data based on groups of competitive runners and swimmers. The increasing precision and use of DXA in measuring these components can be invaluable to the athlete seeking to compare their body composition to what is deemed optimal or healthy. With DXA technology, an athlete can become more aware of their increased risk of stress fracture due to their low bone density. Currently, large normative reference databases for DXA body composition among athletes are still being developed, but will undoubtedly soon be a great benefit to athletes. Once such data become widespread, athletes will be able to determine how their body composition ranks in comparison to similar athletic groups, and optimal ranges for fat and lean mass amounts may be determined. Athletes can thereby benefit from realizing that carrying excess body fat when compared to others at their position is not likely to contribute to optimal movement in the performance of their sport. For example, one recent study on male soccer players found that increased fat mass was positively correlated with decreases in speed (Silvestre et al., 2006). One exception to this rule might be with swimmers, as Avlonitou et al., (1997) pointed out: "for swimmers, the upper part of the body seems to be more important for performance, compared to the lower part of the body, although more fat in this area enables an individual to float better, thus enabling a better propulsion through the water."

While the present study was observational, it is apparent that the current sample of athletes who were primarily involved in lower body weight-bearing exercise (runners) possessed greater bone density, more leg muscle mass, and less total body fat at all measured sites; the last result potentially being the most surprising. These findings lead the author to speculate whether runners have a higher whole-body fat metabolism than swimmers as a result of their more frequent weight-bearing training, due perhaps in part to a greater lean body mass among large lower body muscle groups that contain more metabolically active tissue. Variables such as an athlete's caloric intake, dietary patterns, and cultural background within a sport will require that more comprehensive physiological factors of weight-bearing and non-weight-bearing athletes are examined or controlled for before drawing comparative conclusions in future research.

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Appendix A

Lean Research Criteria for Participation

Lean Research

To meet criteria to participate in this study, you must be able to answer "YES" to all the following questions:

Do you confirm that you have NOT been diagnosed or treated for coronary artery disease, peripheral artery disease, congestive heart failure, diabetes, chronic kidney disease, chronic liver disease, abnormal liver or renal function tests, anorexia nervosa, bulimia, HIV, AIDS, cancer?	YES
If you are *younger* than 50, do you confirm that you have *not* been diagnosed or treated for high blood pressure or high cholesterol?	YES
Do you confirm that you have no indwelling devices or any type of metal, plastic or silicone implants, except for minor cosmetic ones in the face?	YES
Do you confirm that you are not pregnant or lactating?	YES
Do you confirm that you do not drink more than 2 servings of alcohol per day, have not smoked in 6 months, and have not had prolonged hospitalization or immobilization within the last 6 months?	YES
Do you confirm that your weight has not fluctuated more than 10 lbs in the last 6 months?	YES
Do you confirm that you have not had liposuction or surgery for obesity such as lap-band or gastric bypass surgery?	YES
Do you confirm that you are not taking prescription drugs for dieting?	YES
Do you confirm that you have an active lifestyle or job, and get 30 minutes of exercise at least 3 times weekly?	YES
Do you confirm that you are NOT a professional athlete?	YES
Do you confirm that you do NOT have neurological or muscular disorders such as stroke, spinal cord injury, multiple sclerosis, muscular dystrophy, paralysis, or amputation?	YES

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Appendix B

Lean Research Consent Form & Test Procedures

Body Composition in Healthy Adults

Consent Form

Investigators

Mary Oates, M. D.
Private physician, certified X-ray supervisor and operator
Mary K. Oates, M. D., Inc., Santa Maria, CA
Certified Clinical Densitometrist
(805) 922-4224

David Oates, M. D.
Private physician, limited X-ray technician, certified X-ray supervisor and operator
Certified Clinical Densitometrist
Mary K. Oates, M. D., Inc., Santa Maria, CA
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Purpose

The purpose of this study is to establish a normative database for healthy total body composition using the newest generation Dual Energy X-ray Absorptiometry (DXA) machine, the Lunar iDXA. This instrument scans the entire body. It is hypothesized that the ease of administration and insignificant radiation exposure will make the instrument a standard in the estimation of body composition for health and fitness. The estimations will be used to establish body composition norms for healthy, adult populations.

Location

Each testing session will take place at the office of Dr. Mary K. Oates, 116 S. Palisade Dr., Ste. #200, Santa Maria, CA 93454.

Time Commitment

The test will require one hour

Description of the Tests

The tests that will be administered are:

- Height and weight measurements
- Circumference measurements

- Dual-energy X-ray absorptiometry

Complete description of each test is attached to this document.

Pretest Instructions/Responsibilities

To ensure safe and effective assessment, please follow these guidelines.

- Wear or bring shorts and T-shirt.
- Please bring a list of or the actual bottles of your current medications, vitamins, and supplements.
- Please do not take your regular calcium or vitamin pill until after your test session.

Risks and Discomforts Associated with Your Participation

Risks of participation in the tests include but are not limited to:

- Exposure to X-ray radiation (5 microSV, which is equal to 2 hours of a cross-country plane flight)

Discomforts associated with participation in the tests include but are not limited to:

- Pinching of skin

Our Actions to Minimize Your Risks and Discomforts

- Emergency equipment (First Aid Kit) and trained personnel (medical doctors and/or CPR and First aid certified technicians) are available during each test session.
- An emergency phone is available for immediate access to emergency medical service should it be required.
- To prevent the possibility of even minimal X-ray exposure to a developing embryo/fetus, all female participants will be administered a commercially available home-pregnancy test. If you test positive on the test you will not be allowed to continue in the study.
- The investigators will familiarize you with each test and its equipment prior to the assessment to ensure your understanding and ease.
- If at any time you feel uncomfortable with any test you may stop it immediately. At that time, we will ask if you'd like to try again. If you answer in the negative, we will assist you from the testing site with no prejudice and with sincere thanks for your participation. At that time, you can choose to participate in the other assessments, or to terminate your participation in the investigation.

Your Responsibilities During the Tests

- Follow the instructions of the investigators at all times.
- Inform the investigators of any problems or physical symptoms experienced during the tests.
- Terminate a test if you feel unsafe or unable to continue the test.

Benefits of Your Participation

The test results will provide you with information regarding your body composition. These results can assist you in planning safe, effective plans for health management and fitness development.

Your deidentified data may be used anonymously to improve our testing methods. The results may be presented at professional meetings, or published in professional journals. In all such cases of public presentation of the results, data will only be used as group data; no data will be identifiable as linked to a specific individual.

Your Rights

- You have the right to ask any questions that you feel are relevant to your safety and well-being regarding your participation in any of the tests.
- You have the right to have all such questions answered to your satisfaction.
- You have the right to refuse to answer any questions, either verbal or in questionnaire form. However, this may limit your participation in some assessments.

- **You have the right to withdraw your consent and terminate participation without penalty at any time.**

Confidentiality

All information gathered from you will be kept confidential. You will be assigned an ID number that will be used as the only means of identifying you on all data sheets. The only individuals who will have access to the information are the investigators. At no time will your information be identified by name to anyone else. Any information that is presented in professional reports will be done in group form without identifying you.

If you have any questions about this test or your participation, or to obtain a copy of the study results, please contact

Dr. Mary K. Oates
116 S. Palisade Dr., Ste. #200
Santa Maria, CA 93454
805.922.4224
drmaryoates@dxabodycomp.com

If you would like a copy of these results for your physician or other health care professional, please inform us. We will print you an additional copy, and you may put your name on it and deliver it to your physician.

Body Composition in Healthy Adults

This is to certify that I agree to participate in a variety of tests used to estimate my body composition as part of an authorized study of the office of Dr. Mary K. Oates.

The tests and my participation in the tests have been defined and fully explained to me and I understand the explanations. The procedures of these tests and their risks and discomforts have been discussed with me.

I have been given an opportunity to ask whatever questions I may have and all such questions and inquiries have been answered to my satisfaction.

I understand that I am free to deny any answer to specific items or questions in interviews or questionnaires. I understand that refusal to answer such questions may disqualify me from participating, or limit my participation in this program.

I understand that I will not receive any financial compensation for my participation.

I understand that any data or answers to questions will remain confidential with regard to my identity.

I understand that, in the event of injury resulting from these tests, neither financial compensation nor free medical treatment is provided for such an injury. Individuals who are injured will be referred to their personal physicians.

If I have questions about the protection of human subjects , I can contact Dr. Mary K. Oates, 116 S. Palisade Dr., Ste. #200, Santa Maria, CA 93454. 805.922.4224.

To the best of my knowledge and belief I have no physical or mental illness or weakness that would increase the risk associated with my participation.

I understand that I am free to withdraw my consent and terminate my participation at any time without penalty.

Participant Name	Participant Signature	Date	Birthdate

I, the undersigned, have fully explained the tests to the above named individual.

Investigator Name	Investigator Signature	Date

Thank you for your participation in this study.

Test Procedures

Height

Height will be measured to the nearest 0.1 cm using a wall mounted stadiometer (Seca Corporation). You will remove shoes prior to the measurement.

Weight

Weight will be measured to the nearest ¼ lb using a standard balance scale (General Medical Corporation). You will remove shoes prior to the measurement.

Circumferences

A spring tape measure will be placed around your body at the following sites. Measurements will be taken to the nearest 0.1 cm.

1. waist, above the iliac crest and below the lowest rib margin at minimum respiration
2. hip, at the greatest protuberance of the buttocks

Dual-energy X-ray Absorptiometry (DXA)

You will be asked to change into a paper gown, and then you will lie on your back on the padded x-ray table. You will be asked to lie as motionless as possible for 5-10 minutes while the arm of the instrument passes over your body. The total scan time for 1 scan is about 5-10 minutes, and exposes you to less radiation than that encountered during one hour of a cross-country airline flight, or one day of background radiation here at sea level. The instrument to be used is a Lunar iDXA scanner (see attached instrument illustration), widely used in measuring bone density, particularly in older women to evaluate for osteoporosis.
You will be asked to either have a second scan completed on the same scanner (iDXA) for precision testing, a second scan on a different DXA scanner (Prodigy) for cross calibration, or a lateral total body scan on the iDXA to assess abdominal visceral fat.

Pregnancy Test

All women, except those who identify as at least 3 years postmenopausal, will be given a commercially available early pregnancy test (One Step Plus hCG Pregnancy Test). You will be asked to urinate in a small container. The technician will collect the sample, and complete the test. You will be informed of the results of your test, and referred to your personal doctor if the test results are positive.

Appendix C

Lean Research Health Screening Form

Body Composition in Healthy Adults

Health Questionnaire

Personal / Emergency Information

Last Name ______ First Name ______ Middle Initial ______

Date of Birth ______ Age ______ Sex (M/F) ______

Mailing Address (optional) ______ City ______ State ______ Zip ______

Email Address (optional) ______ (____)______ Home Phone (____)______ Work Phone

Ethnicity Asian_____ Black_____ Hispanic_____ White_____ Other__________

Family Physician (optional) ______

Medical History

- Do you know the date of your last medical examination? Yes No
  If you answered Yes, when was it? (month/year)____________________

Present Medical Status

- Please provide the information below (if known).
  Blood pressure __________ mmHg Total Cholesterol _____ mg/dL
  HDL _____ mg/dL LDL _____ mg/dL Triglycerides _______ mg/dL
  Height__________ Weight______________
- Do you have diabetes? Yes No
  If "YES", you do not qualify for the study
- Do you have any of the following? (Circle all that apply.)
  Asthma Cancer Anorexia Bulimia
  Inherited Bone Disease Inherited Muscle Disease Kidney Disease

- If you are female, did you go through menopause? YES NO
  - If NO, please describe your current menstrual pattern. (Circle one.) or

very regular	usually regular	not regular, but seldom miss a period	mostly irregular	completely unpredictable	no or few periods

- Please list any allergies you have.

____

____

- Please describe any prescription medications you are currently taking.

Name/Type	Dosage	Reason for Taking

- Please describe any over-the-counter medications (Tylenol, Advil, Nyquil, etc.) or nutritional supplements you are currently taking.

Name/Type	Dosage	Reason for Taking

- Do you currently have any implants or indwelling devices? Yes No

  If you answered Yes, you do not qualify for the study

  ____

Lifestyle Considerations

Exercise History

- Are you currently, or have you ever, participated on an organized sport / activity team? Yes No

  If you answered Yes, please describe your activities.

  Professional ____

Amateur ____________________

College ____________________

Recreational ____________________

Other ____________________

Exercise habits

- Do you participate in recreational activities that require you to be physically active? Yes No

  If you answered Yes, please describe your activities.

  ____

  ____

- Do you exercise on a regular basis? Yes No

  If you answered Yes, please describe your activities.

	Aerobics	Resistance	Other ________
Minutes/session	________	________	________
Sessions/week	________	________	________
Intensity	________	________	________

- Does your occupation usually require you to be physically active? Yes No

  If you answered Yes, please rate the activity. (Circle one.) Light Moderate Heavy

Nutritional habits

- Do you consume alcoholic beverages? Yes No

  If you answered Yes, how many alcoholic drinks do you consume in a typical week? ______ drinks in a typical week

Smoking

- Have you ever smoked cigarettes? Yes No

  If you answered YES, when did you quit? (month/year) ______

Is there any health issue or behavior that has not been addressed on this questionnaire that might affect your ability to participate in this research? YES NO

If you answered Yes, please describe the health issue or behavior.

____

____

Do you confirm that you have not been diagnosed or treated for **coronary artery disease, peripheral artery disease, congestive heart failure, diabetes, chronic kidney disease, chronic liver disease, abnormal liver or renal function tests, anorexia nervosa, bulimia?** YES

If you are *older* than 50, do you confirm that *if* you have been diagnosed **with high blood pressure or high cholesterol** that you are adequately treated with medications? YES

If you are *younger* than 50, do you confirm that you have *not* been diagnosed or treated for **high blood pressure or high cholesterol?** YES

Do you confirm that you have no indwelling devices or any type of metal, plastic or silicone implants, except for minor cosmetic ones in the face? YES

Do you confirm that you are not pregnant or lactating? YES

Do you confirm that you do not drink more than 2 servings of alcohol per day, have not smoked in 6 months, and have not had prolonged hospitalization or immobilization within the last 6 months? YES

Do you confirm that your weight has not fluctuated more than 10 lbs in the last 6 months? YES

Do you confirm that you have not had liposuction or surgery for obesity such as lap-band or gastric bypass surgery? YES

Do you confirm that you are not taking prescription drugs for dieting. YES

Do you confirm that you have an active lifestyle or job, and get 30 minutes of exercise at least 3 times weekly? YES

Do you confirm that you are not highly trained for a specific sporting activity. YES

Do you confirm that you do not have neurological or muscular disorders such as stroke, spinal cord injury, multiple sclerosis, muscular dystrophy, paralysis, or amputation? YES

The information I have provided is true and complete. I understand that my responses are confidential. My participation may be limited by my responses. I am free to withdraw my consent and stop participation at any time without penalty.

Participant Name	Participant Signature	Date
Researcher Name	Researcher Signature	Date

Appendix D

Two-Sample T Tests for Dependant Variables

Two-Sample T-Test and CI: BMD, Sport

Two-sample T for BMD

Sport	N	Mean	StDev	SE Mean
s	20	1.2161	0.0973	0.022
t	20	1.3343	0.0875	0.020

Difference = mu (s) - mu (t)
Estimate for difference: -0.1182
95% upper bound for difference: -0.0688
T-Test of difference = 0 (vs <): T-Value = -4.04 P-Value = 0.000 DF = 37

Two-Sample T-Test and CI: BMD (legs), Sport

Two-sample T for BMD (legs)

Sport	N	Mean	StDev	SE Mean
s	20	1.281	0.142	0.032
t	20	1.495	0.101	0.023

Difference = mu (s) - mu (t)
Estimate for difference: -0.2143
95% upper bound for difference: -0.1483
T-Test of difference = 0 (vs <): T-Value = -5.49 P-Value = 0.000 DF = 34

Two-Sample T-Test and CI: % Fat (total body), Sport

Two-sample T for % BF

Sport	N	Mean	StDev	SE Mean
s	20	14.62	3.40	0.76
t	20	12.02	2.43	0.54

Difference = mu (s) - mu (t)
Estimate for difference: 2.605
95% lower bound for difference: 1.024
T-Test of difference = 0 (vs >): T-Value = 2.79 P-Value = 0.004 DF = 34

Two-Sample T-Test and CI: % Fat (legs), Sport

```
Two-sample T for % Fat (legs)

Sport   N   Mean  StDev  SE Mean
s      20  17.56   4.21     0.94
t      20  14.46   2.88     0.65


Difference = mu (s) - mu (t)
Estimate for difference:  3.09
95% lower bound for difference:  1.16
T-Test of difference = 0 (vs >): T-Value = 2.71  P-Value = 0.004  DF = 33
```

Two-Sample T-Test and CI: LTL ratio, Sport

```
Two-sample T for LTL ratio

Sport   N    Mean   StDev  SE Mean
s      20   1.949   0.102    0.023
t      20  1.7931  0.0887    0.020


Difference = mu (s) - mu (t)
Estimate for difference:  0.1556
95% lower bound for difference:  0.1047
T-Test of difference = 0 (vs >): T-Value = 5.15  P-Value = 0.000  DF = 37
```

Appendix E

Linear Regressions of Group Anthropometric and Descriptive Variables

Regression Analysis: BMD versus Wt, X-sport

```
The regression equation is
BMD = 0.746 + 0.00791 Wt - 0.149 X-sport


Predictor       Coef   SE Coef      T      P
Constant      0.7460    0.1050   7.11  0.000
Wt          0.007910  0.001397   5.66  0.000
X-sport     -0.14881   0.02237  -6.65  0.000


S = 0.0686467   R-Sq = 62.5%   R-Sq(adj) = 60.5%


Analysis of Variance

Source          DF       SS       MS      F      P
Regression       2  0.29087  0.14544  30.86  0.000
Residual Error  37  0.17436  0.00471
Total           39  0.46523


Source   DF   Seq SS
Wt        1  0.08235
X-sport   1  0.20852


Unusual Observations

Obs    Wt     BMD     Fit  SE Fit  Residual  St Resid
  4  84.1  1.4380  1.2625  0.0174    0.1755     2.64R

R denotes an observation with a large standardized residual.
```

Regression Analysis: BMD versus Age (yrs), X-sport

```
The regression equation is
BMD = 1.15 + 0.0091 Age (yrs) - 0.113 X-sport


Predictor       Coef  SE Coef      T      P
Constant      1.1525   0.2143   5.38  0.000
Age (yrs)    0.00906  0.01063   0.85  0.400
X-sport     -0.11317  0.02996  -3.78  0.001


S = 0.0928893   R-Sq = 31.4%   R-Sq(adj) = 27.7%
```

```
Analysis of Variance

Source          DF        SS        MS     F      P
Regression       2  0.145977  0.072988  8.46  0.001
Residual Error  37  0.319252  0.008628
Total           39  0.465228


Source     DF    Seq SS
Age (yrs)   1  0.022860
X-sport     1  0.123116


Unusual Observations

       Age
Obs  (yrs)     BMD     Fit  SE Fit  Residual  St Resid
  4   21.4  1.4380  1.2332  0.0289    0.2048      2.32R
 21   24.6  1.4030  1.3753  0.0524    0.0277      0.36 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Regression Analysis: BMD versus LTM, X-sport

```
The regression equation is
BMD = 0.777 + 0.00897 LTM - 0.132 X-sport


Predictor      Coef   SE Coef      T      P
Constant     0.7770    0.1112   6.99  0.000
LTM        0.008967  0.001770   5.07  0.000
X-sport    -0.13176   0.02295  -5.74  0.000


S = 0.0720790   R-Sq = 58.7%   R-Sq(adj) = 56.4%
Analysis of Variance

Source          DF       SS       MS      F      P
Regression       2  0.27300  0.13650  26.27  0.000
Residual Error  37  0.19223  0.00520
Total           39  0.46523


Source   DF   Seq SS
LTM       1  0.10176
X-sport   1  0.17124


Unusual Observations

Obs   LTM     BMD     Fit  SE Fit  Residual  St Resid
  4  63.0  1.4380  1.2098  0.0162    0.2282      3.25R

R denotes an observation with a large standardized residual.
```

Regression Analysis: % BF versus Age (yrs), X-sport

```
The regression equation is
% BF = 17.1 - 0.253 Age (yrs) + 2.46 X-sport


Predictor      Coef  SE Coef      T      P
Constant     17.086    6.862   2.49  0.017
Age (yrs)   -0.2527   0.3403  -0.74  0.462
X-sport      2.4648   0.9591   2.57  0.014


S = 2.97358   R-Sq = 18.2%   R-Sq(adj) = 13.8%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       2   72.736  36.368  4.11  0.024
Residual Error  37  327.161   8.842
Total           39  399.898


Source     DF  Seq SS
Age (yrs)   1  14.341
X-sport     1  58.395


Unusual Observations

       Age
Obs  (yrs)    % BF     Fit  SE Fit  Residual  St Resid
  3   19.7  20.700  14.573   0.668     6.127     2.11R
  4   21.4  20.100  14.144   0.924     5.956     2.11R
 15   18.5   8.600  14.876   0.749    -6.276    -2.18R
 21   24.6   8.100  10.870   1.679    -2.770    -1.13 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.
```

Regression Analysis: % BF versus Wt, X-sport

```
The regression equation is
% BF = 8.09 + 0.0527 Wt + 2.40 X-sport


Predictor      Coef  SE Coef     T      P
Constant      8.095    4.535  1.78  0.082
Wt          0.05271  0.06033  0.87  0.388
X-sport      2.4010   0.9663  2.48  0.018


S = 2.96522   R-Sq = 18.6%   R-Sq(adj) = 14.3%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       2   74.573  37.287  4.24  0.022
```

Residual Error	37	325.324	8.793
Total	39	399.898	

Source	DF	Seq SS
Wt	1	20.290
X-sport	1	54.283

Unusual Observations

Obs	Wt	% BF	Fit	SE Fit	Residual	St Resid
3	70.9	20.700	14.233	0.797	6.467	2.26R
15	82.3	8.600	14.834	0.707	-6.234	-2.16R

R denotes an observation with a large standardized residual.

Regression Analysis: FFM/FM ratio versus Age (yrs), X-sport

The regression equation is
FFM/FM ratio = 2.66 + 0.249 Age (yrs) - 1.17 X-sport

Predictor	Coef	SE Coef	T	P
Constant	2.658	4.144	0.64	0.525
Age (yrs)	0.2487	0.2055	1.21	0.234
X-sport	-1.1695	0.5792	-2.02	0.051

S = 1.79567   R-Sq = 15.5%   R-Sq(adj) = 10.9%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	21.820	10.910	3.38	0.045
Residual Error	37	119.303	3.224		
Total	39	141.123			

Source	DF	Seq SS
Age (yrs)	1	8.673
X-sport	1	13.146

Unusual Observations

Obs	Age (yrs)	FFM/FM ratio	Fit	SE Fit	Residual	St Resid
15	18.5	10.620	6.090	0.452	4.530	2.61R
21	24.6	11.345	8.777	1.014	2.568	1.73 X

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Appendix F

Correlations Between Anthropometric Variables

Correlations: BMD, Wt

```
Pearson correlation of BMD and Wt = 0.421
P-Value = 0.007
```

Correlations: BMD, Age (yrs)

```
Pearson correlation of BMD and Age (yrs) = 0.222
P-Value = 0.169
```

Correlations: LTM, BMD

```
Pearson correlation of LTM and BMD = 0.468
P-Value = 0.002
```

Correlations: LTM, Wt

```
Pearson correlation of LTM and Wt = 0.932
P-Value = 0.000
```

Correlations: Age (yrs), LTM

```
Pearson correlation of Age (yrs) and LTM = 0.138
P-Value = 0.395
```

Correlations: % BF, Age (yrs)

```
Pearson correlation of % BF and Age (yrs) = -0.189
P-Value = 0.242
```

Correlations: % BF, Wt

```
Pearson correlation of % BF and Wt = 0.225
P-Value = 0.160
```

Correlations: BMD, FFM/FM ratio

```
Pearson correlation of BMD and FFM/FM ratio = 0.119
P-Value = 0.466
```

Correlations: LTL ratio, Age (yrs)

```
Pearson correlation of LTL ratio and Age (yrs) = 0.099
P-Value = 0.545
```

Correlations: FFM/FM ratio, Age (yrs)

```
Pearson correlation of FFM/FM ratio and Age (yrs) = 0.248
P-Value = 0.123
```