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VALIDITY OF LABORATORY AND FIELD METHODS FOR PREDICTING FAT FREE MASS IN ELITE MALE ROWERS

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VALIDITY OF LABORATORY AND FIELD METHODS FOR PREDICTING FAT FREE MASS IN ELITE MALE ROWERS

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

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ABSTRACT

The purpose of this study was to determine the validity of air displacement plethysmography, ultrasound, near-infrared interactance, and skinfold measurements in estimating fat-free mass in elite male rowers. Twenty-three elite-level male rowers participated in this investigation. All participants were members of the High Performance Training Center located in Oklahoma City, OK and had a minimum of 4 years of training experience. All body composition assessments were performed on the same day in no particular order, except for hydrostatic weighing (HW), which was measured last. All participants were asked to refrain from food 8 to 12 hours prior to testing (ad libitum water intake was allowed up to one hour prior to testing), and were instructed to avoid exercise for at least twenty-four hours prior to testing. Hydration status was determined prior to all testing using specific gravity via handheld refractometry to ensure proper hydration prior to testing. Fat-free mass (FFM) was evaluated using the four compartment model (4C), which included the measures of total body water (TBW) from bioimpedance spectrospcy (BIS), body volume from hydrostatic weighing (HW), and total body bone mineral (TBBM) via dual energy x-ray absorptiometry (DEXA). Estimates of FFM via air displacement plethysmography (BOD POD®), near infrared interactance (Futrex® 6100/XL), ultrasound (IntelaMetrix BX-2000), and the 3-site Jackson and Pollock skinfold equation (Sum3) were validated against the criterion method, 4C model. The major findings of the study were that all independent techniques evaluated overestimated FFM and should not be considered valid for the assessment of FFM in elite male rowers. Future studies should use multiple

compartment models for the estimation of FFM, and include the measurement of TBW and TBBM.

CHAPTER I
INTRODUCTION

The sport of rowing demands a high level of both strength and endurance, as a rower performs more than 200 strokes with a peak force of over 1000N during a 2000-meter (m) race [1]. While maximal anaerobic and aerobic power have been reported to have strong correlations with rowing performance, body size and body mass are related to performance as well [2]. A study by Yoshiga and Higuchi found that the greater the fat-free mass (FFM) and maximal oxygen consumption (VO_2max) values in male and female rowers, the better the rowing performance, supporting the argument that rowing is a sport that demands high aerobic capacity and a large relative muscle mass [3]. The interest in examining physiological factors that may predict race success has increased over the last ten years, with measurements of VO_2max, lactate threshold, and peak power output showing significant relationships to performance. However, in sports that also demand repeated high force output, like rowing, FFM may be more significantly associated with performance success.

For weight bearing endurance activities, such as long-distance running, a large body mass hinders exercise performance [4, 5]. However, a large FFM and therefore large body mass, does not penalize rowers, whose body weight is supported in the boat. Among both junior and senior heavyweight rowers, FFM has been significantly correlated to 2000-m race performance, and despite the weight limitations imposed on lightweight rowers, FFM remains a predictor of competitive success [6]. Cosgrove et al. demonstrated a high correlation between FFM and velocity in a 2000-meter time trial, indicating that muscle mass is an important predictor in rowing performance [7]. In support of these findings, Slater and colleagues found that lower body fat and higher levels of FFM (and total mass), were associated with faster heat times and superior overall regatta placing among lightweight rowers [6]. It has been hypothesized that the correlation between rowing performance and FFM may be due to the direct relationship between skeletal muscle mass (a large component of FFM) and its capacity to consume oxygen for energy metabolism [8, 9] [10]. Additionally, FFM may also be related to central circulatory factors known to influence maximal aerobic capacity [11]. Specifically, FFM is strongly related to blood volume and left ventricular hypertrophy, and may be a determinant of stroke volume [12, 13].

For athletes competing in weight categories, monitoring individual weight fluctuations and their consequences on body composition is important to optimize performance during competition [14]. With higher rates of body mass loss (greater than 0.5-0.9 $kg \cdot wk^{-1}$ [15]), reductions in both fat mass (FM) and FFM occur, with the proportional loss of FFM increasing with the rate of body mass loss [16]. This loss in FFM could potentially lead to loss in strength, power, and overall competition success. Therefore, accurate measurements of body composition are important for athletes to evaluate the effectiveness of training and nutritional regimes on fat and fat-free mass during periods of weight reduction. Previous studies measuring body composition in rowers have utilized dual energy x-ray absorptiometry (DXA) and skinfolds [17-20]. Cost, required technician skill, and error associated with these measurements may limit the practically of these tools in a universal setting.

A more convenient technique, air displacement plethysmography (ADP) via the BOD POD, uses the relationship between pressure and volume, to determine BV. Body density (Db) is then as: Db=BM/BV, which can be used in any of the 2C models equations to estimate body fat (BF), fat mass, and fat-free mass [21]. This method has been shown to be highly reliable and a valid method for determining Db in adults in comparison to hydrostatic weighing (HW), producing a constant error of -0.3% BF, a standard error of the estimate of 1.81% BF with 95% limits of agreement of -4.0%-3.4% [22]. Additionally, Moon and colleagues demonstrated high validity coefficient, “excellent” SEE and “very good” TE values from the BOD POD when compared to HW [23]. Their findings add to the current body of literature suggesting that the BOD POD is a valid method for estimating %fat in males.

Having portable methods to assess fat and fat-free mass is important to determine an athlete’s ideal weight category and to individualize their training regime. With that in mind, several field-based techniques for estimating body composition variables have been suggested as alternative methods for body composition assessment, including ultrasound, near-infrared interactance, and skinfolds. The ultrasound technique is a non-invasive, harmless method to measure Db and subcutaneous fat thickness. It is cheap, both to acquire and to use, and has the advantage of being portable. Ultrasound scanners are capable of measuring subcutaneous fat at depths of 100 mm or more and can detect density interfaces with an accuracy of 1 mm [24]. A strong correlation between ultrasound and computed tomography has been found when measuring intraabdominal adipose tissue in overweight patients [25]. Ultrasound has also shown significant correlations (r=-0.58 to -0.70) between Db determined by HW and subcutaneous fat thickness using ultrasound in white men [24]. In a more recent study, Utter and colleagues demonstrated that ultrasound (IntelaMetrix BX-2000) estimated fat-free mass (FFM) within an acceptable range when compared to HW in wrestlers [26]. Also noted were no significant differences in mean FFM predicted by ultrasound and the criterion HW, “excellent” SEE and prediction error values, and no systematic under- or overestimation of FFM despite a wide range of body weight. Ultrasound may provide an attractive alternative to those who do not have access to more sophisticated laboratory methods or for coaches and trainers who need a portable method of measuring body composition.

Near-infrared (NIR) interactance applies the principle of light absorption and reflection by using NIR spectroscopy to estimate body composition. Following placement of a detector on the belly of a muscle (typically the biceps brachii), the NIR emits a light that penetrates the tissue and is reflected off the bone and back to the detector. The detector measures intensity of the re-emitted light, which is expressed as optical density (OD). This method is based on the concept that ODs are inversely and linearly related to subcutaneous and total body fat. Then, using a regression equation, the NIR estimates percent body fat (%BF). Seen as a convenient, fast, and noninvasive way to measure body composition, the NIR method has recently become popular in clinical settings. However, validation studies using several different models of the NIR device have had less than optimal results. Studies examining the Futrex-5000, Futrex-5000A, and Futrex-1000 have demonstrated significant constant error values and have found the errors associated with the instruments to be too large to be of practical use [27]. More recently, a newly-developed NIR model (Futrex 6100 X/L) that uses six wavelengths rather than two. was validated [23]. Similar to the other machines, the new instrument was found to produce unacceptable total error values as well as high standard error of the estimate values [23].

The use of anthropometric measures in prediction equations to estimate body composition variables is a simple, portable, and cheap way to estimate and monitor fat and fat-free mass in athletes. Skinfolds are a practical way to measure subcutaneous fat, with research demonstrating similar values of between skinfold measurements and magnetic resonance imaging and computed tomography [28, 29]. It is estimated that approximately 30% to 50% of the total body fat is located subcutaneously in men and women [30]; however, there are variations in subcutaneous, intramuscular, intermuscular, and internal organ fat deposits [31], as well as in essential lipids in bone marrow and the central nervous system. Age, gender, and degree of fatness all affect variations in fat distribution [30]. Research has indicated that population-specific and equations based on gender may accurately estimate the Db of athletes in many different sports [21]. Durnin and Womersley [32], Jackson and Pollock [33], and Lohman [34] are three such equations that are applicable to a wide range of ages and fatness. Due to mixed results using these equations, cross-validation studies are needed before they are used with specialized groups. Additionally, many commonly used prediction equations, based on skinfolds and derived from a general population, have been shown to be invalid when applied to athletes[35].

Little research involving body composition measurements has been conducted in rowers, and therefore some of the methods traditionally used to measure body composition may not be valid in this population. Although several of the above-mentioned techniques have been validated in the general population, it is unclear whether these same devices and methods could potentially be used for a group of elite-level athletes competing in weight class sports. Therefore, the purpose of this study was to determine the validity of air displacement plethysmography, ultrasound, near-infrared interactance, and skinfold measurement in estimating fat-free mass in elite male rowers.

Hypotheses

1. It was hypothesized that both the BOD POD and Ultrasound methods would result in valid estimates of fat-free mass compared to the four-compartment model.
2. It was hypothesized that near-infrared interactance (NIR) would produce large errors compared to the four-compartment model when estimating fat-free mass.
3. It was hypothesized that skinfold estimates of fat-free mass (Jackson and Pollock 3-site) would produce good agreement with the 4-C model, but may produce mean differences and subsequent large total error values.

Operational Definitions

Body density-Overall density of the fat, water, mineral, and protein components of the human body; total body mass expressed relative to total body volume.

Percent Body Fat- Fat mass expressed relative to body mass.

Fat Mass- All extractable lipids from adipose and other tissues in the body.

Fat-Free Mass- The amount of muscle, bone, water, and other non-adipose tissues.

Pearson product moment correlation coefficient- Statistical test that quantifies the degree of relationship between two continuous variables.

Standard error of estimate- Measure of prediction error; quantifies the average deviation of individual data points around the line of best fit.

Total error- Average deviation of individual scores of the cross-validation sample from the line of identity.

Constant error/mean difference- Average difference between the measured and predicted values for the cross-validation group.

Limits of agreement- A statistical method used to assess the degree of agreement between methods; also known as the Bland and Altman method.

Abbreviations

HT-Height (cm)

BM- Body mass (kg)

ICW- Intracellular water

ECW- Extracellular water

BIS- Bioelectrical spectroscopy

DXA- Dual-energy X-ray absorptiometry

TBW- Total body water (L)

r- Pearson product moment correlation coefficient

SEE- Standard error of estimate

TE- Total error

CE-constant error/mean difference

LOA- Limits of agreement

Db- Body density

FFM- Fat-free mass

FM- Fat mass

2C- Two-compartment

4C-Four-compartment

Delimitations

Twenty-three elite-level male rowers participated in this investigation. All participants completed a general health history questionnaire and a written informed consent prior to all testing. All participants were members of the High Performance Training Center located in Oklahoma City, OK and had a minimum of 4 years of training experience.

Assumptions

Theoretical Assumptions

1. Accurate health history will be provided.
2. Participants will be fasted for a minimum of twelve hours with ad libitum water consumption.
3. Equipment is calibrated and working properly.
4. Proper hydration is accurately reflected in urine specific gravity.

Statistical Assumptions

1. Normality- The sample population is evenly distributed.
2. Independent observations- Each condition is independent of each other.
3. Equal variances- The variance between variables are equal.

Limitations

1. Participants were only selected from the High Performance Training Center in Oklahoma City, OK; therefore, the process of subject selection was not truly random. In addition, the sample was made up of volunteers; therefore, it did not meet the underlying assumption of selection.
2. The use of bioelectrical impedance spectroscopy, rather than deuterium oxide for the estimation of total body water may also be a limitation. Although data suggests both methods are valid, deuterium oxide is considered the criterion method for estimating total body water.

CHAPTER II
REVIEW OF LITERATURE

Relationship between fat-free mass and rowing performance

Yoshiga CC and Higuchi M., 2003[36]

Bilateral leg extension power and fat-free mass in young oarsmen.

The authors of the current study hypothesized that the ability to produce a high bilateral leg extension power and a large fat-free mass would be strong predictors of rowing performance. Three hundred and thirty two oarsmen (21 ± 2 yrs, 1.76 ± 0.05m, 70 ± 6 kgs) volunteered to participate in the study, which involved the estimation of percent body fat using the Brozek equation and the body density from the BOD POD and an all-out 2000m row on a rowing ergometer (Concept II Model C). Fat-free mass was assessed as the difference between body mass and fat mass. Linear regression analysis was used to evaluate the relationship between rowing performance time and the physiological characteristics of the rowers. Forward stepwise multiple regression analysis was used to determine independent physiological correlated of rowing performance time. Statistical significance was set at $P<0.05$. Rowing performance was related to height, body mass, fat-free mass and bilateral leg extension power. Multiple regression revealed that fat-free mass was the strongest independent predictor of rowing performance. For weight-bearing physical activities, such as long distance running, a larger body mass often hinders exercise performance, but the main findings of the current study indicate that a large body mass contributes to favorable rowing performance, possibly due to the fact that the weight is supported during rowing. Previous authors have hypothesized that body size is influential to rowing performance because of the volume of the respiratory system and the maintenance of a high ventilation rate. Additionally, it has been noted that fat-free mass is not only an indication of muscle mass and, therefore, the energy source during exercise, but it is also related to blood volume and to stroke volume of the heart. The findings of the present study demonstrate the relevance of fat-free mass for rowing performance, suggesting the importance of measuring and tracking changes in fat-free mass for competitive oarsmen.

Purge P, Jurimae J, and Jurimae T., 2004[17]

Body Composition, physical performance and psychological factors contributing to 200m sculling in elite rowers.

The purpose of the current study was to measure a wide range of different parameters in order to determine which parameters could be used to monitor training and are more indicative of specific sculling performance. Ten male elite rowers (20.7 ± 3.3 yrs; 192.7 ±4.9cm; 91.6 ±5.8kg) volunteered for this study. Participants had an average training age of 7 years prior to the start of testing. Measurements were taken at the beginning of their preparatory period, with all rowers performing a 2000m competition for single sculling followed by body composition assessment one week later. Using dual energy x-ray absorptiometry (DXA), scans of the whole body were performed using a Lunar DPX-IQ scanner and analyzed for fat (FM) and fat free (FFM) mass. Recovery-stress state assessment, as well as maximal arm pull, arm press, and leg press were also measured. Using Pearson product moment correlations, the strength of the relationship between each of the dependent variables and competition time was determined. Significant relationships were observed between the 2000m maximal sculling time and body mass, arm muscle mass, arm pull, leg press, and stress and recovery values. Multiple regression analysis demonstrated that performance variables predicted performance time of 2000m best (R=0.86), followed by body composition (R=0.71), and mood state (R=0.56) variables. Body composition analysis using DXA revealed that arm muscle mass was a strong predictor of sculling performance, indicating that the development of upper body muscles may have a high importance in sculling. To date, more research has been completed on the development of leg muscles and leg muscle strength in rowers, specifically sweep rowers; however, the results of the current study indicate that upper body size and strength may have more importance in elite sculling than sweep rowing, and resistance training should reflect that.

Jurimae J, Maestu J, Jurimae T, and Pihl E., 2000[18]

Prediction of rowing performance on single sculls from metabolic and anthropometric variables.

The authors of the current study hypothesized that a combination of metabolic and anthropometric variables would predict the performance of 2000m distances for single sculls and the rowing ergometer better than any one single variable. Ten experienced male rowers volunteered for this study, testing on three separate occasions over a two week period. Height, body weight, body mass index (BMI), and sum of six skinfolds were measured and calculated for each rower. The sites for the skinfolds were triceps, subscapular, abdominal, supraspinale, front-thigh, and medial calf and measurements were taken using Holtain skinfold calipers. Body density was determined according to the skinfold prediction equation of Durnin and Womersley, and percent body fat was calculated from body density using the Siri equation. In addition, muscle mass was calculated, using the Martin et al equation, skeletal mass was calculated according to Martin, and cross-sectional area of the thigh was estimated according to Hawes. Maximal oxygen consumption (VO_{2max}), maximal aerobic power (Pa_{max}) and the power corresponding to the 4mmol/l blood LA concentration (AT_4) was determined for each rower using a progressive incremental exercise test on a Concept II rowing ergometer. The second testing session consisted of a 2000m "all-out" test, in which rowers were asked to cover a distance of 2000m on a rowing ergometer in the least time possible. The last testing session consisted of a 40 second "all-out" test on a rowing ergometer to determine mean work rate in watts. On-water competition results for the 2000m race distance for single sculls were obtained and used as an independent variable, along with the 2000m ergometer rowing. Pearson Product Moment Correlation coefficients were used to determine the strength of relationship between each of the dependent variables and competition times for the 2000m rowing performances (on-water and ergometer). Forward stepwise multiple regression analysis was used to predict the 2000m competition results for single sculls. Significant relationships were observed between the on-water 2000m time trial and muscle mass, VO_{2max}, Pa_{max}, and AT_4. Ergometer rowing performance was significantly related to height, body mass, BMI, lean body mass, CSA of the thigh, muscle mass, skeletal mass, VO_{2max}, Pa_{max}, and AT_4. In addition, there was a strong relationship between on-water performance and ergometer performance (r=0.72). Multiple regression analysis demonstrated that a prediction model using both anthropometric and metabolic variables predicted performance time of 2000m on single sculls best (R=0.89). These findings are in contrast of those of Russell et al.[37], who found that anthropometric variables alone predicted the performance time best for a rowing ergometer. The prediction equation developed in the current study is specific to scullers, while the subjects were sweep rowers in the Russell et al study. The differences may be explained by the difference in height and body weight, as sweep rowers have been reported to be taller and heavier and are characterized by a greater muscle development as compared to sculling subject. Thus, some caution should be used when examining models to predict performance for scull and sweep rowers.

Slater GJ, Rice AJ, Mujika I, Hahn AG, Sharpe K, Jenkins DG.,2005[38]
Physique traits of lightweight rowers and their relationship to competitive success.

The primary aim of the current study was to examine the relationship between physique traits and competitive success among lightweight rowers. Additionally, the authors sought to quantify the effect of small differences in muscle mass and fat mass on competitive performance. It was hypothesized that larger, more muscular athletes would be more successful. A total of 107 lightweight rowers competing at the 2003 Australian Rowing Championships volunteered to participate in this study. Full anthropometric profiles were assessed using skinfolds at 8 sites, 11 girths, 12 lengths, and 6 breadths. Body mass was measured on a digital scale and skinfolds were assessed using the Harpenden calipers. Anthropometric variables were used to create a four-way fractionation of body mass, partitioning total body mass into fat mass, muscle mass, bone, and residual mass using the phantom model. Performance was assessed via heat times and overall placing at the 2003 Australian Rowing Championships. Association between physique traits and heat times were assessed by an analysis of covariance (ANCOVA), with final placing as the dependent variable, gender and division (under 23 or open) as categorical predictors, and physique traits as a covariate. Lower body fat and higher levels of muscle mass were associated with faster heat times and better overall placing amongst athletes. Successful female and male rowers tended to have lower body fat levels than their less successful competitors, both in the under 23 and open categories. In addition, more muscle mass was evident in successful male and female rowers. The primary finding of this study is that amongst competitive lightweight rowers, physique traits are related to performance outcomes, with successful rowers possessing more muscle mass and less body fat than their less successful counterparts. These findings are in agreement with previous studies examining the relationship physique traits in elite lightweight oarsmen. The strength of association between body composition and performance confirms that lightweight rowers should prioritize the manipulation of not only fat mass, bit also muscle mass and they prepare to make weight for upcoming competition. It is important to notes that physique measurements and competitive success may have been influenced by acute body mass management strategies undertaken by rowers prior to racing. The majority of rowers used in the current study were hypohydrated at the time of weigh in, suggesting that the strength of association between physique traits and performance reported in the present investigation could be considered conservative. Due to the fact that hydration status has negligible impact on results of anthropometric profiling, anthropometry was considered the most appropriate tool for estimating body composition variables in the present investigation.

Cosgrove MJ, Wilson J, Watt D, Grant SF., 1999[7]

The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000m ergometer test.

The aim of the present study was to examine the relationship between selected physiological variables of male rowers and rowing performance as determined by a 2000m time-trial. Thirteen male rowers with at least one year of experience volunteered to participate in this study. Participants performed three tests on separate days, including measures of body mass and percent body fat, maximal oxygen consumption (VO_{2max}), a lactate profile, and a 2000m performance test. Percent body fat was estimated using skinfold measurements following the method of Durnin and Womersley. Pearson's correlation coefficients were used to examine the interrelationships between variables. Variables were then entered into a forward stepwise multiple linear regression using time-trial velocity as the response variable. The most significant relationships were between VO_{2max} and time-trial performance (r=0.848) and between lean body mass and time-trial performance (r=0.848), indicating their importance for success in rowing. The authors do bring up some reservation about the strength of the relationship between lean body mass and rowing performance because of some error associated with using the Durnin and Womersley method of estimating body fat. However, individuals with a high lean body mass possess a larger muscle mass than individuals with low lean body mass and, therefore, are potentially able to produce a greater force during each stroke, leading to more successful rowing performances. The authors conclude that the high correlation between lean body mass and velocity in the 2000m time-trial shows that muscle mass is an important variable in rowing performance and that rowers and coaches should use these findings when designing training programs.

Mikulic P, 2009[20]

Anthropometric and metabolic determinants of 6,000-m ergometer performance in internationally competitive rowers.

The aim of the current study was to examine the anthropometric and metabolic determinants of performance during 6,000-m ergometer rowing in male heavyweight rowers. Twenty five current or former members of the Croatian nation team volunteered for this study. All participants were highly trained and laboratory measurements tool place in the middle of their preparatory period. For the estimation of lean body mass, anthropometric measurements, including body mass, arm span, arm girth, gluteal girth, chest girth, and 6 skinfolds, were used. The percentage of body fat was estimated using the Carter equation. Following the anthropometric measurement, each rower performed an incremental maximal two on the Concept II model C rowing ergometer to determine maximal exercise capacity. Maximal oxygen consumption (VO_{2max}), power output at VO_{2max}, ventilatory threshold (VT), maximal ventilation, VO_2 and VT, and power output at VT were obtained during the ergometer test. The 6,000-m ergometer performance data was based on the results of the 2007 Croatian Indoor Rowing Championship. Pearson correlation coefficients were used to determine the strength of association of each of the independent variables and their relationship to the 6,000-m rowing time. Variables that were highly correlated with performance were selected for the development of the regression models using stepwise multiple linear regression analysis. Performance was significantly correlated with body mass, lean body mass, and all girth measurements. Using the regression models, lean body mass was the first and only predictor to enter the model. The formula used for the anthropometric prediction model had an adjusted R^2 value of 0.575 and standard error of 22.8 seconds. Power output at VT was the strongest and only true predictor for the metabolic prediction model, with an R^2 of 0.530 and standard error of 24.7 seconds. The present study suggests that the strongest overall correlate of 6,000-m rowing ergometer performance is lean body mass (r=-0.767). A large lean body mass contributes to a higher level of rowing performance due to almost every muscle being used during the stroke. This finding is consistent with previous studies that have found lean body mass to be a major predictor in 2,000-m rowing performance. Training programs for rowers striving to improve their 6,000-m ergometer time should be tailored to the improvement of devote their training time to the lean body mass and power output at VT.

The validity of Ultrasound techniques for estimating fat-free mass

Pineau JC, Filliard JR, Bocquet M., 2009[14]

Ultrasound techniques applied to body fat measurement in male and female athletes.

The purpose of the current study was to determine total body fat (BF) using a portable ultrasound technique (UT) device and establish a new predictive model to measure body composition of top athletes. Ninety-three athletes, ranging in age from 18-33 volunteered for this study. Percent body fat measurements were obtained using dual energy x-ray absorptiometry (DEXA) and ultrasound measurements taken at the abdomen and midthigh. Height, mass, body mass index (BMI), and umbilical and midthigh circumferences were recoded using stand anthropometric techniques. New models were developed to produce BF estimates with ultrasound and anthropometric dimensions versus DEXA. Separate models were developed for both men and women.

For men, the model used to estimate BF was a stepwise linear regression with a breakpoint using BF (DEXA) as a dependent variable. A multiple linear regression analysis provided an estimate of BF, which was used to determine which of the linear regressions was appropriate. The relationships between %BF estimates by DEXA and UT were examined using paired-samples t tests. A regression equation was created using the first 47 athletes, and then evaluated using the remaining athletes. The accuracy of BF prediction with regression analysis was evaluated using the coefficient of determination (r^2), the standard error of the estimate (SEE), and the total error (TE). Agreement between body composition estimates was examined using Bland Altman plots. All %BF estimates by UT were correlated with BF% estimates by DEXA ($r>0.96$). The TE was small for the UT technique regardless of sex. Moreover, the SEE was small for all athletes, despite the range of BF% (<2.00). The relatively small limits of agreement, ranging from -2.3 to 2.3 BF% reflect a high level of accuracy for the UT. The results obtained with the UT GEM device were more accurate than those obtained through traditional techniques routinely used, such as BIA and skinfolds. Additionally, the model used to estimate BF% proved to be accurate regardless of the size of the sample. The precision of the predictive equation with the first 47 athletes ($R^2=0.97$, SEE=1.29) did not increase with the remaining 46 athletes or with the total sample. These findings demonstrate that the response variable and the predictor variables are highly correlation, and therefore, provide a stable equation. In conclusion, the accuracy of the UT device for estimating BF%, along with its portability and lower cost, may be an attractive alternative for evaluating body composition in elite athletes.

Pineau JC, Guihard-Costa AM, Bocquet M, 2007[39]

Validation of Ultrasound techniques applied to body fat measurement.

The purpose of this study was to determine total body fat using a portable ultrasonic technique (UT) that measures the thickness of subcutaneous fat and to cross-validate the results of UT, along with bioimpedance (BIA) and air displacement plethysmography (ADP), against the dual energy x-ray absorptiometry (DEXA) reference technique. Sixty women and 83 men had a total of four body composition measurements completed on the same day, and included DEXA, UT, BIA, and ADP. The relationships between DEXA and BF% estimates according to the different techniques used were examined using pair-sample t-tests. The accuracy of body fatness prediction with the regression analysis was evaluated using the coefficient of determination (r^2), the standard error estimate (SEE), and total error (TE). When comparing all subjects, BF% determined from UT (29.5 ±10.6%) or BIA (29.9 ±12.7% was not significantly different compared to DEXA (29.6 ±10.8%). In contrast, BF% determined from ADP (30.9 ±14.7) was significantly greater than that obtained by DEXA. In males only, BIA significantly overestimated BF%, while ADP produced a non-significant overestimation compared to DEXA. All BF% estimates by UT, BIA, and ADP were significantly correlation with BF% from DEXA ($r \geq 0.91$, $p < 0.01$), regardless of gender. TE was greater for the BIA (TE=2.57%) and the ADP (TE+2.99) technique compared with the UT (TE=1.00%) regardless of gender. In conclusion, the comparisons of BF% estimates using the different techniques and cross-validation studies indicate that BF% estimates by UT versus DEXA are more accurate than BF% estimates with BIA or ADP, regardless of gender.

Yasukawa M, Horvath S, Oishi K, MiKimura M, Williams R, and Maeshima T, 1995[40]

Total body fat estimations by near-infrared interactance, A-mode ultrasound, and underwater weighing.

The authors of the current study had three aims; 1) to assess the relationship between subcutaneous fat thickness and NIR data, 2) to compare zero order correlation coefficients between percent fat (%fat) as determined by underwater weighing (UWW), NIR and ultrasound, and 3) to compare the prediction ability via multiple regression. A-mode and NIR measurements were carried out at the same sites (subscapular, abdomen, suprailiac, biceps, triceps, quadriceps, and hamstrings. NIR measurements were taken using the Fitness Analyzer BFT-2000 and subcutaneous fat thickness was determined by means of an A-mode ultrasound (Fukuda, FT-100). Percent body fat was assessed for each subject using the UWW method, with residual volume being measured on land. Multiple regression equations on ultrasound and NIR data were performed by the Wherry-Doolittle tests selection method[41]. Correlation coefficients were computed after each variable was added to the equation. Statistically significant coefficients were obtained at all sites measured by the ultrasound. The zero order correlation coefficients exceed 0.6 for all sites except for the triceps and hamstrings in the men. Correlation coefficients for NIR were low (<0.6) for both genders in all sites except for the biceps. Interestingly, the NIR data had higher correlations at the thinner fat sites and lower correlations at the thicker fat sites. Results from the multiple regression equations revealed four sites using the ultrasound (suprailiac, quadriceps, biceps, and abdomen), plus height gave the lowest standard errors and highest correlation coefficient for the ultrasound method (2.71 and 0.904, respectively). Equations using the NIR data incorporated the biceps and triceps site, plus height, weight, and age. The multiple correlation coefficients and standard errors for the estimation were 0.819 and 3.72%, respectively. In the present study, 92.7% of the men were within ±4% fat from the UWW using the A-mode ultrasound method. Consequently, only 73.2% of the men were within ±4% fat using the NIR method. These findings are in agreement with previous studies that showed relatively high multiple correlation coefficients and low standard error values[24, 42, 43]. In conclusion, %fat can be estimated with a correlation coefficient >0.9 using fat thickness measurements at four sites via A-mode ultrasound along with height.

Utter AC and Hager M, 2008[26]

Evaluation of ultrasound in assessing composition of high school wrestlers

The purpose of the current investigation was to evaluate the accuracy of the ultrasound (ULTRA) for measuring fat-free mass (FFM) when compared with hydrostatic weighing (HW) in high school wrestlers. All measurements were made in the preseason, with baseline hydration status obtained prior to any measurements via handheld refractometer. Skinfolds (SK) were measured on the right site of the body at three sites: triceps, subscapular, and abdomen). Body density (Db) was predicted using the Lohman equation[34], and percent body fat (%BF) was determined using the Brozek equation[44]. This % BF equation was also used with the Db from HW and ULTRA. Db from HW was measured, using the average of the two highest underwater weight trials. Residual volume was measured outside the tank using the oxygen dilution method[45]. ULTRA measurements were made using the IntelaMetrix BX-2000. The BX-2000 is an A-mode ULTRA device that uses a 2.5 MHz transmitter and separate receiver to measure tissue thickness. Multiple paired sample t-tests were performed to examine body composition differences. Linear regression analyses were performed to assess the agreement in FFM measured by ULTRA versus HW. Bland-Altman plots were used to observe the 95% limits of agreement[46]. The standard error of the estimate (SEE) and prediction error (PE) were also used to compare FFM measurements by ULTRA and HW. Pearson product-moment correlations between ULTRA and SK measures at each site were also calculated. Results revealed a strong correlation ($r=0.97$) and no significant differences in mean FFM predicted by ULTRA (57.2 ± 9.7) and the criterion method HW (57.0 ± 9.8). A significant underestimation was found for FFM predicted by SK compared with HW, despite a strong correlation ($r=0.96$). The regression equation for ULTRA resulted in a good SEE, and high adjusted R^2, and a non-significant mean difference in estimating FFM. The SEE value is comparable to previous findings using field based measures of body composition in wrestlers, including SK and bioelectrical impedance (BIA)[47, 48]. ULTRA predicted FFM within 2.31 kg 68% of the time and within 7.3kg 95% of the time in the present sample. Conversely, SK had a higher SEE and a significant mean difference in the estimation of FFM. This was the first study to demonstrate, when using SK, an underestimation of FFM and an overestimation of %BF when employing the Lohman equation for estimating Db and the Brozek equation for %BF in a wrestling population, Significant correlations were found for the ULTRA and SK measures at each site (triceps, subscapular, and abdomen). The findings from this study demonstrate that the ULTRA system estimates FFM within an acceptable range when compared with HW in young wrestlers. When examining the Bland-Altman plot, no significant correlation was found between the difference of FFM measured by ULTRA and HW versus average FFM by the two methods. Furthermore, these results indicate no systematic under- or overestimation of FFM despite a wide range of body weight.

The validity of skinfold measurement in estimating body composition variables

Steward AD and Hannan WJ, 2000[49]

Prediction of fat and fat-free mass in male athletes using dual x-ray absorptiometry as the reference method.

The authors of the current study sought to determine whether bioelectrical impedance analysis (BIA) or anthropometric equations applied to an athletic population is the preferred prediction technique, by comparing results to the reference method of dual energy x-ray absorptiometry (DXA). Eighty-two individuals, with a minimum of 3 years competing in their selected sports, were recruited for this study. DXA measurements were taken using a Hologic QDR 1000W scanner and using the enhanced version 5.55 software. BIA was measured using an analyzer operating at 50kHz and 800μA (RJL Systems). The measured impedance was used to predict fat and fat-free masses measured by DXA, in addition to using equations by Lohman and Lukaski and Bolonchuk[50]. Body girths and skinfolds measurements were taken for anthropometric measurements. All measurements were taken at the right side of the body and skinfold sites included the pectoral, axilla, chest, biceps, triceps, forearm, subscapular, abdominal, supraspinale, suprailium, thigh, and calf. Body density was calculated using three equations, and converted to percent body fat using the formula of Siri (1956). Stepwise regression analysis was used to determine the optimal prediction equations for fat and fat-free masses determined by DXA using predictor variables from anthropometry and BIA. The results of the current study suggest that percent fat is predicted better from anthropometry than BIA. Of the anthropometric predictions, the equation that used the three sites of Jackson and Pollock[33] appears to agree more closely with the DXA value and to have a smaller prediction error than that of Durnin and Womersley[32]. For male athletes, prediction of fat and fat-free masses is best when using skinfolds, especially at the abdominal, thigh, and suprailium sites. Despite its greater precision, BIA offers a less accurate prediction of percent fat than skinfolds. The difference in accuracy may be more closely linked to lean tissue rather than fat tissue distribution.

Hortobagyi T, Israel RG, Houmard JA, O'Brien KF, Johns RA, and Wells JM, 1992[51]

Comparison of four methods to assess body composition in black and white athletes.

The purpose of the present study was to compare the estimates of percent body fat (%BF) obtained with hydrostatic weighing (HW), seven site skinfolds (7 SF), bioelectrical impedance analysis (BIA), and near-infrared analysis (NIR). Subjects were 90 men (55 blacks and 35 whites) and recruited from a varsity, NCAA Division I football team. As described by Jackson and Pollock, skinfold (SF) measurements were obtained with a Harpenden caliper in a fixed order at seven sites (chest, axilla, triceps, subscapula, abdomen, suprailium, thigh). Body density (Db) was calculated from SF using the Jackson and Pollock generalized equations for seven sites, and % BF was computed with the Siri equation. Body composition was also assessed with a portable, battery –powered NIR device (Futrex-5000). The light wand was placed on the midpoint of the right arm, on the anterior midline of the biceps midway between the antecubital fossa and the acromion process. Subjects were then tested for body composition by BIA with the RJL Spectrum II system, following the manufacturer's instructions. Hydrodensitometry was determined by taking the mean of the three heaviest trials out of ten, with residual volume being measured on land prior to getting in the water. Db was calculated from the equation of Brozek et al. and %BF from Db with the Schutte equation. The means of %BF for each method (HW, 7SF, BIA, NIR) were compared with one-way analysis of variance with repeated measures (ANOVA), with races as a grouping variable. Pearson correlation coefficients were obtained for %BF among the five methods. Forward and backward stepwise regression analyses were performed to evaluate the independent contribution of various NIR and BIA variables to the variance in %BF measured with HW. A standard error of estimate (SEE) was calculated using HW as the criterion. ANOVA revealed a significant difference among the methods used to predict %BF. Using HW as the criterion, NIR significantly under predicted mean %BF by -2.1% in blacks and -1.3 in whites, while BIA significantly over predicted mean %BF by 5.4% in blacks and 3.3 in whites. The estimates of % BF by 7 SF were not different from %BF obtained with HW in wither group. 7 SF also correlated more highly with HW than either NIR or BIA in both groups. Previous findings consistently demonstrate that NIR under predicts %BF in athletes and non-athletes. Such under predictions may give a coach the impression that their athletes have lower than actual %BF and may fail to recommend fat loss necessary for optimal performance. In contrast, BIA overestimated % BF, suggesting that lean athletes could potentially be considered overweight, or be told to lose weight to optimize performance. The 7 SF equation predicted %BF accurately, with a SEE of 2.2% in blacks and 2.9% in whites. Compared to NIR and BIA, the SEE and SD were lower and the correlation coefficients were higher, suggesting that neither NIR nor BIA estimated body composition as accurately as 7 SF, in relation to HW.

Sinning WE, Dolny DG, Little KD, Cunningham LN, Racaniello A, Siconolfi SF, and Sholes JL, 1985[35]
Validity of "generalized" equations for body composition analysis in male athletes.
The aim of the present study was to validate these newer equations with male athletes. In addition, other selected equations which utilized a linear model were included to compare their accuracy tot that of the newer equations. Skinfolds and underwater weighing (UWW) were performed on 265 athletes. Twenty-one estimation equations from six studies were evaluated. Equations by Jackson and Pollock, Durnin and Womersley, and Lohman represented the newer, generalized models. The validity of the equations was evaluated on the basis of analysis of the differences and correlations between estimated densitometry values. The t-test was used to compare differences between means. Product moment correlations, regression lines, total error (TE) and standard errors of estimates (SEE) were also computed. Generally speaking, the equations tended to overestimate % fat, especially the Durnin and Womersley equation. Differences between criterion and estimated means were significant for all equations except three by Jackson and Pollock. Correlations ranged from 0.58 to 0.85 (the highest value coming from a Jackson and Pollock equation. The TE values ranged from 2.38-6.97%, again, the Jackson and Pollock equation producing the lowest TE. Taken all together, the 3 equations by Jackson and Pollock met Lohman's criteria that the means for true and estimated values be similar. One of the Jackson and Pollock equations tended to underestimate fat in those with higher %BF values and overestimate %BF in

leaner subjects, while another equation of Jackson and Pollock demonstrated the opposite effect. By all criteria, the three Jackson and Pollock equations met the criteria for their use in the screening of male athletes for fat content. Sources of error from skinfold estimations may include the type of caliper used, the type of fold used, and differences in procedures.

Eckerson JM, Housh TJ, and Johnson GO, 1992[52]
The validity of visual estimations of percent body fat in lean males.

The purpose of the present study was to compare the validity of body composition estimates from visual inspection with those from skinfolds equations and bioelectrical impedance analysis (BIA) in lean males. Body composition determinants, including BIA, UWW, skinfolds, and visual estimations were performed on thirty-five males. Skinfold measurements were taken on the right side of the body at the triceps, scapular, midaxillary, chest, suprailiac, abdominal, and thigh as described by Jackson and Pollock. Body density (BD) was calucaulted using both sum of seven (SUM7) and sum of three (SUM3) skinfold equations of Jackson and Pollock. Percent body fat was calculated using the revised formula of Brozek. Body density was assess from USS with correction for residual volume. BIA was measured using the RJL Systems BIA-106 Spectrum analyzer using the standardized protocol described n the User reference. Visual estimations were performed by two raters who had extensive experience in body composition assessment. The validity of the procedures was based in the evaluation of the predicted % fat (SUM7, SUM3, BIA, and visual inspection) versus the actual % fat (UWW) via the calculation of constant error (CE), Pearson Product Moment correlation (r), and total error (TE). A one-way repeated measures ANOVA was used to determine the differences between the means of the different procedures used to estimate % fat. The results indicated that there were significant differences among the mean values for % fat. The CE values for skinfolds and BIA were significant at the adjusted family-wise alpha. The validity coefficient for the skinfold equations was 0.68 and was significant ($p<0.001$). In contrast, the correlation for BIA was not significant ($r=0.32$, $p>0.05$). For the skinfold equations, the SEE was 1.7%, compared to 5.0% for BIA. The results of this study indicate that the generalized skinfold equations (SUM7 and SUM3) accurately predicted % fat in lean males. Although they significantly underestimated % fat, the differences were small and comparable to values reported in previous investigations. Based on the low TE, SEE, and CE values, the generalized SUM7 and SUM3 skinfold equations of Jackson and Pollock are recommended over visual inspection for estimating % fat of lean males in field settings.

The validity of air displacement plethysmography in measuring body composition

Levenhagen DK, Borel MJ, Welch DC, Piasecki JH, Piasecki DP, Chen KY, Flakoll PJ, 1999[53]

A comparison of air displacement plethysmography with three other techniques to determine body fat in health adults

The purpose of the present study was to compare ADP with HW and two other standard body composition measurement methods, bioelectrical impedance (BIA) and dual energy x-ray absorptiometry (DXA). 20 health adults participated for this study and had their body composition assessed using all four techniques on the same day. For ADP and HW, Db was calculated using either the Siri or Schutte equations, depending on ethnic background. Whole body electrical resistance was measured using a 500Ω resistor (Biodybamic model 310 Body Composition Analyzer) and total body water and the corresponding percent fat were calculated. Whole body bone, fat, and fat-free soft tissue masses were determined via DXA. Differences between the mean body fat values for each of the four techniques were assed using a repeated-measures analysis of variance (ANOVA). Regression analysis was performed to determine the slopes, intercepts, and correlation coefficients for body fat using ADP versus HW, BIA, and DXA. The data was also analyzed according to Bland and Altman to assess the agreement in fat content measured by ADP versus the other techniques. Body fat determined by ADP was not different from that determined by HW. However, a significant gender difference did exist, with body fat measured by ADP 16% less in males and 7% greater in females compared to the values produced by HW. The mean values determined by ADP and BIA were also similar. Using the total population, correlation coefficients (r value) for ADP versus each of the other techniques were greater than 0.90 in each case. Plots of body fat measured by ADP versus HW, BIA, and DXA revealed that AD P slightly underestimated body fat at lower body fat vales and overestimated body fat at higher body fat values. Bland-Altman analysis indicated that the average difference between ADP and HW was less than -0.5%. The 95% confidence interval for this mean was between -6.7% and +5.7%, with none of the individual data points outside this confidence interval. Of concern with use of ADP are gender-related differences. In the current study ADP under predicted %fat in males and over predicted %fat in females. One possible explanation may be the slight overestimation of body fat by ADP at higher levels of body fat, and since women as a group tended to have higher levels of body fat in this study, their values were typically overestimated. Further experiments are required to validate body composition estimates with ASP using a more diverse population; however, ADP provides a less expensive, portable alternative to estimating body composition.

McCrory MA, Mole PA, Gomez TD, Dewey KG, and Bernauer EM, 1998[54]

Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes.

The purpose of this analysis was to compared predicted tidal volume (Vtg) to measured tidal volume, determine the effect of using predicted Vtg on the estimation of % BF, and to compare and contrast the use of predicted Vtg with air displacement with the use of predicted residual volume (V_R) in conjunction with hydrostatic weighing (HW). Percent body fat (%BF) was estimated with the BOD POD using both measured tidal volume and predicted tidal volume. The criterion method, HW, was measured on the same day, with residual volume being measured on land prior to getting in the water. Group means were compared by either one sample or two sample t tests where appropriate. Association between variables were assessed by calculating Pearson correlation coefficients. Regression equations were developed to determine how well the predicted variables reflected the measured variables. There were no significant differences between measured and predicted tidal volume, nor in % BF measured by ADP calculated by using predicted Vtg vs. measured Vtg. In contrast, V_R was over predicted by 14% and have the effect of significantly underestimating %BF by HW when using the predicted value. Results from the linear regression analyses indicated moderate agreement between predicted and measured lung volumes. R^2 values for regression of %BF calculated by using the measured lung volume vs. predicted lung volume were high for both methods (Vtg and V_R). Air displacement estimates of %BF using predicted Vtg were within ±1% BF calculated from measured Vtg in 58% of the subjects and within ±2% BF for 82% of the subjects. In contrast, HW estimates of %BF using the predicted V_R were within ±1% BF calculated by using measured V_R for 25% of subjects and ±2% BF for 46% of subjects. When Vtg is under predicted, %BF is underestimated and the opposite with Vtg is over predicted. Conversely, when V_R is under predicted, %BF is overestimated and when V_R is over predicted, %BF is underestimated. In conclusion, the findings of the current study support the use of predicted Vtg in conjunction with air displacement plethysmography for group mean comparisons and when screening you to middle-aged individuals.

Utter AC, Goss FL, Swan PD, Harris GS, Robertson RJ, and Trone GA, 2003[55]
Evaluation of air displacement for assessing body composition of collegiate wrestlers.

The aim of this study was to evaluate the accuracy of air displacement plethysmography (ADP) for measuring body density (Db) and subsequent estimation of percent body fat (%BF) when compared with hydrostatic weighing (HW) in a collegiate wrestling population during a hydrated and acutely hydrated state. Skinfolds (SK) were also included for comparative purposes. The first measurements of body composition were made in a euhydrated state. Baseline hydration was established by obtained a urine specimen to measure specific gravity by using a hand-held optical refractometer. After the first testing session was completed, subjects were instructed to decreased body mass 2-3% via acute dehydration through exercise. Three site skinfold measurements were taken using Lange calipers and the Lohman equation to calculate Db[34]. %BF was determined from Db using the Brozek equation[44] for Caucasians and the Schuette equation for African-American subjects[56]. Db was also determined via HW and ADP. A repeated-measures one-way ANOVA was performed to detect significant differences in body composition variables (Db, %BF, and FFM) by using three methods (SK, HW, and ADP) in both a euhydrated a dehydrated state. Multiple paired sample t tests were performed to examine body composition variables during hydrated versus dehydrated states. Linear regression and Bland-Altman analyses were conducted to assess the agreement between Db and %BF measured by ADP and HW. In the hydrated state, Db, %BF and FFM determined by ADP did not differ significantly from the corresponding variables determined by HW. In contrast, Db from SK was significantly lower than that of HW, which accounted for a significant overestimation of percent body fat by SK. In the dehydrated state, there were no significant differences n Db, %BF, and FFM determinants by ADP versus HW. However, SK produced significantly lower values of Db when compared to HW. FFM measurements in the dehydrated state were significantly lower for all three measurements compared to the hydrated state. In addition, Db from ADP and %BF from ADP were significantly different during the hydrated state versus the dehydrated state. Linear regression and Bland-Altman analyses of Db and %BF determined by ADP versus HW during the hydrated state and dehydrated states indicated a high degree of agreement. Regression equations resulted in a very low SEE and high adjusted R2 in both hydrated and dehydrated states, indicating good agreement of Db between ADP and HW. Similar results were seen between %BF from ADP and %BF from HW for both hydrated and dehydrated states. The findings of this study add to the support for measuring Db via ADP. Although previous research has indicated that the validity of ADP may be less accurate when using lean individuals, this was not the case in the present study, where the average %BF from HW (11.3 ± 4.8%) for the wrestlers was lower than that of previous research (14.1-17.0%). Based on the results, ADP is a valid measurement of Db, %BF and FFM.

McCrory MA, Gomez TD, Bernauer EM, and Mole PA, 1995[22]

Evaluation of a new air displacement plethysmography from measuring human body composition.

The present study was designed to evaluate the reliability and validity of the BOD POD (BP) in reference to hydrostatic weighing (HW). Sixty-eight subjects were recruited for this study. All testing took place within a two hour period on a single day, with BP testing occurring first, followed by HW. BP measurements, including tidal volume were measured following the manufacturer's recommendations. HW was used at the criterion method, with residual volume measured on land prior to getting in the water. Reliability testing was completed for each procedure, with each measurement being repeated by the same technicians immediately following the first trial. Reliability of estimating %Fat from BP and HW was determined by calculating the standard deviation (SD) and coefficient of variation (CV) for repeated measurements. The first and second trials within each method were compared with a paired t test. Repeated measures analysis of variable was used to compare mean %BF from each method. Repeated measures of covariance, with gender as the covariate was used to determine if the relationship between %Fat from the BP and %Fat from HW differed for men and women. Linear regression analysis was performed with %Fat from HW as the dependent variable. Results demonstrated no significant differences between the first and second trials in % fat for either BP or HW. Additionally, there were no significant differences between

%fat measurements comparing both methods for either gender. Analysis of covariance indicated that there was no difference between males and females in the relationship between %fat from BP and %Fat from HW. The reliability of both BP and HW methods was found to be excellent in both men and women. Additionally, the validity results indicate excellent agreement between %Fat from the BP and %Fat from HW in both men and women. The low SEE in this study (1.81) is lower than that of other studies evaluating different methods against HW. This study also demonstrated a high agreement between %Fat estimated by BP and HW for individual subjects, as 75% of the subjects fell within the range of ±2% of the mean difference between methods. In summary, the BOD POD was found to be highly valid and reliable for measuring body composition compared with HW in healthy subjects.

The validity of near infrared interactance for body composition determination

McLean KP and Skinner JS, 1992[57]

Validity of Futrex-5000 for body composition determination.

The primary purpose of this study was to determine if the Futrex-5000 (FTX) could predict body fat as accurately as anthropometric measures using under water weighing (UWW) as the criterion method. Additionally, the authors examined the variance explained by NIR in predicting body fat and if additional sites would improve the NIR body fat prediction. Thirty males and 31 females were recruited for this study. Height, weight, and BMI were measured and calculated for each participant. Five skinfold measurements were taken at the triceps, subscapula, abdomen, suprailium, and thigh for females and males had the same 5 sites plus the pectoralis. For the NIR measurement, height, weight, frame size, and activity level were entered into the FTX. The optical density (OD) was measured on the right biceps muscle belly, midway between the acromion and antecubital fossa. Body densitometry was measured using UWW, with residual lung volume determined on land. Body density and body fat were calculated using the equation of Brozek et al. Pearson correlation coefficients were obtained for % body fat estimated by the FTX, skinfolds, and UWW. Standard errors of estimate (SEE) were calculated, and correlation coefficients were compared using depended t-tests. A repeated measures ANOVA was used to determine significant difference between % body fat values determined by UWW, FTX and skinfolds. The correlation between skinfolds and the criterion measure (UWW) was significantly greater than that between FTX and UWW. Additionally the SEE for prediction of body fat was much lower for skinfolds compared to FTX (2.6 versus 4.9). The results of this study indicated that FTX did not estimate body fat as accurately as SKF when using UWW as the criterion method. The error in FTX estimation is greatest at the extremes of body fatness, with FTX underestimating body fat in subjects with >30% body fat and overestimating body fat in all subjects with <8% body fat. While it has been suggest that predictive capabilities of the FTX could be improved by measuring additional anatomical sites commonly associated with total body fat, the measurement of the triceps, subscapula, and other sites did not improve the body fat prediction. In summary, skinfolds give more information than NIR measurement and allow a more accurate prediction of body fat, especially at the extremes of the body fat continuum.

<u>Stout JR, Eckerson JM, Housh TJ, Johnson GO, and Betts NM, 1994[58]</u>
Validity of percent body fat estimations in males.

The present investigation was designed to examine the validity of % fat estimated form sum of three SF (Sum3), BIA and NIR in young adult males. Fifty-seven Caucasian males participated in this study. Body density was assessed from US with correction for residual lung volume. Percent body fat was estimated from Db using the revised formular of Brozek et al. Skinfold measurements were taken on the right side of the body at the chest, abdomen, and thigh. Body density was calculated using the Sum3 equation of Jackson and Pollok and converted to % fat using the revised formula of Brozek et al. NIR was measured using both the Futrex-5000 (F5000) and Futrex-1000 (F1000). Values were obtained at the anterior midline of the biceps brachii midway between the antecubital fossa and the acromion process of the dominant arm. BIA analysis was performed with an RJL Systems BIA-106 Spectrum Analyzer using the standard protocol described by the manufacturer. The validity of the procedures were based on the evaluation of the predicted % fat (Sum3, BIA, F5000, F1000) versus the actual % fat (UUW) via the calculation of constant error (CE), r value, standard error of the estimate (SEE), total error (TE), and the similarity between the standard deviation values of predicted and actual % fat. A one-way repeated measures ANOVA indicated that there were significant difference among the mean values for % fat, with post hoc analyses indicating there were significant mean differences for 5 fat from the F1000 and BIA equations versus UWW. The validity coefficients ranged from r=0.63 (F1000) to 0.90 (Sum3) and the SEE values ranged from 2.7% fat (Sum3) to 4.8% fat (F1000). TE values ranged from 3.6% fat (Sum3) to 6.1% ft (F1000). The results of the present study indicate that the generalized equation of Jackson and Pollock most accurately estimated fat, supporting the findings of previous investigations. However, regression analysis showed that the Sum3 equation systemically underestimated % fat across the sample, while F1000 overestimated fat and F5000 underestimates % fat in lean subjects and overestimated % fat in individual with higher % fat values.

Housh TJ, Johnson GO, Housh DJ, Cramer JT, Eckerson JM, Stout JR, Bull AJ, Rana SR, 2004[27]

Accuracy of near-infrared interactance instruments and population-specific equations for estimating body composition in young wrestlers.

It has been suggested that the accuracy of the NIR estimates of % fat may be improved by modifying the instrument-generated values specifically for use in athletes. Recent studies have proposed NIR equations for estimating body composition in high school wrestlers and adult men; however, these new NIR equations for use in young male athletes has not been examined. Therefore, the authors of the current study set out to determining the accuracy of the NIR instruments and population specific NIR equations for estimating fat in young wrestlers. Thirteen NIR % fat estimates were cross-validated against the criterion % fat from UWW. The NIR 5 fat estimates were generated from Futrex-5000 (F5000), Futrex-5000A (F5000A), and Futrex-1000 (F1000) instruments, or calculated using modified instrument-generated NIR equations and population specific equations. The constant error (CE) values ranged from -27.0(equation derived for adult males) to 3.1 (modified F1000) % fat. All NIR % fat estimated resulted in significant CE values, with validity coefficients ranging from r=0.60-0.80). Standard error of the estimate (SEE) values ranged from 4.4 (equation developed for youth wrestlers) to 5.9% (F1000 and modified F1000). Overall, the means for 11 of the 13 NIR % fat estimated in the present study were significantly greater than that of UWW % fat. The results of the present study support those of previous investigations that have demonstrated that the errors associated with NIR instrument-generated % fat estimates are too large to be used in athletic and non-athletic children and adolescents. Although modifying the % fat estimates using the cross-validation CE from Housh et al. improved the accuracy of each instrument, the TE values still ranged from 5.7 to 6.8% fat. Thus, neither the modified equations, nor the instrument-generated equations can be recommended for use in youth athletes.

<u>Moon JR, Tobkin SE, Smith AE, Roberts MD, Ryan ED, Dalbo VJ, Lockwood CM, Walter AA, Cramer JT, Beck TW, Stout JR, 2008[23]</u>

Percent body fat estimates in college men using field and laboratory methods: A three-compartment model approach.

The purpose of this study was to compare % fat estimates between laboratory methods (air displacement plethysmography via BOD POD (BP) and hydrostatic weighing (HW) and an invalidated field method, near-infrared interactance (NIR, Futrex-6100/XL) to the 3 compartment (3C) model 5 fat values in college-aged Caucasian men. Thirty-one Caucasian men volunteered for this study, completing all tests on one day, following a 12-hour fast. Body density was assessed from HW, with percent body fat calculated using the revised formula of Brozek et al. Body density was also estimated via BOD POD, with % body fat estimated using the revised formula of Brozek et al. The Futrex 6100/XL was used to measure the %fat of each participant according to the procedures recommended by the manufacturer. BIA analysis was performed using the Quantum II Bioelectrical Body Composition Analyzer following the procedures recommended by the manufacturer. Bioimpedance spectroscopy was used to estimate total body water (TBW). Body density from UWW, TBW, and body mass were used to calculate the criterion % fat (3C model). Validity of %fat estimates (BP, HW, NIR, BIA) were based on an evaluation of predicted values versus the criterion value from the 3C model by calculating the constant error (CE), r value, standard error of estimate (SEE), and total error (TE). The mean differences between predicted and actual %fat values were analyzed using dependent t-tests. Additionally, Bland-Altman plots were used to identify the 95% limits of agreement between the criterion and predicted %fat values. All laboratory methods (HW and BP) resulted in acceptable TE values (≤2.7% fat), along with both BIA field methods (TE ≤2.1% fat). NIR resulted in unacceptable TE values (≥4.7% fat. Of the field methods, the 95% limits of agreement were largest for NIR, while the BIA measurements produced smaller limits of agreement. Due to the ease in procedure, speed, and improved subject compliance, BP provides an attractive alternative to HW. With a high validity coefficient (r=0.86), and low SEE and TE, BP appears to produce acceptable estimations of % fat and may be used when HW or multiple compartment models are not available. However, the current findings suggest BP may over-predict % bf by as much as 5.43% and under-predict by as much as 5.35%. Due to unacceptable SEE and TE values, caution should be used when using NIR to estimate % fat in a population of male Caucasians.

The validity of bioimpedance spectroscopy in estimating total body water

Moon JR, Tobin SE, Roberts MD, Dalbo VJ, Kerksick CM, Bemben MG, Cramer JT, and Stout JR, 2008[59]

Total body water estimations in health men and women using bioimpedance spectroscopy: a deuterium oxide comparison.

To improve the accuracy of body composition measurements, the estimation of total body water (TBW) has been suggested. Criterion isotope methods for estimating TBW include deuterium oxide, hydrogen, tritium, oxygen-18, and oxygen; however, the methods are time-consuming and costly. An alternative method, bioimpedance spectroscopy (BIS), which uses a range of frequencies to pass an electrical current around and though the cells, has been shown to produce valid measurements when compared to a criterion method. With that being said, past investigations on the validity of BIS have predominately focused on one specific model (XiTRON 4000B), and have only recommended the use with groups rather than individuals due to large individual errors. Therefore, the purpose of this study was to compare a new device (Imp SFB7 (SFB7) to deuterium oxide (D_2O) for estimating TBW, and to compare the TBW values attained from the XiTRON 4000B and SFB7. It was hypothesized that both BIS devices would produce valid measurements compared to D_2O and that the SFB7 would reduce the error between D_2O and BIS due to the increased number of frequencies used from the estimation of TBW. Twenty-eight men and women had hydration status analyzed via refractometer prior to any testing. TBW was measured by BIS using the SFB7 and XiTRON 4000B following the manufacturer's guidelines. A D_2O tracer was used as the criterion method to estimate TBW. Subjects were instructed to void their bladder prior to ingesting approximately 11 grams of D_2O along with 100ml of deionized water. After a 4-hour period where subjects were not allowed to eat or drink anything, subjects were instructed to provide a post-urine sample. Isotope abundances in the urine were calculated following the method of Wong et al. TBW was calculated from the dilution of isotopic water and corrected for the exchange of deuterium with non-aqueous tissue. Validity of TBW estimates (SFB7 and 4000B) was based on evaluation of predicted values versus the criterion D2O by calculating constant error (CE), r value, standard error of estimate (SEE) and total error (TE). Mean differences between the predicted and actual values were analyzed using dependent t-tests. Both BIS devices produced valid estimations of TBW compared to D2O. The use of the SFB7 reduced individual TBW errors, and is therefore recommended over the use of 4000B for use in small groups or individuals. The SEE and r values from both machines agree with past BIS research in healthy adult men and women. However, the CE value for all subjects (CE=2.26 L) was significantly lower than the D2O TBW values, which is inconsistent with past findings. In all subjects, the TE values for 4000B were greater than the TE values from the SFB7, indicating the SFB7 is more accurate for predicting TBW. Individual subject results were compared by calculating the limits of agreement and it was found that the 4000B may over-predict TBW by as much as 3.88L and under-predict by as much as 8.39L, while the SFB7 may over-predict TBW by as much as 4.50 L and under-predict as much as 4.31L in all subjects. While the new SFB7 device improves upon the older 4000B, there is still a small margin of disagreement between BIS and D2O TBW values. However, due to the non-invasive nature and portability, they may be considered valid and appropriate to use with healthy individuals.

Van Loan MD, Withers P, Matthie J, Mayclin PL, 1993[60]

Use of bioimpedance spectroscopy to determine extracellular fluid, intracellular fluid, total body water, and fat-free mass.

The aim of this study was to evaluate bioimpedance spectroscopy (BIS) estimates of total body water (TBW), extracellular fluid (ECG), intracellular fluid (ICF), and fat-free mass (FFM) and compare these values to standard laboratory methods. Criterion TBW and ECF were determined using a dilution method, deuterium oxide (D2O). ICF was calculated by subtracting ECF from TBW. Predicted ECF and TBW were obtained using a Bio-Impedance Spectrum Analyzer (Model 4000, Xitron). ECF and ICF volumes were predicted using equations from mixture theory and from those equations; estimates of ECG, ICF, TTB, and FFM were computed. Percent body fat was assessed by hydrostatic weighing (HW). The Siri equation was used to calculate percent body fat and FFM was calculated by subtracting body fat from body weight. Correlation coefficients and paired t-tests were performed to determine any significant differences. The BIS estimates of ECF, ICF, TBW, and FFM were not significantly different from the criterion method. The correlations among the BIS estimates for fluid compartments and FFM and the criterion values ranged from 0.879-0.938. Based on these results, BIS can be used successfully for the estimation of body fluid compartments and FFM. BIS is a safe, rapid, noninvasive technique for assessing fluid compartments and body composition with the use of dilution techniques of underwater weighing.

Use of the four-compartment model for estimating body composition variables

Friedl KE, DeLuca JP, Marchitelli LJ, and Vogel JA, 1992[61]

Reliability of body-fat estimates from a four-compartment model by using density, body water, and bone mineral measurements.

This study was conducted to determine whether the additive errors from the individual measurements for the four-compartment model (4C) might introduce more error in precision than gains in accuracy obtained by assessing the additional major body components of total body water (TBW) and total body bone mineral (TBBM). Each subject underwent TBBM measurements via dual energy x-ray absorptiometry (DXA), TBW via bioelectrical impedance (BIS), TBW mass via serum concentrations of deuterium, and body density (Db) via underwater weighing. Percent body fat (%BF) calculations were made as follows: the two compartment model used Db from UWW and TBW[62], the three compartment model used Db from UWW and TBW from BIA, and the four-compartment model used Db, TBW mass, and TBBM. All data was analyzed using T-tests and analysis of variance (ANOVA). Repeatability of the measurements and fat estimations were expressed by within-subjects standard deviations and by the standardized Cronbach's alpha reliability statistic. The reliability coefficient for TBBM was 0.999, 0.992 for Db, and 0.989 for TBW mass. Body water estimations from BIS were very close in approximation of the deuterium-measured volumes (r=0.92, constant error= -1.2±2.1 L). The measurement of TBBM varied within subjects by ±40g. As a percentage of the FFM determined by the 4C model, TBBM ranged from 5.6% to 7.9% of FFM. Reliability was slightly higher when correcting for day-to-day variation in TBW in the three-compartment model than for UWW alone. The 4C model did not further increase this reliability with correction for TBBM. Fat mass from the various models gave the same pattern of reliabilities. 4C corrected values showed consistent differences for subjects where the mean differences was >1kg fat. The data from the current study indicate that the multi-compartment model can be used to improve the accuracy of body-fat measurement from UWW without being invalidated by the sum of errors from the multiple measurements. Adjustments for hydration produced sizeable changes in the fat estimates for some of the subjects and those adjustments appeared to be more important than corrections for TBBM. Fat weight means from the 3C model were significantly different from the 2C model; however, there was little additional change from the correction of The TBBM used in the 4C model. The estimates of TBW via BIS were very similar to the values for TBW determined by deuterium dilution and had smaller day-to-day variations compared to the deuterium method. Overall, the 4C model approach to %BF estimation approves upon the 2C model of Siri and Brozek in terms of accuracy, by accounting for bone mineral and water components.

Withers RT, LaForgia J, Pillans RK, Shipp NJ, Chatterton BE, Schultz CG, and Leaney F, 1998[63]

Comparison of two-, three-, and four-compartment models of body composition analysis in men and women.

The aims of this study were to examine the differences in body composition variables using two-, three-, and four-compartment models and to calculate the extent to which measurement errors are propagated when body composition is estimated via the four-compartment model. Testing was done on 48 young adults in a euhydrated state on the same day. Body density (BD) was measured by underwater weighing with corrections for residual volume. Total body water (TBW) was measured by the deuterium oxide (D_2O) dilution method. Dual energy x-ray absorptiometry (DXA) was used to measure bone mineral content. The BMC was then converted to bone mineral mass (BMM) by multiplying it by 1.0436[64, 65]. The two compartment model, via hydrodensiometry (HW) partitions the body into fat mass (FM) and fat-free mass, which assume constant densities (0.9007 and 1.1000 g/cm^3, respectively). The three-compartment model builds on the two compartment model by adding in TBW. The four-compartment model incorporates the additional variable of bone mineral. The means and variances for the percent body fat (%BF) differences between the two- and three-compartment models were compared with those between the three- and four-compartment models by using dependent t-tests. The standard error of the estimate (SEE) and technical error measurement (TEM) from the reliability data for the measurement for the BD, TBW, and BBM were used to calculate propagated errors for %BF. Large errors in %BF (-1.5-5.6%) occurred when there was no control for biological variability in TBW (i.e. 2C model). In contrast, controlling for inter-individual difference in the BMM had little effect on the %BF values of the subjects (3C model versus 4C model). Individual differences between the 2C and 3C models for all subjects exhibited significantly greater means and variance than those between the 3C and 4C models. Reliability data for the measurements of BD, TBW, and BMM yielded standard deviations (SD) for propagated error of 1.0 and 0.6% for the SEE and TEM data, respectively. The results from this study demonstrate conventional hydrodensitometry underestimates %BF by 2.3-2.8% compared to the 4C model. BD from the 4C model indicated FFM densities ranging from 1.0974 to 1.1177 g/cm^3 with a SD (0.0049 g/cm3), which equates to ± 1.6% BF; the differences between the 4C and 2C model spanned -0.9 to 5.9% BF. In conclusion, the data from this study suggests that 2C models underestimate the %BF because the 4C body composition model indicates that the FFM is greater than 1.100 g/cm3. Additionally, the differences between the 2C and 4C models were significantly associated with biological variability in FFM hydration. BBM provided only a marginal increase in accuracy.

CHAPTER III
METHODS

Participants

Twenty-three elite-level male rowers were recruited to participate in this study. Participants were members of the Oklahoma City High Performance Olympic Training Center and had their body composition assessment taken during a period of weight stability, prior to their competition season. This study was approved by the University Institutional Review Board for Human Subjects, and prior to all testing, written informed consent was obtained from each participant.

Research Design

All body composition assessments were performed on the same day in no particular order, except for hydrostatic weighing (HW), which was measured last. All participants were asked to refrain from food 8 to 12 hours prior to testing (ad libitum water intake was allowed up to one hour prior to testing) and were instructed to avoid exercise for at least twenty-four hours prior to testing.

Hydration status was determined prior to all testing using specific gravity via handheld refractometry (Model CLX-1, precision= 0.001 ±0.001, VEE GEE Scientific Inc., Kirkland Wash.) to ensure proper hydration prior to testing. In order to complete the testing, specific gravity values had to fall within the range of >1.004 and <1.029[66, 67].

Variables

Variables were classified as either a predictor or criterion variables. Predictor variables included air displacement plethysmography (BOD POD), ultrasound (US), near infrared interactance (NIR), and skinfolds (SKF). Criterion FFM was calculated using a four-compartment (4C) model and included the measurements of total body water (TBW), body volume (BV) from HW, and total body bone mineral (Mo) from dual energy x-ray absorptiometry (DXA).

Hydrostatic Weighing

Hydrostatic weighing (HW) was used to determine body density (Db) and body volume (BV) as previously described by our laboratory and others[68-70]. Residual volume was determined with the participant in a seated position using the oxygen dilution method via a metabolic cart with residual volume software (True One 2400®, Parvo-Medics, Inc. Provo, Utah). Participants completed a minimum of two trials and the average of the closest two trials within 5% were used to represent residual volume. Underwater weight (UWW) was measured to the nearest 0.025 kg in a submersion tank in which a seat made of polyvinyl chloride tubes was suspended from a calibrated Chatillon® 15-kg scale (Model # 1315DD-H, Largo, Florida). The average of the three highest values (6 to 10 trials) was used as the representative UWW. Previous test-retest reliability data for UWW from our laboratory demonstrated an intraclass correlation coefficient (ICC) of 0.99 with a standard error of the measurement (SEM) of 0.8% fat, 0.34 liters for body volume, and 0.002729 $g \cdot cc^{-1}$ for body density.

Total Body Water

Bioimpedance spectroscopy (BIS) was used to estimate TBW following the procedures recommended by the manufacturer (Imp SFB7; ImpediMed Limited, Queensland, Australia). This technique, previously described[71], uses a range of frequencies, encompassing both low and high ranges that allow electrical current to pass around and through each cell, and has produced valid estimates of TBW when compared to deuterium oxide[71, 72]. Additionally, BIS has been used to assess TBW for multi-compartment equations in previous validation studies[68, 73]. After resting in a supine position for 5 to 10 minutes, TBW estimates were taken while the participant laid in the supine position on a table with arms ≥30° away from the torso and legs separated. Prior to each analysis, each participant's height, weight, and sex were entered into the BIS device. Electrodes were placed at the wrist (dorsal surface at the ulnar styloid process) and ankle (dorsal surface between the malleoli) with additional electrodes being placed 5 centimeters from the wrist and ankle. Before electrode placement, excess body hair was removed, and the skin was cleaned with alcohol at each site. Using a range of frequencies (1-1000 kHz), the BIS generates complex Cole plots in the shape of an inverted "U", allowing for the calculation of the resistance of electrical current through the body at both zero and infinite frequencies[74]. These resistance values are used to calculate extracellular water (ECW) and intracellular water (ICW) and summed to equal TBW. The average of two trials within ±0.05L was used as the representative TBW. Previous test-retest measurements for TBW using the Imp SFB7 BIS produced an SEM of 0.40L and an ICC greater than 0.99.

Dual Energy X-ray Absorptiometry (DXA)

DXA (software version 10.50.086, Lunar Prodigy Advance, Madison, WI) was used to estimate total bone mineral content (BMC). BMC was then converted to total body bone mineral (Mo) using the following equation: Mo=total-body BMC x 1.0436 [75]. Prior to testing, a quality assurance phantom was performed. Before the test, participants' height, weight, sex, and race was entered into the computer program. The participants were positioned supine on the DXA table with hands pronated and flat on the table. Total body mode was selected for each scan, and scanning thickness was determined by the DXA software. All DXA scans were performed by a certified enCORE^{TM} software operator. Previous test-retest scans of 11 men and women measured 24-48 hours apart for Mo produced an SEM of 0.05kg with ICCs greater than 0.99.

Air Displacement Plethysmography (BOD POD®)

Body density (Db) was determined from air-displacement plethysmography using the BOD POD® (BP). Prior to each test, the BP was calibrated according to the manufacturer's instructions with the chamber empty using a cylinder of known volume (49.558 L). Participants, wearing tight fitting compression shorts and a swimming cap, were asked to enter and sit in the fiberglass chamber. The BP was sealed, and the participant was instructed to breathe normally for 20 seconds while BV was estimated. Thoracic gas volume was estimated using the BOD POD® software. This value was used to correct body volume for thoracic gas volume. Percent body fat (%BF), fat mass

(FM), and fat-free mass (FFM) will be calculated from Db using the revised formula of Brozek et al.[76].

Near-Infrared Interactance

The Futrex® 6100/XL was used to measure FFM of each of the participants according to the procedures recommended by the manufacturer (Futrex®, Hagerstown, MD). This device emits infrared light of six specific wavelengths (810, 910, 932, 944, 976, and 1,023) in the anterior midline of the biceps brachii midway between the antecubital fossa and acromion process of the right arm. A silicon-based detector then measures the intensity of the re-emitted light, which is expressed as optical density. FFM was estimated using a pre-programmed generalized multiple regression equation that included height, weight, and optical density values. The instrument was calibrated prior to each measurement with the manufacturer-supplied optical standard.

Ultrasound

Ultrasound measurements will be made using the IntelaMetrix BX-2000 (IntelaMetrix Inc, Livermore, CA). The BX-2000 is an A-mode ultrasound device that uses a 2.5-MHz transmitter and separate receiver to measure tissue thickness. Measurements were made by applying a thin layer of water-soluble gel to the contact surface on the device and then applying the device to the tissue. The transducer was applied manually, and care was taken to avoid compression of the subcutaneous fat. During the measurement, the BX-2000 slid back and forth along the skin surface (approximately ±5 mm for the measurement site) to provide local averaging of the measured signal. In the measured ultrasound signal, the first strong reflection occurred at the fat-muscle interface, which can easily be identified. Seven anatomical sites were used for the estimation of FFM (triceps, biceps brachii, chest, abdomen, thigh, hamstring, and calf).

Anthropometric Measurements

Skinfold thickness measurements were taken on the right side of the body with a calibrated Lange caliper by an investigator who has previously demonstrated a test-retest reliability of an ICC >0.95 and an SEM <0.52% fat. Measurements were taken according to the recommendations of Jackson and Pollock[77] at the sites of the chest, abdomen, and thigh. Body density (Db) values were calculated using the generalized skinfold equation of Jackson et al.[78]. Percent body fat was calculated from Db using the revised formula of Brozek et al.[76].

Four- Compartment Model (4C model)

The criterion FFM was estimated using the 4C model described by Wang et al.[79]. The equation includes measurements of BV, TBW, Mo and body mass (BM). The equation for FM and FFM are listed below:

$FM(kg)= 2.748(BV)-0.699(TBW)+ 1.129(Mo)- 2.051 (BM)$

$FFM=BM-FM$

Propagation of error

While multicompartment models are recommended over 2C models for assessing body composition, the potential propagation of errors due to the inherent measurement error of each device used to assess each variable may offset the improved accuracy of the 4C model estimates of body composition[70]. It has been suggested to calculate the total error of measurement (TEM) to account for the accuracy of the 4C equation[68]. The standard errors of measurement (SEM) of BV, TBW, and Mo were used to calculate propagated errors for FFM[70]. The TEM for the 4C model was calculated using the following equation[70]:

$\text{4C TEM} = (\text{TBW SEM}^2 + \text{BV SEM}^2 + \text{Mo SEM}^2)^{1/2}$

$\text{4C TEM} = (0.40^2)+0.34^2)+ 0.05^2)^{1/2}$

4C TEM= 0.53kgs FFM

Statistical Analyses

Data was analyzed using PASW Statistics (V. 18.0, SPSS Inc., Chicago, Ill) and Microsoft Excel 2010 version (Microsoft Corporation Redmond, WA, USA). The validity, precision, and bias was examined in each of the independent body composition techniques. FFM by the 4C model was selected as the criterion method because the model involves the fewest assumptions. Statistical significance was set at $p<0.05$. Regression analysis was used to determine the accuracy of the individual body composition techniques. The technique was considered accurate if the regression between FFM by the 4C model and the technique being tested has a slope not significantly different from 1. Precision of the techniques was assessed by the validity coefficient (R^2) and the standard error of the estimate (SEE). Additionally, the evaluation of predicted values versus the criterion values from the 4C model was assessed by calculating the constant error (CE= actual-predicted), r value (Pearson product moment correlation coefficient), and total error, TE= $\sqrt{\sum[predicted - actual]^2 / n}$ (31). The mean differences (CEs=constant errors) between the criterion value and the predicted values was analyzed using dependent t-tests with Bonferroni alpha adjustments. Student's t-distribution was used to identify the 95% limits of agreement (LOA) between the criterion and predicted values[79].

CHAPTER IV
RESULTS

The descriptive characteristics of the subjects are listed in Table 1. The mean fat-free mass (FFM) as determined by 4C was 72.8±9.8kg (Table 2). Significant differences ($p<0.001$) between the four compartment model (4C) estimates of FFM and all other techniques were observed.

Figures 1 – 5 show the relationships between predicted and 4C FFM values for the BODPOD® (BP), near infrared interactance (NIR), Ultrasound (US), and the three site Jackson & Pollock equation (Sum3). The relationship between FFM by the 4C model and by all other techniques significantly deviated from the line of identity, as explained by slope values significantly different from 1.0. Table 2 gives the results of the cross-validation analyses for the field and laboratory methods predictions of FFM. The statistical significance for the mean difference (CE) between the criterion method and the predicted values for each method was determined by dependent t-tests with Bonferroni correction ($p<0.05/5= 0.01$). The CE values ranged from 8.1kg (J&P) to 4.0kg (US) and all were significant at $p<0.01$.

The validity coefficients ranged from $R^2=0.86$ (Ultrasound) to $R^2=0.94$ (NIR). The SEE values ranged from 2.36kg (Sum3) to 3.8kg FFM (Ultrasound). However, TE, which accounts for the errors associated with both the CE and SEE ranged from 5.36kg FFM (BP) to 8.4kg FFM (Sum3). The SD values for all predictor methods (Table 2) were less than 4C FFM (9.8kg). Limits of agreement were the largest for Sum 3 (-3.2-12.8 kg FFM) and smallest for BP (-1.1-10.9 kg FFM).

CHAPTER V
DISCUSSION

This study examined the accuracy, precision, and bias of fat-free mass as assessed by air displacement plethysmography (BODPOD®), near infrared interactance (NIR), ultrasound (US), and a Jackson and Pollock skinfold equation (Sum3) relative to the four compartment (4C) model of Wang et al. in elite level male rowers. Additionally, the recommendations of Lohman et al were used to evaluate the results. These included comparable mean values between the criterion method and independent techniques, low SEE values, low TE values, and standard deviation values that are in close agreement. To our knowledge, this is the first study to examine the validity of common laboratory and field methods used for the assessment of body composition in rowers. The major finding is that none of the methods used in the study are valid for the prediction of FFM in elite male rowers.

Air displacement Plethysmography Findings

Due to the ease in procedure, speed, and subject compliance, the BODPOD® (BP) provides an attractive alternative to hydrostatic weighing (HW). Results from this study demonstrated a high validity coefficient (R^2=0.91) and “very good” SEE (3.0kg), but “poor” TE (5.36kg). Additionally, the regression between FFM by the 4C model and FFM by BP significantly deviated from the line of identity. However, BP did not show significant bias across the range of FFM values (r=0.266). Limits of agreement (LOA) in the current study were relatively large (-1.1-10.9). These findings are in partial agreement with Utter and colleagues [55], who demonstrated a significant deviation from the line of identity when comparing body composition variables from the BP to body composition variables from hydrostatic weighing (HW) in male wrestlers. Contrary to the current findings, Utter demonstrated no significant difference between body composition estimated by the two techniques, a small CE (0.17kg vs. 4.94kg from the present study), and relatively narrow LOA. Interestingly, several studies have found the BP to be less valid for lean individuals in comparison to average weight and overweight individuals using the criterion method of HW[80-82]. Levenhagen et al. demonstrated the regression line representing the relationship between BP and HW was significantly different from the line of identity, resulting in underestimation % body fat (%fat) and overestimation FFM relative to HW values at lower body fat levels and overestimation %fat at higher body fat levels in both males and females of varying fatness[53]. It has been noted that the BP can accurately predict %fat within the "average" range of 20%-30%[22]; however, outside that range the results are typically less accurate. The large CE and TE observed in the current study could be in part explained by the use of a homogenous group of lean athletes, whose average %fat was 11.4. Some caution should be taken when comparing the present results with those of the previously mentioned studies because HW uses a two-compartment model, which carries assumptions concerning the density of fat and fat-free mass. Multiple compartment models are almost free of assumptions, as they take into account the fractions of body mass that are aqueous and/or mineral. Limited research is available on the validity of BP compared to a multiple compartment model, and of the research out there, the results are mixed. Moon et al. [23] examined the validity of the BP in college-aged males using the criterion method of a 3C model and demonstrated a high validity coefficient (r=0.86), "excellent" SEE (2.42%fat), and "very good" TE (2.7%). The authors concluded that the BP is a valid method for estimating body composition, but with large limits of agreement. In contrast, Fields et al.[83] demonstrated that the BP significantly underestimated %fat (and overestimated FFM) in females when compared to the 4C model. The authors concluded that the differences in estimates of %fat from the two techniques were significantly related to the aqueous fraction of the FFM, highlighting the importance of a multi-compartment approach when evaluating body composition.

Near Infrared Interactance Findings

The results from present investigation demonstrated the estimated FFM values by NIR were significantly greater than that of the FFM values from the 4C model. In support of the current findings, Stout et al.[58] showed NIR to underestimate %fat in leaner subjects and overestimate %fat for those subjects with higher %fat values compared to the reference value from HW. Furthermore, Moon et al.[23] reported NIR to underestimate body fat by an average of 1.98% compared to the 3C model in college-aged males, and Hortobagyi et al.[51] found NIR to underestimate %BF and significantly overestimate FFM by 1.7kgs in athletes. Contrary to these findings, Mclean and Skinner[57] reported NIR to overestimate %fat values in leaner individuals when compared to HW. In the current study, the regression between FFM by the 4C model and FFM by NIR significantly deviated from the line of identity. Additionally, NIR showed systematic bias across the range of FFM values (r=0.688). The present study used the newly developed NIR device (Futrex 6100/XL), employing six wavelengths to estimate body composition compared to only two wavelengths of the previous models. Even with the updated model, the Futrex 6100/XL produced a TE value of 5.43kg, showing strong agreement with previous studies demonstrating the Futrex 6100/XL, 5000 and 1000 to produce large TE values[23, 57, 58, 84]. It appears that the additional wavelengths utilized in the Futrex 6100/XL do not improve the accuracy for estimating body composition in this population. The validity coefficient (r=0.89) was higher than previous reports using the Futrex 5000 on adult males (r=0.76-0.80)[57, 58, 84], and both the Futrex 1000 and 5000 on young wrestlers (r=0.29-0.60 and 0.46-0.71, respectively)[27]. The SEE value of 3.4kg in the current study was considered "fairly good" by the subjective ratings of Lohman et al; however, this value was slightly higher than that of Cassady et al.[85] who reported a SEE of 2.2-2.9kg using the Futrex 5000 and the reference method of HW. Not surprisingly, the authors also demonstrated a lower TE (2.7-3.7kg). Interestingly, a study reported by Fornetti and colleagues[86] found the Futrex 5000 to produce a high correlation coefficient (r=0.98) and low SEE and TE values (1.1kg and 1.4kg, respectively) in female athletes, including a sample of rowers. Although the NIR produced a high validity coefficient between NIR FFM estimates and 4C model FFM, significant mean differences and inflated SEE and TE scores indicate the Futrex 6100/XL is not a suitable device for estimating FFM in male rowers and future studies will need to refine the prediction equations to establish validity.

Ultrasound Findings

Ultrasound(US) is a noninvasive, user-friendly, portable method of estimating body composition. Previous studies have proposed the US as an alternative technique to measure body density and subcutaneous fat[87-89]. Results from this study demonstrated a significant overestimation of FFM by the US (76.8±9.1kg) compared to the 4C model (72.8±9.8). Additionally, the regression between FFM by US and FFM by the 4C model significantly deviated from the line of identity. The SEE in the present study was 3.8kg, which is higher than that of a previous report demonstrating an SEE of 2.0-2.5kg comparing US to HW in wrestlers[87]. Moreover, Pineau and colleagues found US to have a low SEE when measuring body composition against the reference method of DXA in male athletes (SEE=0.96%fat)[89]. TE in the present study was 5.43kg, indicating a "poor" level of agreement. Contrary to the current findings, Pineau et al. reported low TE values using the US to predict %fat in male athletes (TE=0.93) and in older male adults (TE=0.95%)[88, 89]. When examining systematic bias of US using the Bland and Altman plot, no significant correlation (r=0.384) was found between the difference of FFM measured by US and the 4C model versus the average FFM by the two methods. Additionally, there was no systematic under- or over-estimation of FFM. However, the limits of agreement (-3.7-11.7) were larger than those previously reported by Pineau et al. and Utter et al.[87-89]. To our knowledge, this is the first investigation to compare estimates of FFM from US to the 4C model, and only the second study to evaluate the validity of the BX-2000 (IntelaMetrix Inc.) device. US had the lowest precision (R^2=0.86) and highest SEE value compared to all other field and laboratory methods tested in the study. Furthermore, the high TE suggests that the US is not an accurate tool in the measurement of FFM in male rowers.

Jackson and Pollock Skinfold Equation Findings

The results of the present study indicated that the generalized sum of three skinfold equation of Jackson and Pollock (Sum3) did not accurately estimate FFM. The skinfold method resulted in a significant overestimated of FFM compared to the 4C model (80.8±9.7kg vs. 72.8±9.8kg). These findings are in contrast to those of Stout et al.[58] who reported the Sum3 to accurately estimate %fat in young adult males. The regression between FFM by the 4C model and FFM by Sum3 significantly deviated from the line of identity; however, there was no systematic bias observed (r=0.172). The Sum3 equation resulted in SEE and TE values of 2.36kg and 8.36kg, respectively, with a validity coefficient of $R^2=0.97$. Supporting these findings, Stout et al.[58] demonstrated similar values (R2=0.90, SEE=2.7%fat) in a sample of adult males, Houmard et al.[90] reported an SEE of 3.06%fat using football players, and Sinning et al.[35] reported an SEE=2.47%fat in college male athletes. However the TE value in the present study was much higher than the TE values reported in the previous studies (TE=2.78-3.6%fat). Differences in procedures and equipment selection between authors and laboratories may help to explain the varying results. The current study used Lange calipers which are optimal for use with the Jackson and Pollock equations[91]. Two of the studies (Sinning et al. and Houmard et al.) used Harpenden calipers, possibly contributing to systematic error. The failure of the Sum3 equation to produce an acceptable TE value warrants the need for further validation studies using this population.

Conclusion

For athletes, body composition measurements are commonly used to assess the effects of training, to determine appropriate body weight, and to optimize performance. In sports with weight categories such as rowing, determination of a weight class is often based on the minimal weight an athlete can maintain without hindering competitive performance. Accurate measurement of body composition is therefore crucial for monitoring the reduction of fat mass and maintenance of fat-free mass during periods of weight reduction.

Two-compartment models, such as HW and ADP have inherent error because of the assumptions of FFM components, such as hydration and bone mineral content [44, 70, 92, 93]. Deviations from the assumed constants results in error in the calculation of body composition variables, including FFM. Lohman[92] calculated the estimated error of a 2C model, based on the work of Siri [94], to be 3.9% fat in the general population. Moon et al. reported similar findings using HW compared to a 3C model in college-aged men and women [23, 68]. Additionally, DXA has been categorized with an error similar to that of a 2C model because both models assume a constant FFM hydration. Multiple-compartment models are therefore considered the favored criterion method due to the added measurements of total body water (TBW) and bone mineral content (BMC)[70].

This is the first study to examine the validity of both laboratory and field methods for the estimation of FFM in elite male rowers using a comprehensive model based on body density, body water, and bone as the criterion method. The major findings of the study are that all independent techniques evaluated in the investigation significantly overestimated FFM, and based on the recommendations of Lohman, are not valid for the assessment of FFM in male rowers. Limitations of the current study include the use of BIS to obtain TBW measurements, which is a valid measure, but not a criterion method. The use of deuterium oxide, a criterion method for the measurement of TBW, could influence the values found in the current study. Additionally, the small sample size could have influenced results.

In summary, findings from the study further illustrate the need to use multiple compartment models for the estimation of FFM in elite athletes. Due to significant differences in mean estimates of FFM as well as considerable individual differences, the BP, NIR, US, and Sum3 are not recommended for use in this population.

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APPENDIX A. TABLES

Table 1

Variable	Mean ± SD	Range
Age (yr)	24.6 ±2.2	22.0–30.0
Height (cm)	191.4 ±7.2	175.0–204.5
Weight (kg)	87.2 ±11.2	72.6–104.3
Bone Mineral (kg)	3.8 ±0.55	3.0–4.9
Body Density (g/ml)	1.074 ±0.008	1.06–1.08
Total body water (kg)	53.9 ±7.0	43.2-64.1
Fat mass (kg)	14.4 ±3.5	8.7-22.0

Table 2

Method	FFM (M+SD)							
4C	72.8±9.8							
		Intercept	Slope	CE	r	SEE	TE	Limits
BODPOD®	77.7±9.5	-4.2	0.99*	4.9	0.96	2.96	5.36^{I}	-1.1-10.9
NIR	76.9±7.8	-18.5	1.19*	4.1	0.94	3.37	5.43^{I}	-3.4-11.6
Ultrasound	76.8±9.1	-4.3	1.00*	4.0	0.93	3.80	5.43^{I}	-3.7-11.7
Jackson & Pollock	80.8±9.7	-6.8	0.99*	8.05	0.97	2.36	8.36^{I}	3.2-12.8

*Represents slope significantly different from 1.0 ($p<0.05$), ^{I} Represents an unacceptable TE (TE>4.5kg)
CE = Constant Error, TE = Total Error, SEE = Standard error of the estimate, r = Pearson product-moment correlation coefficient, Limits = 95% limits of agreement (CE + 2.074 SD of residual scores (Predicted – Actual)). FFM = Fat free mass.

APPENDIX B. FIGURES

Figure 1

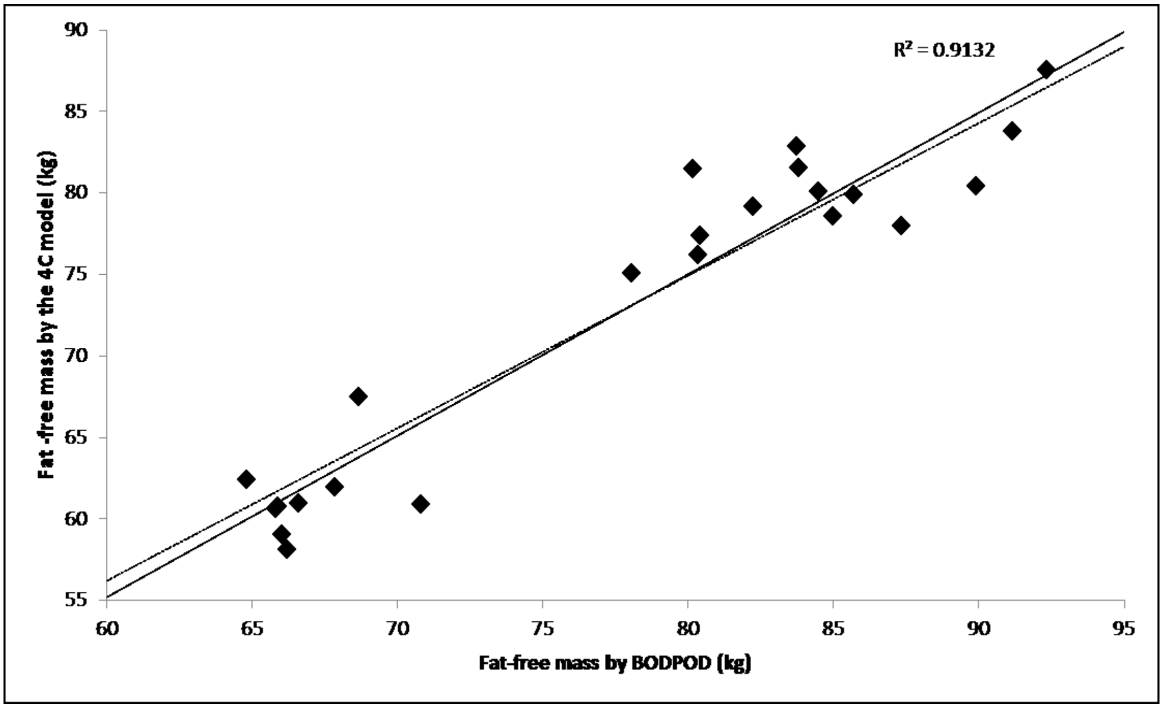

R² = 0.9132
Fat -free mass by the 4C model (kg)
90
85
80
75
70
65
60
55
60
65
70
75
80
85
90
95
Fat-free mass by BODPOD (kg)

Figure 2.

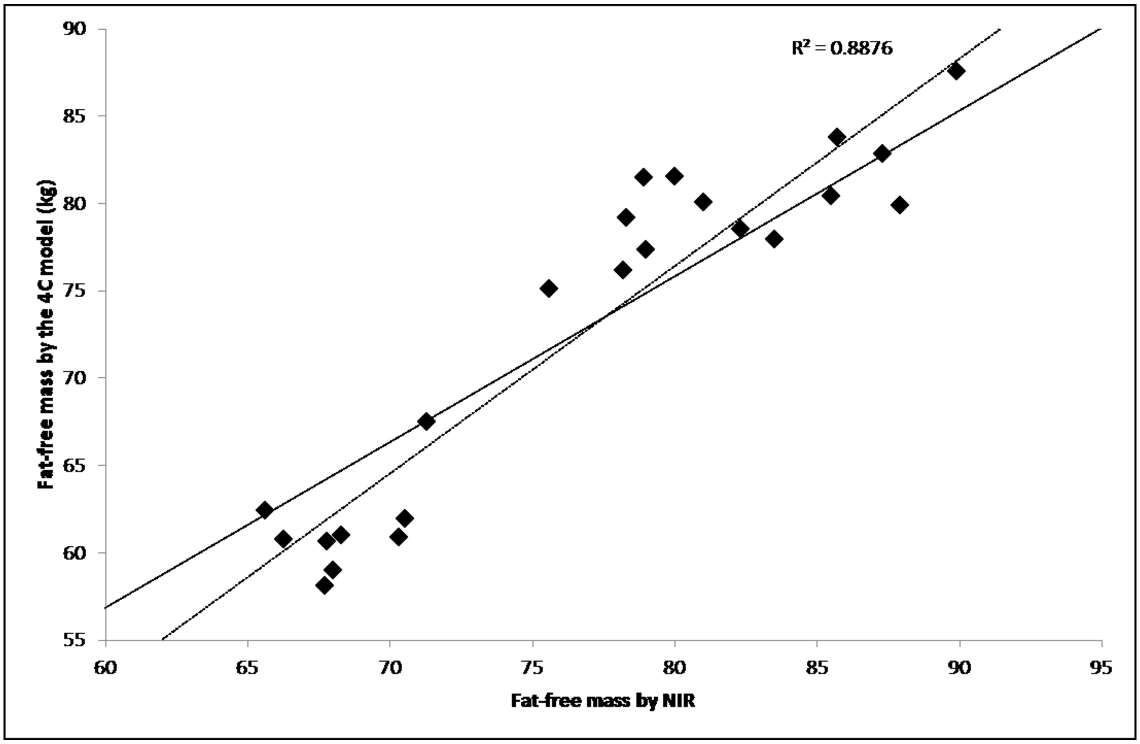

R² = 0.8876
Fat-free mass by the 4C model (kg)
90
85
80
75
70
65
60
55
60
65
70
75
80
85
90
95
Fat-free mass by NIR

Figure 3.

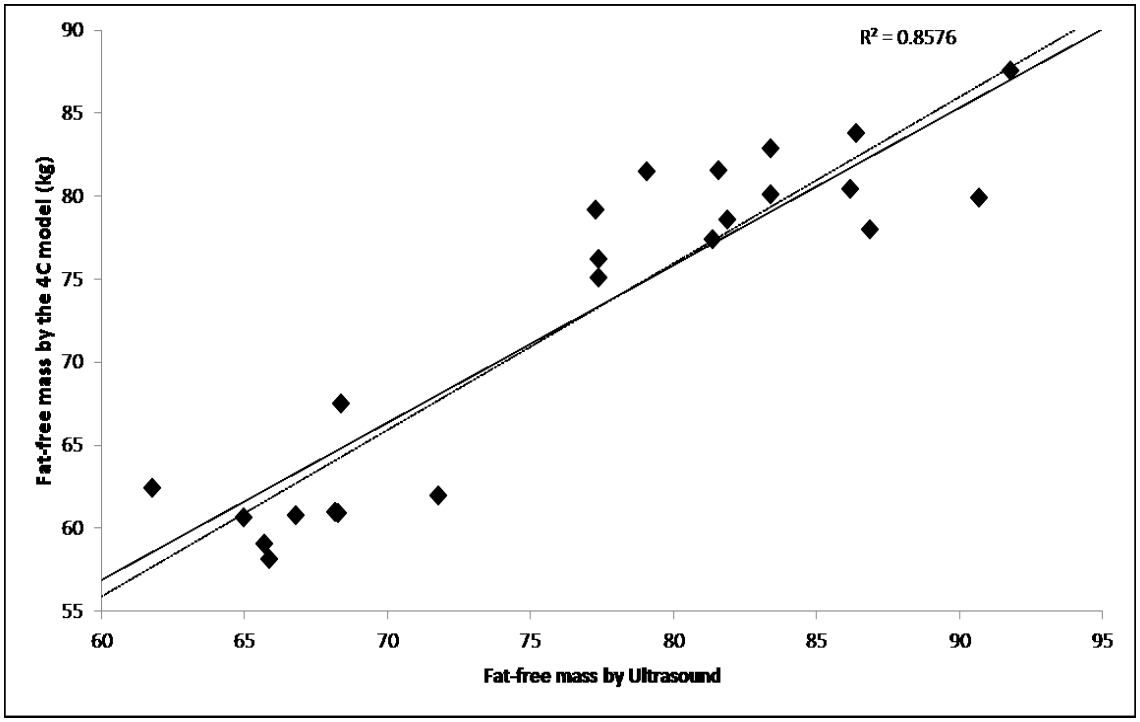

R² = 0.8576
Fat-free mass by the 4C model (kg)
Fat-free mass by Ultrasound
90
85
80
75
70
65
60
55
60
65
70
75
80
85
90
95

Figure 4.

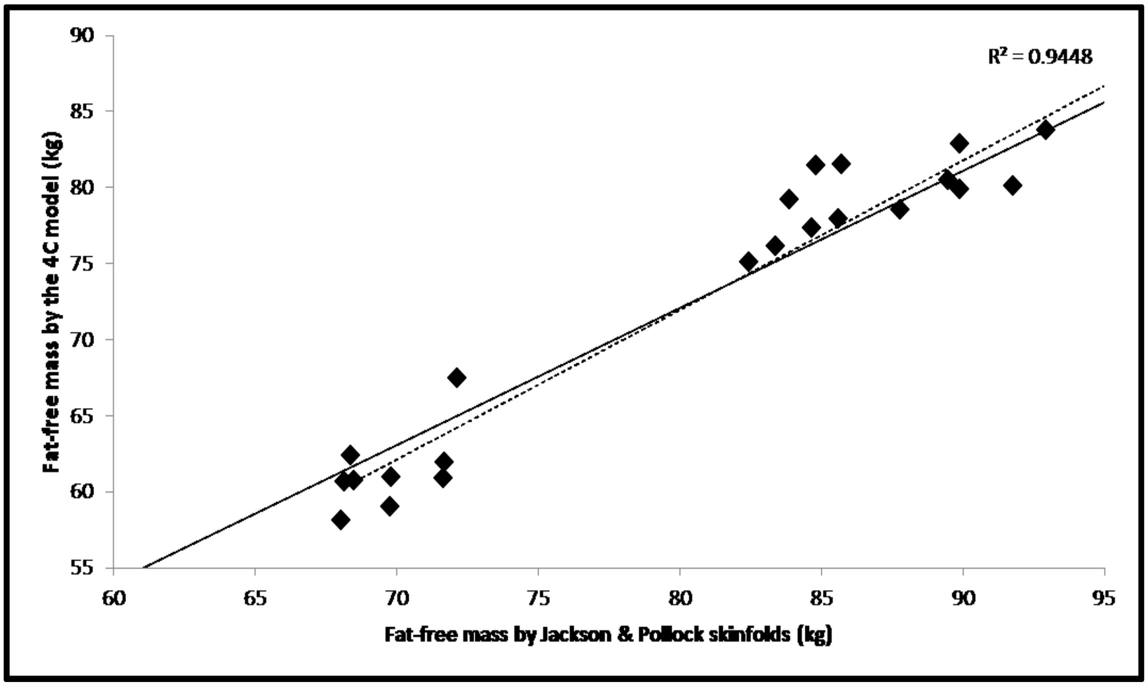

R² = 0.9448
Fat-free mass by the 4C model (kg)
Fat-free mass by Jackson & Pollock skinfolds (kg)
90
85
80
75
70
65
60
55
60
65
70
75
80
85
90
95

Figure 5.

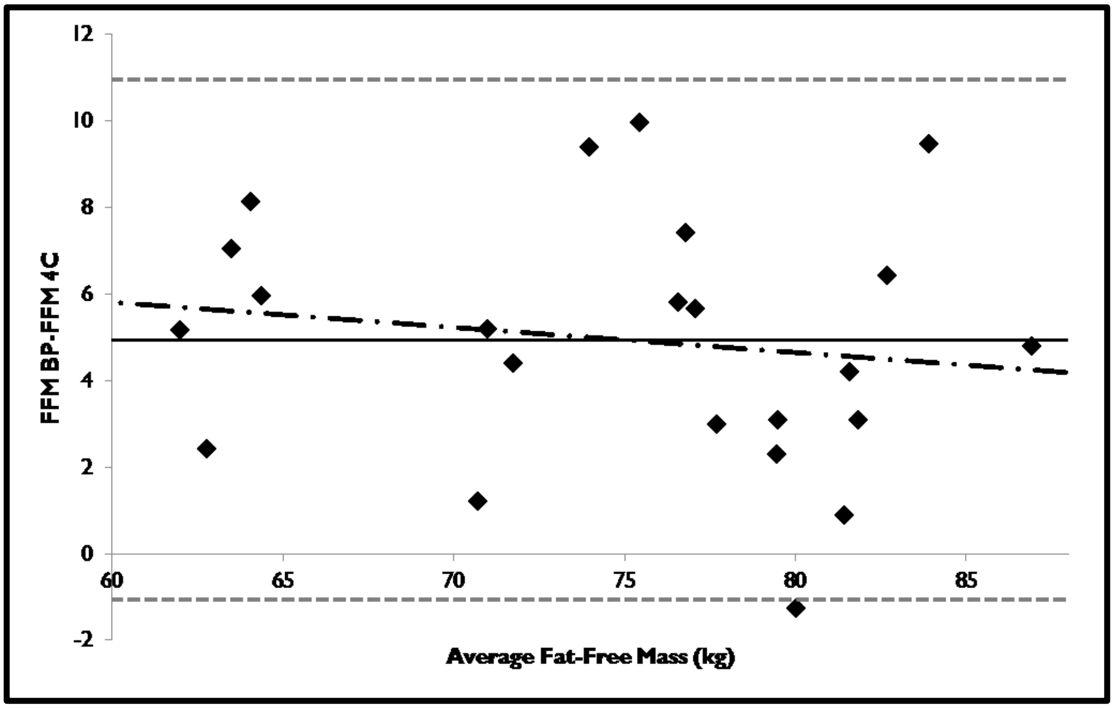
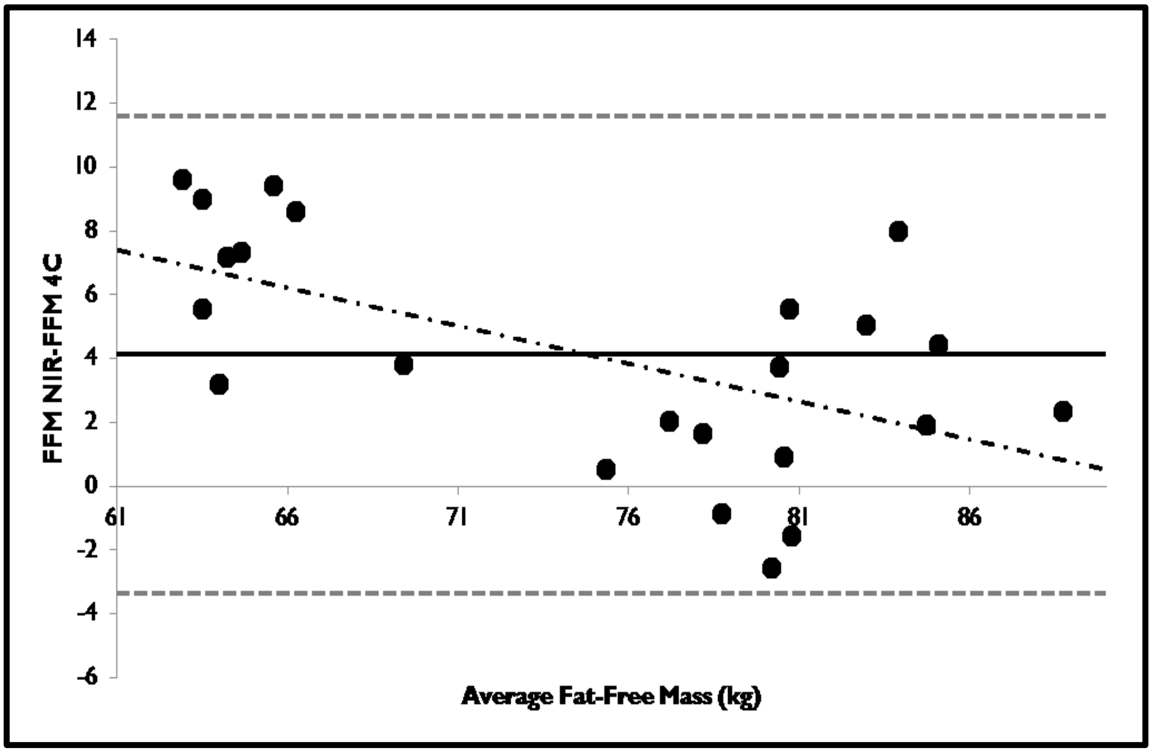
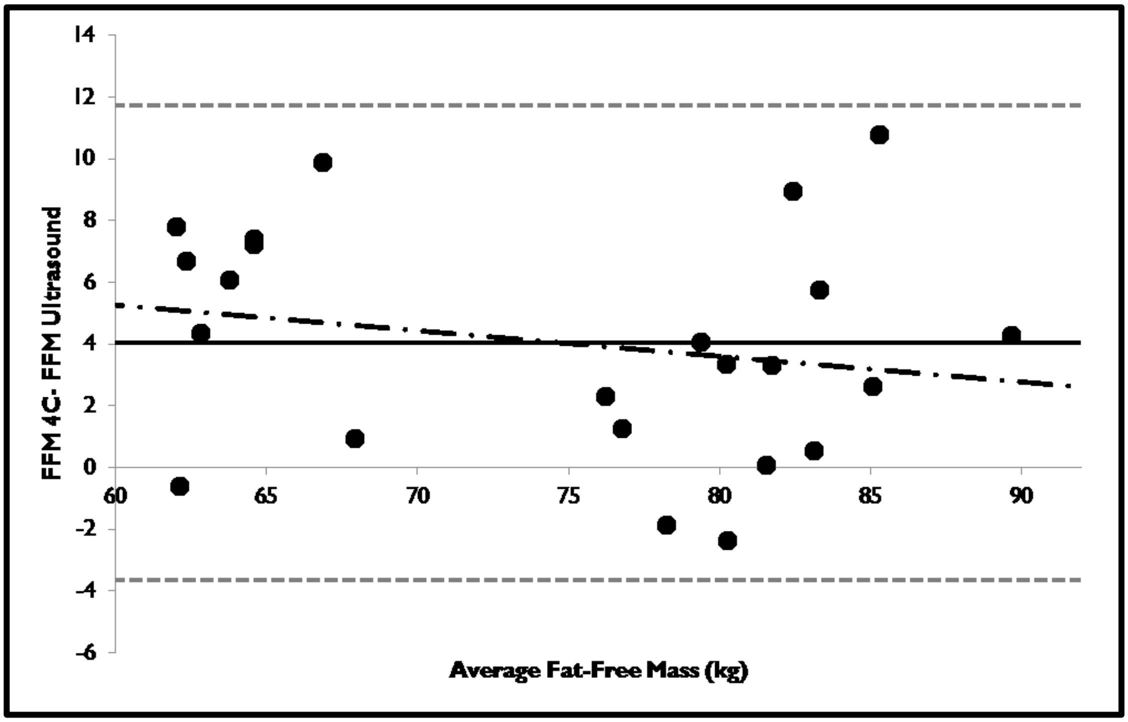

12
10
8
6
4
2
0
-2
60
65
70
75
80
85
FFM BP-FFM 4C
Average Fat-Free Mass (kg)

Figure 6.



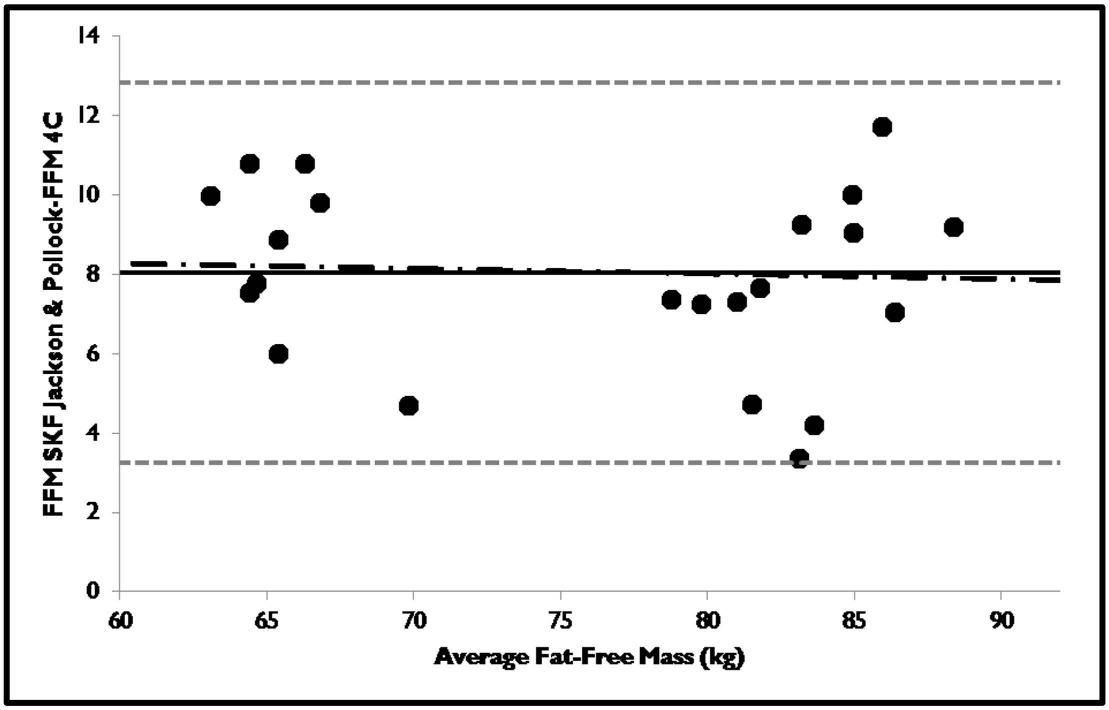
14
12
10
8
6
4
2
0
-2
-4
-6
61
66
71
76
81
86
FFM NIR-FFM 4C
Average Fat-Free Mass (kg)

Figure 7.



14
12
10
8
6
4
2
0
-2
-4
-6
60
65
70
75
80
85
90
FFM 4C- FFM Ultrasound
Average Fat-Free Mass (kg)

Figure 8.



FFM SKF Jackson & Pollock-FFM 4C
14
12
10
8
6
4
2
0
60
65
70
75
80
85
90
Average Fat-Free Mass (kg)

APPENDIX C. FIGURE LEGENDS

Figure 1. Comparison of fat free mass by the 4C model vs. the BODPOD®. The dashed line indicates the line of best fit and the solid line indicates the line of identity (regression slope= 1.0, regression intercept= 0).

Figure 2. Comparison of fat free mass by the 4C model vs. near infrared interactance. The dashed line indicates the line of best fit and the solid line indicates the line of identity (regression slope= 1.0, regression intercept= 0).

Figure 3. Comparison of fat free mass by the 4C model vs. Ultrasound. The dashed line indicates the line of best fit and the solid line indicates the line of identity (regression slope= 1.0, regression intercept= 0).

Figure 4. Comparison of fat free mass by the 4C model vs. the 3-Site Jackson and Pollock skinfold equation. The dashed line indicates the line of best fit and the solid line indicates the line of identity (regression slope= 1.0, regression intercept= 0).

Figure 5. 95% limits of agreement between the criterion method and the BODPOD®.

Figure 6. 95% limits of agreement between the criterion method and near infrared interactance (NIR).

Figure 7. 95% limits of agreement between the criterion method and Ultrasound.

Figure 8. 95% limits of agreement between the criterion method and the 3-Site Jackson and Pollock skinfold equation.

APPENDIX D. INFORMED CONSENT

701-A

V1, 03/15/11 ***IRB No: 15808***

Consent Form

University of Oklahoma Health Sciences Center (OUHSC)
University of Oklahoma-Norman Campus
Assessing body composition changes throughout a competition season in elite-level rowers.
Principal Investigator: Jeffrey R. Stout, PhD
University of Oklahoma
(405)325-9023

This is a research study. Research studies involve only individuals who choose to participate. Please take your time to make your decision. Discuss this with your family and friends.

Why Have I Been Asked To Participate In This Study?

You are being asked to take part in this trial/study because you are a member of the High Performance Training Center in Oklahoma City.

Why Is This Study Being Done?

The purpose of this study is to assess body composition changes throughout a competition season in elite-level rowers

How Many People Will Take Part In The Study?

About 40 people will take part in this study. All of these individuals will participate at this location.

What Is Involved In The Study?

If you agree to participate in this study, you will be asked to visit the Metabolic and Body Composition lab, located at the University of Oklahoma-Norman Campus, a total of 3 times. The data collection process will last approximately one hour. At any time during your participation, you may stop and choose not to complete the testing. You will participate in a series of data collection stations, each station will be made private by the use of room dividers and the use of separate closed rooms. Additionally, you will be required to complete a medical questionnaire. After a 12-hour fast, with water consumption allowed up to one hour prior to testing, your will participate in a series of data collection stations:

1. Specific Gravity (5 minutes)-(To test hydration status)

Upon arrival at the lab, you will be asked to give a urine sample to test hydration status.

2. Residual volume (10 minutes)- (The amount of air left inside the lungs after someone has blown out all the air they can)

You will breathe a mixture of pure oxygen from a mouthpiece attached to a bog for 4-8 breaths and will be wearing a nose clip through this collection process. This

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volume will be subtracted from your under water weight and is crucial in determining your body fat percentage from hydrostatic weighing.

3. Bioelectrical Impedance (15 minutes)-(Body impedance is measured when a small, harmless electrical signal is passed through the body, carried by water and fluids)

You will be asked to lie on a table and two electrodes will be placed on both your right foot and hand, at the ankle and wrist and toe and finger, respectively. The device conducts a harmless and painless electrical current though the body, this is a widely used commercial device that is FDA approved.

4. BOD POD Measurements (10 minutes)-(The BOD POD is an egg shaped pod with a front window and is used for measuring and tracking body fat and lean mass using patented air displacement technology)

You will be weighed while wearing your tight spandex or swimsuit and given a swimming cap to wear on your head. You will then enter the egg-shaped pod and told to breathe normally and not to move around.

5. Dual X-Ray Absorptiometry (DEXA) (10 minutes)-(The DEXA is an x-ray machine that measures bone mineral density using low dose radiation)

You will lie on your back, in tight spandex or swimsuit, on a table with your feet together while the DEXA arm moves over your body without contact. The amount of radiation to which you will be exposed from each DEXA scan is approximately equivalent to the amount of radiation that you receiver in several days from naturally occurring sources of radiation. You will receive 3 DEXA scans if you complete this study.

6. Ultrasound Thickness Measurements (10 minutes)- (The thickness of your skin and muscle tissue)

This technique involves applying a thick layer of gel on the surface of your skin and a metallic transducer gently applied over the surface of your skin. During the measurement, the ultrasound transducer is slid back and forth along the surface of your skin. Measurements will be taken at the following eight sites: biceps, abdomen, thigh, calf, hamstring, front hip (females only), triceps (females only), and chest (males only).

7. Hydrostatic weighing (15 minutes)-(Under water weighing-weight of subject under water)

You will enter an open tank filled with 4 feet of water. You will be asked to expel as much air as possible while leaning forward and going completely under the water while holding your breath for 5-15 seconds. This process will be performed 6-10 times.

How Long Will I Be In The Study?

We think that you will be in the study for 3 visits, occurring over a six month period, with each visit lasting approximately one hour.

There may be anticipated circumstances under which your participation may be terminated by the investigator without regard to your consent, for reasons such as not adhering to all study guidelines for continued participation.

You can stop participating in this study at any time. However, if you decide to stop participating in the study, we encourage you to talk to the researcher and your regular doctor first.

What Are The Risks of The Study?

While on the study, you are at risk for these side effects. You should discuss these with the investigator prior to providing consent to participate to ensure that you fully understand the risks.

While the possible risks are few, they include both physiological and physical consequences associated with wearing a bathing suit or spandex while having human contact and small levels of radiation from the DEXA scans. Specific risks vary by the data collection station; the risks per station are as follows:

1. Residual volume-No additional risk with consuming pure oxygen for a very short time (less than 1 minute)

2. Bioelectrical Impedance- No known risk or injuries have been associated with this type of device.

3. BOD POD Measurements- No additional risk, possibility of anxiety from sitting in a small closed space.

4. Dual X-Ray Absorptiometry (DEXA)- This research study involves exposure to radiation from three DEXA scans, which is a type of x-ray procedure. This radiation is not necessary for medical care and is for research purposes only. You will receive radiation exposure of less than 2 mrem from each scan and a total dose of (6 mrem), which is less than the radiation received in 7 days from natural background radiation (~ 300 mrem/yr), such as naturally occurring radioactivity in soil. Although the amount of radiation you will receive in this study is small, it is important for you to be aware that the risk from radiation exposure is cumulative over your life time. Additionally, radiation exposure may be harmful to a fetus; if you are pregnant or think you might be pregnant you will not be allowed to participate in this study.

5. Hydrostatic weighing- Possible risk equivalent to standing in the shallow end of a pool and dunking your whole body under water.

6. Ultrasound-No know risk or injuries have been associated with this type of device.

Risks for females:

If you are a female, you must not be and should not become pregnant nor breast-feed an infant while on this study. Undergoing DEXA scans involved in this study while pregnant or breastfeeding may involve risks to an embryo, fetus or infant, including birth defects which are currently unforeseeable. In order to reduce your risk of pregnancy, you or your partner should use one or more of the acceptable methods of birth control listed below, regularly and consistently while you are in this study. Additionally, if pregnancy is unknown and you are not currently taking or receiving birth control medication, you will be required to provide a pregnancy test prior to testing.

Acceptable methods of birth control (continuing throughout the study) include:

- An approved oral contraceptive (birth control pill)
- Intra-uterine device (IUD)
- Hormone implants
- Contraceptive injection (Depo-Provera)
- Barrier methods (diaphragm with spermicidal gel or condoms)
- Transdermal contraceptives (birth control patch)
- Vaginal contraception ring (birth control ring)
- Sterilization (tubal ligation, hysterectomy or vasectomy)

If you are already using a method of birth control, you should check with the study doctor to make sure it is considered acceptable for this study.

If you become pregnant or suspect that you are pregnant during this study, you should immediately inform the study personnel. If you become pregnant or suspect that you are pregnant while in this study, a pregnancy test will be done. If pregnancy is confirmed, you may be withdrawn from the study.

For more information about risks and side effects, ask the researcher.

Are There Benefits to Taking Part in The Study?

If you agree to take part in this study, there will be no direct benefit to you. However, you will receive information on body composition measurements including percent body fat.

What Other Options Are There?

You may choose not to participate in the study.

What About Confidentiality?

Efforts will be made to keep your personal information confidential. You will not be identifiable by name or description in any reports or publications about this study. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. You will be asked to sign a separate authorization form for use or sharing of your protected health information.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include the faculty members and graduate students appointed to the protocol from the Department of Health and Exercise Science at the University of Oklahoma, and the OUHSC Institutional Review Board.

What Are the Costs?

There is no cost to you for participating in this study.

What if I am Injured or Become Ill While Participating in this Study?

In the case of injury or illness resulting from this study, emergency medical treatment is available. However, you or your insurance company will be responsible for the costs of this treatment. No funds have been set aside by The University of Oklahoma Health Sciences Center or the Department of Health & Exercise Science, to compensate you in the event of injury.

What Are My Rights As a Participant?

Taking part in this study is voluntary. You may choose not to participate. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you agree to participate and then decide against it, you can withdraw for any reason and leave the study at any time. However, at certain times during the treatment, it may be dangerous for you to withdraw, so please be sure to discuss leaving the study with the principal investigator or your regular physician. You may discontinue your participation at any time without penalty or loss of benefits, to which you are otherwise entitled.

We will provide you with any significant new findings developed during the course of the research that may affect your health, welfare or willingness to continue your participation in this study.

You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study has completely finished and you consent to this temporary restriction.

Whom Do I Call If I have Questions or Problems?

If you have questions, concerns, or complaints about the study or have a research-related injury, contact Dr. Jeffrey Stout at 405-325-9023 or Kristina Kendall at 405-325-1368

If you cannot reach the Investigator or wish to speak to someone other than the investigator, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

For questions about your rights as a research participant, contact the OUHSC Director, Office of Human Research Participant Protection at 405-271-2045.

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Signature:

By signing this form, you are agreeing to participate in this research study under the conditions described. You have not given up any of your legal rights or released any individual or entity from liability for negligence. You have been given an opportunity to ask questions. You will be given a copy of this consent document.

I agree to participate in this study:

PARTICIPANT SIGNATURE (age ≥18)	Printed Name	Date
Person Obtaining Consent	Printed Name	Date

IRB Office Version Date: 09/08/2010

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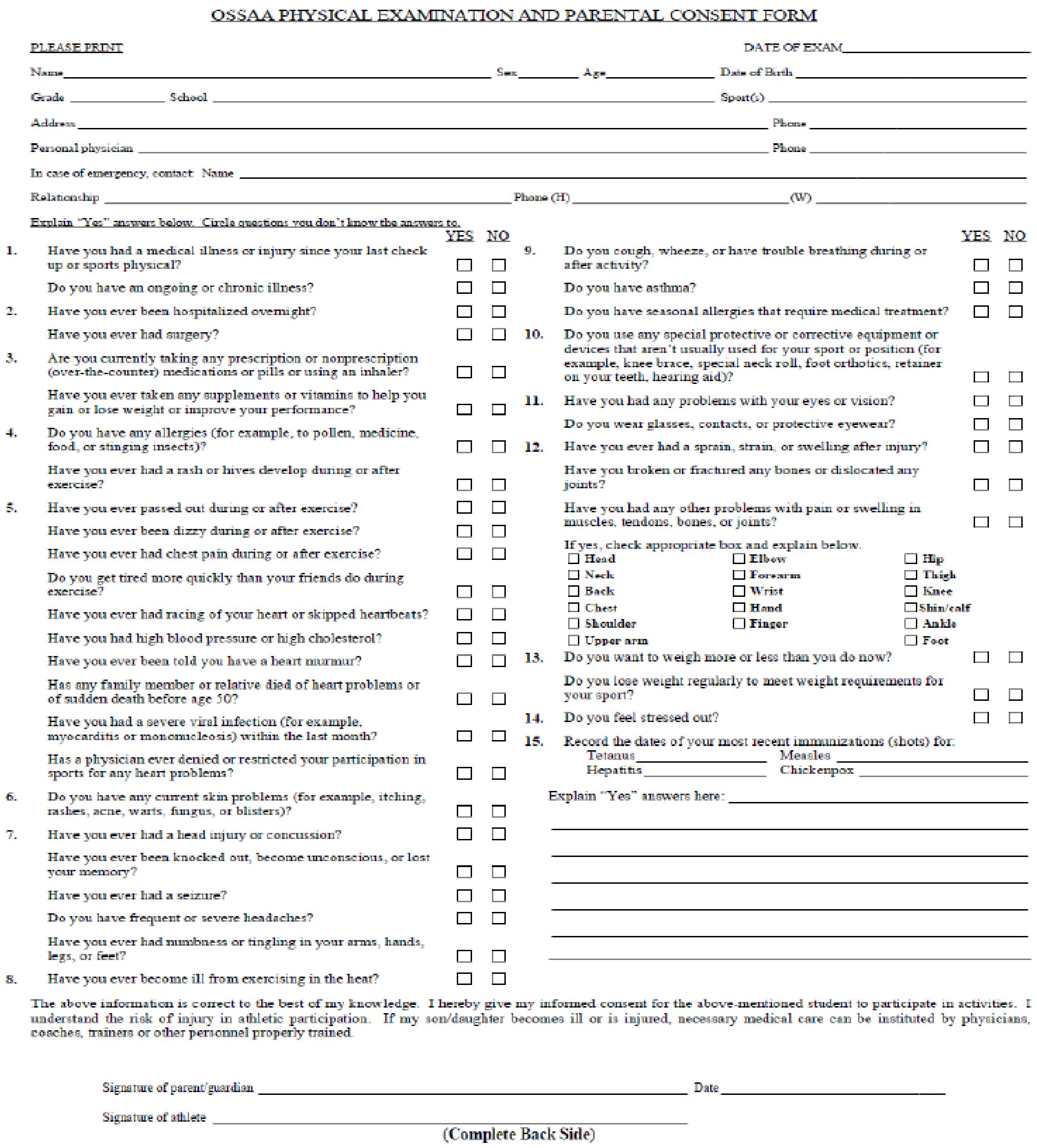
APPENDIX E. HEALTH HISTORY QUESTIONNAIRE



OSSAA PHYSICAL EXAMINATION AND PARENTAL CONSENT FORM

PLEASE PRINT

DATE OF EXAM____________________

Name____________________ Sex______ Age______ Date of Birth ____________

Grade ______ School ____________________ Sport(s) ____________

Address ____________________ Phone ____________

Personal physician ____________________ Phone ____________

In case of emergency, contact Name ____________________

Relationship ____________________ Phone (H) ____________ (W) ____________

Explain "Yes" answers below. Circle questions you don't know the answers to.

		YES	NO
1.	Have you had a medical illness or injury since your last check up or sports physical?	☐	☐
	Do you have an ongoing or chronic illness?	☐	☐
2.	Have you ever been hospitalized overnight?	☐	☐
	Have you ever had surgery?	☐	☐
3.	Are you currently taking any prescription or nonprescription (over-the-counter) medications or pills or using an inhaler?	☐	☐
	Have you ever taken any supplements or vitamins to help you gain or lose weight or improve your performance?	☐	☐
4.	Do you have any allergies (for example, to pollen, medicine, food, or stinging insects)?	☐	☐
	Have you ever had a rash or hives develop during or after exercise?	☐	☐
5.	Have you ever passed out during or after exercise?	☐	☐
	Have you ever been dizzy during or after exercise?	☐	☐
	Have you ever had chest pain during or after exercise?	☐	☐
	Do you get tired more quickly than your friends do during exercise?	☐	☐
	Have you ever had racing of your heart or skipped heartbeats?	☐	☐
	Have you had high blood pressure or high cholesterol?	☐	☐
	Have you ever been told you have a heart murmur?	☐	☐
	Has any family member or relative died of heart problems or of sudden death before age 50?	☐	☐
	Have you had a severe viral infection (for example, myocarditis or mononucleosis) within the last month?	☐	☐
	Has a physician ever denied or restricted your participation in sports for any heart problems?	☐	☐
6.	Do you have any current skin problems (for example, itching, rashes, acne, warts, fungus, or blisters)?	☐	☐
7.	Have you ever had a head injury or concussion?	☐	☐
	Have you ever been knocked out, become unconscious, or lost your memory?	☐	☐
	Have you ever had a seizure?	☐	☐
	Do you have frequent or severe headaches?	☐	☐
	Have you ever had numbness or tingling in your arms, hands, legs, or feet?	☐	☐
8.	Have you ever become ill from exercising in the heat?	☐	☐

		YES	NO
9.	Do you cough, wheeze, or have trouble breathing during or after activity?	☐	☐
	Do you have asthma?	☐	☐
	Do you have seasonal allergies that require medical treatment?	☐	☐
10.	Do you use any special protective or corrective equipment or devices that aren't usually used for your sport or position (for example, knee brace, special neck roll, foot orthotics, retainer on your teeth, hearing aid)?	☐	☐
11.	Have you had any problems with your eyes or vision?	☐	☐
	Do you wear glasses, contacts, or protective eyewear?	☐	☐
12.	Have you ever had a sprain, strain, or swelling after injury?	☐	☐
	Have you broken or fractured any bones or dislocated any joints?	☐	☐
	Have you had any other problems with pain or swelling in muscles, tendons, bones, or joints?	☐	☐

If yes, check appropriate box and explain below.

- ☐ **Head**
- ☐ **Neck**
- ☐ **Back**
- ☐ **Chest**
- ☐ **Shoulder**
- ☐ **Upper arm**
- ☐ **Elbow**
- ☐ **Forearm**
- ☐ **Wrist**
- ☐ **Hand**
- ☐ **Finger**
- ☐ **Hip**
- ☐ **Thigh**
- ☐ **Knee**
- ☐ **Shin/calf**
- ☐ **Ankle**
- ☐ **Foot**

		YES	NO
13.	Do you want to weigh more or less than you do now?	☐	☐
	Do you lose weight regularly to meet weight requirements for your sport?	☐	☐
14.	Do you feel stressed out?	☐	☐

15. Record the dates of your most recent immunizations (shots) for:

Tetanus____________ Measles ____________

Hepatitis____________ Chickenpox ____________

Explain "Yes" answers here: ____________________

The above information is correct to the best of my knowledge. I hereby give my informed consent for the above-mentioned student to participate in activities. I understand the risk of injury in athletic participation. If my son/daughter becomes ill or is injured, necessary medical care can be instituted by physicians, coaches, trainers or other personnel properly trained.

Signature of parent/guardian ____________________ Date ____________

Signature of athlete ____________________

(Complete Back Side)

Assessing Body Composition Changes Throughout a Competition Season in Elite-Level Rowers

Current Medication Usage (List the drug name, the condition managed, and the length of time used; Please include anti-inflammatory.)

MEDICATION	CONDITION	LENGTH OF USAGE
____________________	____________________	____________________
____________________	____________________	____________________
____________________	____________________	____________________

Exercise Status

How long have you participated in the sport of rowing _______Years________Months

How many hours per week do you spend for this type of exercise? ________ Hours

Do you regularly Lift Weights? **YES** **NO**

How long have you engaged in this form of exercise? ________ Years ________ Months

How many hours per week do you spend for this type of exercise? ________ Hours

Do you compete as a lightweight or heavyweight rower? (please circle one)

Which of the following boats to you typically race (check all that apply)

☐ Single ☐ Double ☐ Pair ☐ Quad ☐ Four ☐ Eight

If you sweep, are you primarily a port or starboard? (please circle one)

DIET (Check the nutritional supplements you are currently taking or have taken within the past 9 weeks.)

☐ Ribose

☐ Protein

☐ Protein Drinks

☐ Creatine Monohydrate

☐ Vitamins (multi-vitamins, Vit-C, etc)

☐ Calcium

☐ Other: ________________________________

APPENDIX F. SUPPORT LETTER

OKLAHOMA CITY
NATIONAL
HIGH PERFORMANCE
CENTER

A PROJECT OF THE OKC BOATHOUSE FOUNDATION

Jeremy Ivey
USRowing Coach
OKC National High Performance Center
Assistant Rowing Coach
609 424 2513
Jeremy@usrowing.org

18 April 2011

Office of Human Research Participant Protection
1000 Stanton L. Young Blvd.
Library Building, Room 176
Oklahoma City, OK 73117

To whom it may concern:

I am writing this letter in support of IRB # 15808: "Assessing body composition changes throughout a competition season in elite-level rowers". Furthermore, I approve that the data collection be conducted at the University of Oklahoma Metabolic and Body Composition Lab, Norman, OK. This research will provide valuable information and be of great benefit to all of our rowers.

In conclusion, I fully support the efforts of Krissy Kendall in this research endeavor. Please feel free to contact me if I can be of further assistance.

Sincerely,

J. Ivey

Jeremy Ivey