A COMPARATIVE ANALYSIS OF DUAL ENERGY X-RAY ABSORPTIOMETRY AND SKINFOLD MEASUREMENTS IN DETERMINING BODY COMPOSITION AND MINIMUM WRESTLING WEIGHT IN ADOLESCENT WRESTLERS

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CHAPTER I

INTRODUCTION

Wrestling has been around since as early as 2,500 BC and was among one of the five sports in the first Olympiad in 776 BC. Today, wrestling is still a popular sport across the nation, especially among high schools. In general, there are numerous benefits associated with participation in school sports. Examples of such benefits include increased self-esteem and motivation, higher levels of psychological well being, healthy eating habits, decreased anxiety and depression, decreased tobacco, drug, and alcohol abuse, increased leadership skills, and increased academic achievement ("Participation in", 2008). Although high school sports are meant to provide an enjoyable and healthy outlet for adolescents, wrestling is a highly competitive sport that often has many medical concerns. Aside from sports injuries, abuse of supplements, and the spread of contagious diseases, one of the greatest medical concerns associated with wrestling are the harmful weight loss methods used by many wrestlers. Wrestling is classified as a "weight sensitive" sport, meaning that specific weight classes are required (Perriello, 2001). Wrestlers often attempt to drop to their lowest weight possible in order to compete in a lower weight class to gain a competitive advantage (Perriello et al., 1995). They lose weight through severe calorie and fluid restriction as well as more extreme methods such as excessive exercising in hot environments, wearing vapor-impermeable suits made of rubber, nylon, or plastic, using laxatives or diuretics, sweating in saunas, hot rooms, or steam rooms, spitting, and self-induced vomiting (Center for Disease Control (CDC)a, 2006; Housh et al., 1991). These unsafe behaviors can often lead to adverse effects on their health, including decreased plasma and blood volumes, reduced cardiac outputs, impaired thermoregulatory responses, decreased renal blood flow, increased loss of electrolytes, and can have negative effects on growth and development of adolescents (Housh et al., 1991). In addition to adverse health effects, rapid weight loss behaviors can have a negative effect on wrestlers' athletic performance, including aerobic and anaerobic power, protein nutritional status, body composition, metabolism, and nutritional status (Marquart and Sobal, 1994). In 1997, three collegiate wrestlers died due to dehydration while practicing rapid weight loss behaviors (CDCa, 2006). Consequently, the American College of Sports Medicine (ACSM) and National Collegiate Athletic Association (NCAA) mandated that minimum weight classes be established for each wrestler based on body composition testing to decrease these dangerous weight loss behaviors during the season (Ransone and Hughes, 2004).

As a result, the National Federation of State High School Associations (NFHS) developed wrestling rules (1-3-1 and 1-3-2) that required "each individual state high school develop and utilize a specified weight-control program which will discourage excessive weight reduction and/or wide variations in weight, because this may be harmful to the competitor" (Oklahoma Secondary School Activities Association (OSSAA), 2007). These rules also require that minimum weight classes be established with the assistance of medical professionals by body fat testing, hydration testing with a urine specific gravity of no greater than 1.025, and the development of a monitored weight loss program with a reduction of no more than 1.5% of his/her weight per week. These regulations further specified that adolescent males are prohibited from competing below 7% body fat and females are prohibited from competing below 12% body fat. Body composition is tested using skinfold measurements or the Tanita Bioelectrical Impedance 300WA machine. Skinfold thickness is measured with a Lange Skin Caliper at the subscapular, triceps, and abdomen, and a minimum weight is determined using the National Wrestling Coaches Association (NWCA) Optimal Performance Calculator Computer Program (OSSAA, 2007). In 2007, the OSSAA officially adopted these regulations for their weight management program.

Currently, there are numerous methods of body composition testing used in clinical, research, and practical settings such as dual-energy X-ray absorptiometry (DEXA), skinfold measurements, bioelectrical impedance, underwater weighing, near infrared interactance, and air displacement plethysmography (Silva et al., 2006). Dual-energy X-ray absorptiometry (DEXA) was initially developed for testing bone density; however, it is now becoming widely adopted for the measurement of body composition (Roubenoff et al., 1993; Plank 2005). DEXA is based on photon attenuation of fat mass, fat-free mass, and bone mineral (Plank, 2005). DEXA has been replacing many other methods for body composition testing in labs and is gaining status as the “gold standard” in body composition testing (Silva et al., 2006; Ball et al., 2004a). It is regarded as one of the most valid and accurate techniques for body composition testing because it accounts not only for fat mass and fat-free mass, like most models, but it also accounts for bone mineral density (Eston et al., 2005).

Despite the high accuracy of DEXA, it is limited to research settings and is not suitable for field or clinical use due to high cost and complexity (Steinberger et al., 2005). Therefore, anthropometry techniques are commonly used in field settings where DEXA is not available (Rodriguez et al., 2005). The most common method of body composition testing among high school wrestlers is skinfold measurements because it is inexpensive, convenient, and quick (Clark et al., 1993b; Rodriguez et al., 2005). The sites at which to take these measurements as well as the most accurate prediction equation to determine percent body fat for this population has been debated by many researchers (Clark et al., 1993b). Common sites to measure skinfold thickness include the chest, midaxillary, triceps, thigh, subscapular, suprailiac, or the abdomen (Ball et al., 2004a). Most anthropometric equations use some combination of these sites. Currently, Oklahoma high schools measure skinfold thickness at the subscapular, triceps, and abdomen (OSSAA, 2007).

Significance of the Study

Since body composition testing is a vital component of determining minimum weight classes for high school wrestlers, it is important to determine the accuracy of one of the current methods being used. Currently, Oklahoma high schools estimate body fat using either the Tanita Bioelectrical Impedance 300WA machine or skinfold measurements. Skinfold thickness is measured at the subscapular, triceps, and abdomen (OSSAA, 2007). Thus, the purpose of this study is to evaluate the accuracy of the skinfold measurements being used in Oklahoma as a predictor of body composition in adolescent wrestlers from two Oklahoma high schools by comparing skinfold measurements using the sum of three sites to DEXA scans, using DEXA as the reference model. Secondly, minimum wrestling weights were calculated to assess the practicability of current recommendations.

Objectives of the Study

1. To compare body composition obtained from skinfold measurements (the sum of three sites) to DEXA across the period of a wrestling season (pre-, in-, and off-season) in individual adolescent wrestlers.
    a. To determine if skinfold measurements (sum of three sites) are an accurate measure of body composition compared to DEXA.
2. To calculate minimum wrestling weights based on percent body fat from DEXA and skinfolds, and to assess whether these minimum weights are a realistic recommendation and expectation of wrestlers based on:
    a. Body mass index (BMI) of predicted minimum wrestling weights
    b. Average body fat and weight of the wrestlers throughout the season

Limitations of the Study

1. There was a small sample size (25 total participants), which limits the degree to which the results can be generalized and extrapolated.

2. The use of a convenience sample limits how generalizable the results are because the participants may not be an accurate representation of a larger population.
3. There is incomplete data for some participants who came into the study late or dropped out before the completion of the study.
4. There were two different assessors who measured skinfold thickness at various times the wrestlers were tested, which may affect the accuracy of the results.

Nomenclature

%BF – percent body fat

2C model – two-compartment model

3C model – three-compartment model

4C model – four-compartment model

ACSM – American College of Sports Medicine

BMD – bone mineral density

BMI – body mass index

CDC – Center for Disease Control

DEXA – Dual-energy X-ray Absorptiometry

FFM – fat-free mass

FM – fat mass

HW – hydrostatic weighing

L3 – Lohman 3-site equation

MMW – minimum wrestling weight

NCAA – National Collegiate Athletic Association

NFHS – National Federation of State High School Associations

NWCA – National Wrestling Coaches Association

OSSAA – Oklahoma Secondary School Activities Association

WMWP – Wisconsin Minimum Weight Project

CHAPTER II

REVIEW OF LITERATURE

Introduction

Wrestling is a popular sport among all ages today. For many years, wrestlers have practiced unsafe weight loss methods (Perriello, 2001). Wrestlers often try to get to their lowest weight possible before a match, and then gain their weight back after the match is over. This practice of rapid weight loss and regain is known as “weight cycling”. Another term for this is called “weight cutting”, which is defined at the “intentional and purposeful loss of weight to compete in a weight class lower than pre-season weight” (Wroble and Moxley, 1998). Wrestlers rapidly lose weight in a short period of time primarily through means of dehydration. Such methods include excessively exercising in hot environments (saunas, hot rooms, steam rooms), frequent fasting, fluid restriction, exercising in vapor-impermeable suits (made of rubber, nylon, or plastic), taking diuretics, laxatives, or emetics, spitting, or self-induced vomiting (Perriello et al., 1995). Often, wrestlers practice a combination of these rapid weight loss methods close to a match in order to achieve the lowest weight possible. A traditional theory is that competing in a lower weight class than their pre-season weight will give wrestlers a more competitive edge and higher advantage (Perriello et al., 1995; CDCa, 2006). It has been suggested that competing in a lower weight class will improve strength and power, particularly in brief high power activities (Wroble and Moxley, 1998). This theory is based on the idea that wrestling at a lower weight for the same height improves leverage over one's opponent. However, there is no evidence to support this theory (Perriello, 2001).

The harmful methods through which wrestlers attempt to achieve a low body weight has far more disadvantages than advantages on a wrestler's performance and health. If weight loss is necessary, it should be achieved gradually at a rate of two pounds per week through increased exercise and reasonable decreased calorie intake. Two pounds per week is the rate at which the body can burn and lose fat efficiently. Additional weight lost greater than two pounds per week is mostly loss of water, through dehydration, or loss of lean body mass (muscle), through starvation. This combination can be very harmful, even fatal, to a wrestler's health and performance (Perriello et al., 1995). Such harmful effects include decreased plasma and blood volumes, reduced cardiac outputs, impaired thermoregulatory responses, decreased renal blood flow, increased loss of electrolytes, decreased immune function, and even more severe consequences such as pancreatitis and pulmonary emboli (Perriello et al., 1995; Housh et al., 1991; Oppliger et al., 1996). In addition, these rapid weight loss behaviors affect aerobic and anaerobic power, strength, endurance, resting metabolic rate, efficiency of utilizing oxygen, protein nutritional status, and body composition (Marquart and Sobal, 1994; Perriello et al., 1995).

Roemmich and Sinning (1997) evaluated the influence of dietary restriction on growth, maturation, body composition, protein nutrition, and muscular strength in adolescent wrestlers before, during, and after a wrestling season. These researchers concluded that dietary restriction reduced protein nutritional status, body protein and fat stores, and muscular strength and power during season. The reduction in power and strength was primarily due to loss of lean body tissue (Roemmich and Sinning, 1997). Furthermore, "weight cutting" practices can impair hormonal status, impede growth and development, affect psychological state, and impair academic performance (Oppliger et al., 1996). These adverse effects are particularly critical in high school wrestlers who are still growing. Unfortunately, wrestlers do not understand the difference between gradually losing fat and losing total body water quickly (Perriello et al., 1995). A wrestler's goal is usually to compete in a lower weight class, and a lower minimum weight can be achieved by reducing body weight immediately prior to percent body fat measurement through dehydration, giving them an advantage over other wrestlers. This goal usually encourages rapid weight loss methods (Clark et al., 1993b). Aside from the pressure wrestlers put on themselves, wrestlers often receive additional pressure from their coaches, parents, physicians, and other teammates to "cut weight" (Perriello et al., 1995; Oppliger et al., 1995; Luttermoser et al., 1998).

The practice of rapid weight loss has been going on since as early as 1930, and it is still widely prevalent among wrestlers today (Kiningham and Gorenflo, 2001). Kiningham and Gorenflo (2001) surveyed 2,532 wrestlers from various Michigan high schools and found that 72% of participants used at least one potentially harmful weight loss method each week of the wrestling season, 52% of participants used at least two harmful weight loss methods, and 12% of participants used at least five potentially harmful weight loss methods each week. Their primary means of weight loss were fasting and a variety of different dehydration methods. This survey also reported that wrestlers lost an average of six pounds during the wrestling season (Kiningham and Gorenflo, 2001). Additionally, Wroble and Moxley (1998) reported that 33% of a sample of 159 varsity high school wrestlers competed below their minimum wrestling weight (MWW). This was primarily true in lighter weight wrestlers (62% of the sample) compared to heavier weight wrestlers (6% of the sample) (Wroble and Moxley, 1998).

In 1989, The Wisconsin Interscholastic Athletic Association (WIAA) sought to limit dangerous, unhealthy weight loss behaviors among high school wrestlers by developing the Wrestling Minimum Weight Project (WMWP). This project was successful because it involved a multi-disciplinary team, including exercise scientists, physicians, dietitians, athletic administrators, coaches, and parents, who all made a cooperative effort to improve the health and practices of high school wrestlers. First, WMWP changed the rules to set minimum weights for every wrestler and implemented a nutrition education program. To establish minimum weights, the project required body fat to be measured in all wrestlers using a standardized testing protocol and certified testers. Skinfold measurements were used to test body fat at the triceps, subscapula, and abdomen. Equations by Lohman (1981) and modified by Thorland et al. (1991) were used to determine body density and body fat from these measurements. Second, WMWP also required that registered dietitians or registered dietary technicians present a nutrition education program to all wrestlers. This project lasted 3 years (1989-91) including a pilot testing implemented in over half the high schools in Wisconsin (Oppliger et al., 1995). In 1991-1992, Wisconsin was the first state to have mandatory established minimum weight classes established for high school wrestlers (Ransone and Hughes, 2004). After the success of WMWP, the National Federation of High School Associations (NFHS) used this project as a model to present to its members as an effort to institute change and encourage intervention in other states. As a result, more than 35 state associations across the country, from Massachusetts to Arizona, have used the WMWP as model for developing their own rules and regulations. The WMWP was successful in making wrestling safer and healthier for high school athletes and also introduced a common vision among the wrestling community (Oppliger et al., 1995).

Despite the success of the WMWP, dangerous weight loss behaviors were still widespread among wrestlers. In 1997, three collegiate wrestlers died within 33 days of each other in North Carolina, Wisconsin, and Michigan as a result of dehydration. They were exercising intensely in hot environments wearing vapor-impermeable suits under cotton warm-up suits and excessively restricting food and fluid intake. They were attempting to lose an average of eight pounds over a period of three to twelve hours in order to make their weight class (Ransone and Hughes, 2004). These are the first reported deaths associated with weight loss in collegiate wrestling (CDCa, 2006). Consequently, the NCAA passed new regulations in 1998 that sought to eliminate rapid weight loss methods. The new rules established healthier weight classes with adequate time to achieve them safely (increased weight classes by seven pounds), minimized incentives for rapid weight loss, banned the tools used to accomplish rapid dehydration (including laxatives, diuretics, emetics, excessive food and fluid restriction, self-induced vomiting, hot rooms >79 °F, saunas, steam rooms, vapor-impermeable suits, etc.), and penalized noncompliance (Dick et al., 2007; CDCa, 2006). The new NCCA regulations also required that “weigh-ins be held no more than two hours before the beginning of a competition” (CDCa, 2006).

At the time of the three wrestlers’ deaths, NCAA regulations already existed to prohibit rapid weight loss behaviors. However, despite these regulations, these three wrestlers still attempted to lose considerable amounts of weight in a short period of time, even under the supervision of their coaches and athletic staff. This suggests that these unsafe weight loss activities may still be prevalent among the 400,000 wrestlers in the U.S. today, and unfortunately, coaches may be ignoring it or even encouraging this behavior to continue (CDCa, 2006).

Since then, several state high schools have also implemented regulations that establish minimum weight classes based on percent body fat and limit how much weight can be lost each week (Kingman & Gorenflo, 2000). Starting in the 2006-2007 wrestling season, the National Federation of State High School Associations (NFHS) required that every state nationwide implement a weight-management program (NFHS, 2007). The OSSAA adopted new weight management regulations developed by the National Federation of State High School Associations (NFHS) for 2007-2008 that:

1. Establish a minimum weight class based on hydration testing. The hydration test will be a urine analysis, and a wrestler’s urine specific gravity cannot exceed 1.025.
2. Establish a minimum weight for wrestlers that prohibits males from competing below 7% body fat and females from competing below 12% body fat without the consent of a physician.

3. Establish a monitored weight loss program based on a wrestler's body weight at their initial testing with a reduction of no more than 1.5% of his/her body weight per week until he/she reaches the minimum weight established for them.
4. Test body fat using skinfold measurements or the Tanita Bioelectrical Impedance 300WA machine. Skinfold thickness is measured with the Lange Skin Calipers at the subscapular, triceps, and abdomen, and must be performed by a trained assessor who has a medical background and is a licensed medical professional (licensed nurse, nurse practitioner, certified athletic trainer, physician, physician's assistant, physical therapist, emergency medical technician, paramedic, registered, dietitian, certified personal trainer).
5. Testing must be done prior to a wrestler's work out that day.
6. The NWCA (National Wrestling Coaches Association) Optimal Performance Calculator Computer Program is used to determine a wrestler's 7% (males) or 12% (females) minimum weight and a weight loss descent plan of 1.5% of his/her body weight per week to determine the earliest date at which a wrestler can certify his/her minimum weight. The NWCA Optimal Performance Calculator uses the Lohman equation to predict body density and the Brozek equation to predict percent body fat.
7. Require weigh-ins be held a maximum of one hour before the scheduled time of a dual meet or a team's first competition in multiple dual meets.

Weigh-ins should be held a maximum of two hours before the first session each day at a tournament.

8. Allow for one to two additional pounds each day for all wrestlers during a competition that lasts several consecutive days.
9. All weight classifications will increase by two pounds beginning in January 15, 2008.
10. Recommend that each school implement a nutrition education program for all wrestlers and parents (OSSAA, 2007).

Methods of Body Composition Testing

Body composition testing is important in determining desirable body weight for young athletes, optimizing performance, and evaluating the effects of training. Often coaches estimate minimum wrestling weights without using body composition information. Without adequate information on body composition, coaches can significantly under- or overestimate minimum wrestling weights. Housh et al. (1991) investigated the accuracy of high school wrestling coaches' estimations of minimum wrestling weights by comparing them to estimates from underwater weighing. The results of this study found that coaches underestimated minimum wrestling weights 66% of the time, on average, and more likely underestimated minimum wrestling weight for lighter wrestlers and overestimated minimum wrestling weight for heavier wrestlers (Housh et al., 1991). An under- or overestimation of a wrestler's minimum weight creates a health, safety, and legal concern. A minimum weight that is underestimated falsely suggests that a wrestler can safely lose more weight, thus encouraging dangerous weight cutting behaviors. A minimum weight that is overestimated may place a wrestler in an inappropriate weight class, which would be competitively unfair (Clark et al., 2007). Therefore, accurate body composition testing is a vital component of wrestling.

Measurement of body composition is not an exact science, and therefore, it is difficult to determine an accurate and precise body composition (Clark et al., 1993b). The validity of the method of measurement is variable. Currently, there are several methods of body composition testing used in clinical, research, and practical settings. Examples include DEXA, skinfold measurements, bioelectrical impedance, underwater weighing, near infrared interactance, and air displacement plethysmography. There are advantages and limitations to all methods (Silva et al., 2006).

Body composition changes significantly during growth and maturation, specifically fat-free mass and composition of protein and water (Silva et al., 2006). The deposition of fat is also affected during adolescence by gonadal hormones (Bray et al., 2001). These physiological changes are dependent more on gender and pubertal development stage rather than age (Rodriguez et al., 2005). There is debate about which method is most effective for measuring body composition of adolescents during this post-pubertal stage (Silva et al., 2006). Not only physiological changes in adolescents contribute to changes in their body composition but also their level of fitness and strength from their athletic training contributes to the ratio of fat mass (FM) to fat-free mass (FFM) along with the composition of FFM regarding water and protein (Silva et al., 2006). In the present study, we used DEXA and skinfold thickness to test body composition in active adolescents.

Traditionally, body fat is determined using a two-compartment model (2C), which assumes the densities of fat mass (FM) and fat-free mass (FFM) are constant (Silva et al., 2006). The density of FM is assumed to be 0.9007 g/cm^3, and the density of FFM is assumed to fall in between 1.063-1.113 g/cm^3 (depending on gender, race, and age). The 2C model also assumes that the components of FFM (water, protein, bone mineral, and non-bone mineral) remain constant (Rodriguez et al., 2005). An example of a 2C model is hydrostatic weighing (HW). This 2C model is limited since the body is made up of more than two compartments, and the assumptions made about the density of FM and FFM may not be valid, especially in highly trained athletes (Ball et al., 2004a; Andreoli et al., 2004). Multi-compartment models have been developed, including three-, four-, and five-compartment models, which may have improved accuracy of body composition measurement compared to the 2C model (Silva et al., 2006, Andreoli et al., 2004). The three-compartment model (3C) includes an estimate of bone mineral density (BMD) obtained from DEXA. The four-compartment model (4C) is extended to include total-body water (usually by deuterium dilution) in addition to FM, FFM, and BMD. Three- and four-compartment models are commonly used in body composition research today (Ball et al., 2004a; Plank, 2005; Silva et al., 2006). Lastly, a five-compartment molecular model (5C) divides the body into fat, water, bone mineral, soft tissue mineral, and protein. This model involves neuron activation analysis, which determines the content of total body potassium, carbon, nitrogen, calcium, phosphorus, sodium, and chlorine. This model is not widely available and may be dangerous due to high exposure to radiation; therefore, it is rarely used in routine subject testing (Silva et al., 2006; Wang et al., 1998).

Anthropometric equations have been developed from the 2C model because it is not feasible to use a multi-component model in field settings on a large number of subjects. As a result, this causes a wide variation in percent body fat estimates (Ball et al., 2004a).

Dual-Energy X-ray Absorptiometry

Dual-energy X-ray absorptiometry (DEXA) emerged in clinical settings in the 1980’s as a means of measuring bone density. Before DEXA, there was Dual photon absorptiometry (DPA), which used the radioisotope, ^{153}Gadolinium as the photon source because it emits photons at two characteristic energy levels. DEXA later emerged when it was discovered that a broadband x-ray generator could be used as the photon source to reduce subject radiation exposure and decrease the scan time. The broadband beam is passed through a cerium or samarium filter and also emits photons at two characteristic energy levels (Clark et al., 1993a). DEXA technology uses small doses of radiation to determine bone density through photon attenuation of fat, bone mineral, and fat-free mass (Pietrobelli et al., 1996; Plank, 2005). DEXA is based on a 3C model that estimates FM, FFM, and BMD. It is safe, quick, noninvasive, and only requires limited subject cooperation. It has advantages over the traditional 2C model because it can accurately measure bone density, which the 2C model must estimate, and assumptions about the densities of FM or FFM do not have to be made (Ball et al., 2004a).

Because of the advantages DEXA has over the traditional 2C model, DEXA has been gaining acceptance as a reference model in many practical settings and has even been sometimes regarded as a "gold standard" in body composition testing (Ball et al., 2004a; Silva et al., 2006). However, the use of DEXA for body composition testing has several limitations (Silva et al., 2006). One limitation is the variability of hydration level of FFM. Along with the 2C model, DEXA assumes the hydration level of FFM is a constant 0.73 mL/g; however, this is may not be true in people who are critically ill, elderly, or athletes (Roubenoff et al., 1993). The hydration level of FFM may affect DEXA estimates of body composition. Lohman et al. (2000) suggests, "that a 5% change in the water content of FFM affects DEXA estimates of body fatness between 1 and 2.5%". Thus, hydration testing is crucial before assessing body composition using DEXA. Hydration testing is especially important for wrestlers who are often dehydrated when trying to "cut weight". Dehydration affects body weight, total body water (TBW), the distribution and compartmentalization of body water, the hydration of FFM, and the density of FFM. If a wrestler's minimum weight is predicted when he/she is in a dehydrated state, then the predicted weight will be lower than if he/she were hydrated (Bartok et al., 2004). To control this in Oklahoma high schools, OSSAA has a rule that wrestlers must undergo a hydration test that reveals a specific gravity no greater than 1.025 when establishing minimum weights (OSSAA, 2007).

DEXA's validity and accuracy has been reviewed in several studies. Ball et al. (2004a) reviewed the literature on DEXA validation and found high agreement between DEXA and the 4C model. In addition, Clark et al. (2007) evaluated DEXA's ability to predict acceptable minimum weights in 94 high school wrestlers and concluded that

DEXA provided a valid minimum weight in this sample of high school wrestlers. Furthermore, Clark et al. (1993a) compared the prediction of percent body fat (%BF) using DEXA, skinfolds, and hydrostatic weighing in adult, Caucasian males and concluded that DEXA is a viable method for predicting %BF and holds promise. Clark et al. (1993a) suggests that DEXA "exhibits a number of advantages over other methods of estimating %BF. In theory, one advantage of this method is that it removes the effect that varying bone mineral can have on predicted %BF." Another advantage of DEXA according to Clark et al. (1993a) is that DEXA is a passive and noninvasive method compared to other methods such as under water weighing, which requires submersion in water, and neutron activation analysis, which requires high doses of radiation (Clark et al., 1993a; Haarbo et al., 1991). DEXA is a safe alternative because the level of radiation used in one scan is negligible (Haarbo et al., 1991). Therefore, DEXA can easily be used on a variety of subjects, regardless of their health condition or age (Clark et al., 1993a).

There are other studies that have contradictory conclusions. Sopher et al. (2004) compared %BF measurements between DEXA and the 4C model in 411 children and adolescents and found that DEXA tended to overestimate body fat in subjects with higher levels of body fat and underestimate body fat in leaner subjects. The degree of over- or underestimation varied depending on the level of fatness (Sopher et al., 2004). Van der Ploeg et al. (2003b) similarly found that DEXA underestimated %BF in leaner, athletic individuals. Likewise, Gallagher et al. (2000) also found that DEXA underestimated %BF in lean individuals compared to the 4C model, regardless of gender. There was wide variation among individuals in all of these studies (Sopher et al., 2004; van der Ploeg et al., 2003b; Gallagher et al., 2000; Plank, 2005). Despite these limitations and contradictory conclusions, DEXA has many advantages over the 2C model and is a more feasible model to measure body fat in research, clinical, and field settings compared to 4C or 5C models. For the purpose of this study, DEXA is used as the reference standard.

Skinfold Measurement and Anthropometric Equations

Because DEXA is expensive and not available in many schools, skinfold measurements are commonly used to determine body fat in athletic settings. It is inexpensive and quick; however, accuracy is dependent on the formula used and the training and precision of the person taking measurements (Rodriguez et al., 2005; Steinberger et al., 2005). This technique is based on the idea that a collective measure of subcutaneous adipose tissue from various sites on the body may reflect a good estimate of total body fat since most of the body's fat is subcutaneous (40-60%) (Eston et al., 2005; Rodriguez et al., 2005). This method is conventionally based on the 2C model, in which FM is assumed to be 0.9007 g/cm^3 and FFM is assumed to fall in between 1.063-1.113 g/cm^3 (depending on gender, race, and age). This method also assumes that the components of FFM (water, protein, bone mineral, and non-bone mineral) remain constant (Rodriguez et al., 2005).

Skinfold thickness is measured with a caliper at various sites of the body (Rodriguez et al., 2005). Most researchers and dietitians use a Lange caliper, which is a large metal caliper, to estimate body fat. The Lange caliper is the industry standard; however, Lange calipers are expensive (approximately $200-$300), and some facilities, such as schools and family physicians, cannot afford them. Instead, a small plastic caliper, also called an adipometer, may be used to estimate body fat. Unlike Lange calipers, plastic calipers are less expensive and are often distributed at no charge by companies such as Ross Nutritional products (Luttermoser et al., 1998). Luttermoser et al. (1998) compared the agreement between the two calipers in estimating %BF and MWW in junior high and high school wrestlers. The results revealed that there was a high correlation between the two calipers and that the inexpensive plastic caliper could be used to accurately obtain skinfold measurements instead of a Lange caliper (Luttermoser et al., 1998). OSSAA currently uses Lange calipers to estimate body fat (OSSAA, 2007).

Skinfold measurements are usually taken on the non-dominant side of the body (De Lorenzo et al., 1998). The measured sites vary depending on the formula being used. There are numerous skinfold equations, both generalized as well as population specific, that have been developed to estimate percent body fat (Stout et al., 1995). Most of these equations first calculate body density, and then the body density is used to estimate percent body fat using another equation (Rodriguez et al., 2005). The most common equations that convert body density to percent body fat are the Brozek et al. or the Siri equation (Van der Ploeg et al., 2003a; Ball et al., 2004a). The skinfold measurements can be summed or used independently in any of these equations (Rodriguez et al., 2005). Rodriguez et al. (2005) compiled the literature regarding skinfold measurements and found that a common method to estimate body density is to use the equation developed by Durnin and Womersley in 1974 at the British Association of Sport and Exercise Sciences (BASES), which uses the logarithmic sum of four upper body sites (biceps, triceps, subscapular, and iliac crest). Anthropometric measurements are based on a 2C model that divides the body into FM and FFM, and assumes these remain constant (Van der Ploeg et al., 2003a). However, Van der Ploeg et al. (2003a) found that this is not always true because bone mineral mass and total body water varies among individuals, which affects the density of FFM.

Rodriguez et al. (2005) stated that the Slaughter et al. equations are commonly used to determine body density in pre-pubertal, pubertal, and post-pubertal males and females because they use only measures of triceps and subscapular skinfolds and account for gender, ethnicity, and pubertal status (Steinberger et al., 2005). Rodriguez et al. (2005) compared different skinfold equations in male and female adolescents, using DEXA as a reference model. Results from this study revealed that when %FM values were low, most equations overestimated body fat, and underestimated it when %FM values were high, compared to DEXA. Still, the researchers found that the Brook equation most accurately predicted %FM in white female adolescents and the Slaughter et al. equations most accurately predicted %FM in both sexes of white adolescents when compared to DEXA. This study concluded that skinfold thickness measurements were better predictors of body fat compared to other anthropometric methods such as body mass index (BMI) (Rodriguez et al., 2005). Steinberger et al. (2005) also found that the Slaughter et al. equations significantly correlated with DEXA estimations of FM in adolescents.

Since the development of Durnin and Wormersley equation, which uses the log sum of 4 upper body sites, evidence suggests that lower body sites, either independently or summed with upper body sites, may have a significant effect on total body fat (Eston et al., 2005). Eston et al. (2005) compared the literature on lower body sites versus upper body sites as predictors for body composition and found that the correlation between upper adipose volume (specifically abdominal) and lower limb adipose volume (thigh) is greater than the correlation for the sum of the upper sites (biceps, triceps, subscapular, and iliac crest). As a result of these and other similar findings, the British Olympic Association recommended the anterior thigh skinfold should be included with the sum of four skinfolds from the Durnin and Womersley equation (biceps, triceps, subscapular, and iliac crest) to predict a more accurate measure of body fat in adults (Eston et al., 2005).

Furthermore, Eston et al. (2005) compared skinfold thickness from the thigh and calf with four upper body skinfolds as predictors for percent body fat in healthy young adults, using a 4C model as reference model. The results revealed that the thigh and calf skinfolds were more significantly associated with percent body fat compared to upper body skinfolds. Researchers from this study recommended using the thigh, calf, or the sum of the thigh and calf along with the four upper body skinfolds from the Durnin and Womersly method (biceps, triceps, subscapular, and iliac crest) to determine the most accurate estimate of percent body fat (Eston et al., 2005).

Much research has shown that physical training alters the water and mineral composition of FFM. Generally, high levels of physical fitness result in increased muscularity and decreased body fat which can, in turn, affect the prediction of body composition with skinfold equations. Therefore, Evans et al. (2005) developed a new prediction equation, based on a 4C model, to determine percent body fat from skinfold measurements in athletes. Seven skinfold measurements were used to develop this equation, including the subscapular, triceps, chest, midaxillary, suprailiac, abdominal, and thigh. This equation used the sum of seven sites and accounted for race and gender.

This equation is: %BF = 10.566 + 0.12077*(7SKF) – 8.057*(gender) – 2.545*(race). Measuring seven sites can often be burdensome and invasive to some practitioners and athletes, so a similar formula was developed using the sum of three sites, including the abdomen, thigh, and triceps. This equation is: %BF = 8.997 + 0.24658*(3SKF) – 6.343*(gender) – 1.998*(race). These equations are a modification of the Jackson and Pollock (1978) equations that have been established for athletes. In this athlete population studied by Evans et al. (2005), the use of three sites was just as accurate as using seven sites. This finding is important to note.

The Jackson and Pollock equations are widely used in the field of exercise science to estimate body density in athletic populations; however, these equations have not been validated consistently in previous studies. For example, Ball et al. conducted a study in 2004 on men that investigated differences in body composition between three Jackson and Pollock skinfold equations and DEXA. The results of this study displayed a significant underestimation of approximately 3.0% for all three skinfold equations compared to DEXA. Ball et al. states, "it is highly unlikely that the difference resulted from an overestimation by DEXA" (Ball et al., 2004a). Additionally, Ball et al. conducted a similar study in 2004 on women using the same three Jackson and Pollock skinfold equations. These results also demonstrated an underestimation of 3-5% for all three skinfold equations compared to DEXA (Ball et al., 2004b). Since both studies conducted by Ball et al. consisted of samples similar to the one used in the 1980 and 1978 Jackson and Pollock studies from which these equations originated, it is unlikely that the underestimations observed by Ball et al. are a result of increased body fatness (Ball et al., 2004a; Ball et al., 2004b; Jackson et al., 1980; Jackson and Pollock, 1978). The differences observed by Ball et al. are likely due to the disagreement between hydrostatic weighing (HW) and multi-compartment models (Ball et al., 2004a; Ball et al., 2004b). Despite these findings, the Jackson and Pollock equations are still the most popular equations in exercise science and are recommended by the American College of Sports Medicine (ACSM) (Housh et al., 1989; Ball et al., 2004a).

Another popular equation for athletic populations is the Lohman equation. The Lohman equation uses skinfold measurements from three sites: triceps, subscapular, and abdominal. Accuracy depends on the technician, site location, and type of caliper (Wagner, 1996). The NCAA approved the Lohman equation along with hydrostatic weighing as acceptable methods for predicting body density. According to the NCAA rules, body density is then measured and converted into body fat using the Brozek et al. equation. Housh et al. (1989) investigated and compared 23 anthropometric equations for estimating body composition and minimum wrestling weight in high school wrestlers and concluded that the Lohman equation most accurately estimated body density among all 23 equations and recommended it for use in high school wrestlers. Additionally, Wagner (1996) reviewed the literature on the optimal equation for estimating % BF and minimum wrestling weight in high school wrestlers and found the Lohman equation to be most accurate for predicting body density and FFM in this population. Furthermore, Thorland et al. (1991) cross-validated skinfold equations in 860 high school wrestlers and concluded that the Lohman equation revealed the lowest prediction error. A limitation of the Lohman equation is that it is based on a 2C model especially because hydration levels and FFM density vary among wrestlers compared to a non-athletic population. However, it is impractical to use a more accurate multi-compartment model for determining minimum wrestling weights on a large scale due to cost, time, and appropriate instrumentation. For that reason, the Lohman equation has been recommended as the most accurate anthropometric equation to determine body density for wrestlers (Clark et al., 2004). The OSSAA currently uses the Lohman equation to predict body density in high school wrestlers in Oklahoma (OSSAA, 2007). For this reason, the Lohman equation was chosen to estimate body density in the current study.

Most anthropometric research has been conducted on lean individuals; however, the same results may not translate to an overweight or obese population. Some research has demonstrated that skinfold anthropometry may estimate body fat more accurately in adolescents with higher levels of body fat than in leaner individuals. For example, Bray et al. (2001) found this to be true, regardless of race, in a sample of 129 African American and Caucasian boys. Bray et al. (2001) attributes the discrepancy to the possibility that the population used to develop the initial anthropometric equations may have been fatter.

Conversely, Watts et al. (2006) found that skinfolds were a poor indicator of body fat in obese subjects. Watts et al. (2006) compared methods of body composition testing in 39 obese children and adolescents at baseline and again after eight weeks of exercise training and concluded that body fat derived from skinfolds was an inaccurate predictor of total body fat, compared to DEXA. The investigators of this study concluded that measures of body weight, BMI, and waist and hip girths were more highly correlated with DEXA-derived total and abdominal fat that skinfold measurements or skinfold-based equations in an obese population (Watts et al., 2006).

Comparison of Anthropometry to DEXA

Because anthropometry is cost effective and widely available, it is often the assessment tool used by many clinicians and practitioners in athletic settings, hospitals, universities, and health promotion programs. Even though DEXA has been found to be a more accurate model to measure body composition, it is usually not available in these types of settings (Ball et al., 2004b). Therefore, the accuracy of anthropometry compared to DEXA needs to be evaluated.

Most anthropometric equations were originally developed based on the old standard, hydrostatic weighing (HW); however, HW is based on a 2C model, which is often considered obsolete now since it was discovered that the body is made up of more than just two compartments. Given that DEXA, an updated standard, is a 3C model, it is uncertain whether the two can be compared. Hydrostatic weighing has resulted in errors of 3-4% body fat, mostly attributed to variations in body water, adipose tissue, and bone density. These variations are likely a result of the conversion of body density to %BF, which is based on faulty assumptions that are not always true, such as density of fat and fat-free mass are always constant. Higher %BF estimations from DEXA have been observed compared to HW. Therefore, it is important to re-evaluate anthropometric equations and compare them to DEXA, a more accurate model, to see if differences exist (Ball et al., 2004a; Ball et al., 2004b).

Ball and Swan (2001) found that various anthropometric equations significantly underestimated %BF in 25 women compared to DEXA. Specifically, the Jackson and Pollock 7-site equation underestimated %BF in 23 of the 25 women. Bottaro et al. (2002)

found similar results using the Jackson and Pollock skinfold equations in a sample of Brazilian women. Moreover, Hart et al. (1993) found that %BF was underestimated in a sample of 34 men when using skinfolds.

BMI as a Predictor of Body Composition in Athletes

Body mass index (BMI) is an index of weight for height that is used to classify body weight as normal, overweight, or obese. BMI is calculated by dividing weight in kilograms by height in meters squared. In adults, BMI of 25-29.9 $kg{\bullet}m^2$ is classified as overweight, while a BMI $\geq$ 30 $kg{\bullet}m^2$ is classified as obese. In individuals under age 20, BMI at or above the 95^{th} percentile on age-specific BMI growth charts identifies overweight. A high BMI is often correlated with having excess fat; however, many athletes may have a high BMI due to high muscle mass. This may lead to the misclassification of athletes as overweight or obese (Jonnalagadda et al., 2004; Ode et al., 2007). Although a high BMI is often correlated with having high body fat, it does not distinguish between fat and muscle tissue. Therefore, the use of body composition testing to determine % BF is a better indicator of overweight and obesity than BMI in athletes (Jonnalagadda et al., 2004).

Ode et al. (2007) investigated the accuracy of BMI as a measure of % BF in a sample of college athletes and found that BMI $\geq$ 25 $kg{\bullet}m^2$ incorrectly classified male and female athletes as being overweight 87% and 77% of the time, respectively. Both male and female athletes in this population had lower skinfold measurements compared to their untrained counterparts which further demonstrates the ineffectiveness of BMI as a predictor of body fat. This study suggests that BMI cut off points to identify overweight should be increased to 27.9 kg•m^2 for male adult athletes and 27.7 kg•m^2 for female adult athletes. This correlates with the NIH Consensus panel at the NIH Consensus Development Conference on the Health Implications of Obesity in 1985, which defines overweight for adult athletes as a BMI $\geq$ 27.8 kg•m^2 for men and a BMI $\geq$ 27.3 kg•m^2 for women. These cut points should limit the misclassification of overweight and obesity among athletes (Ode et al., 2007).

Additionally, Kyle et al. (2003) evaluated FFM and BFM (body fat mass) in white men and women, age 15-98 years, of all BMI categories and concluded that BMI alone cannot reveal information about FFM and FM as contributors to body weight. A study using participants from the Fels Longitudinal Study (white boys and girls, age 8-18 years) demonstrated that FFM consistently increased with BMI, particularly in adolescent boys who are in a stage of rapid growth. Fat mass (FM) and % BF varied depending on gender, age, and whether BMI was high or low. For instance, boys age 13-18 showed decreases in % BF. This study concluded that increases in BMI among children and adolescents are mostly due to increases in FFM rather than FM as a result of growth and maturation (Demerath et al., 2006). BMI is a good measure of body fat among heavier children and adolescents but not among thinner, leaner children, and adolescents (Freedman et al., 2005). Conversely, Sarria et al. (2001) found that BMI along with triceps skinfold and waist circumference, were good indicators of total fat content among males age 7.0-16.9 years. Sarria et al. (2001) reviewed longitudinal research on BMI, skinfold measurements, and waist circumference among children and adolescents and concluded that BMI more strongly tracks body fat increases compared to skinfold measurements in this population.

However, for the athletic population such as the one used in this current study, BMI is not a good predictor of body fat due to their higher content of lean body tissue, and thus, more accurate measures of body composition testing should be used to determine FM and FFM (Jonnalagadda et al., 2004; Ode et al., 2007).

Summary

Wrestling is a highly competitive sport where body weight is often viewed as an advantage. Wrestlers often try to rapidly lose weight before a match in order to compete in a lower weight class than their ideal weight to gain a competitive advantage (Jonnalagadda et al., 2004). Due to the known health hazards associated with practicing unsafe weight loss methods, the National Federation of High School Associations (NFHS) establishes minimum weight classes before each season to prevent these unsafe behaviors from occurring (OSSAA, 2007). Therefore, body composition testing is an important tool in defining minimum weight classes among high school wrestlers. There are numerous methods of body composition testing and research is inconclusive about the most accurate method for this population. The aim of this study is to evaluate the accuracy of skinfold measurements as a predictor of body composition in adolescent wrestlers by comparing skinfold measurements using the sum of three sites to whole-body DEXA scans, using DEXA as the reference model. Secondly, minimum wrestling weights were calculated to assess the practicability of current recommendations.

CHAPTER III

METHODS

This research study examined body composition of adolescent wrestlers pre-, in-, and off-season from two Oklahoma high schools. The purpose of this study was to evaluate the accuracy of skinfold measurements as a predictor of body fat in adolescent wrestlers by comparing the sum of three sites with DEXA whole-body scans, using DEXA as the reference model. Secondly, minimum wrestling weights were calculated to assess the practicability of current recommendations. The Oklahoma State University Institutional Review Board approved the protocol on October 1, 2007 (Appendix D).

Objectives of the Study

1. To compare body composition obtained from skinfold measurements (the sum of three sites) to DEXA across the period of a wrestling season (pre-, in-, and off-season) in individual adolescent wrestlers.
    a. To determine if skinfold measurements (sum of three sites) are an accurate measure of body composition compared to DEXA.

2. To calculate minimum wrestling weights based on percent body fat from DEXA and skinfolds, and to assess whether these minimum weights are a realistic recommendation and expectation of wrestlers based on:
    a. Body mass index (BMI) of predicted minimum wrestling weights
    b. Average body fat and weight of the wrestlers throughout the season

Subjects

The sample consisted of 25 male high school wrestlers (mean age=15.5 years) from Enid High School (13 participants) and Stillwater High School (12 participants) who were competing in the 2006-07 wrestling season. A convenience sample of high school wrestlers was used.

Research Design and Data Collection

This research study was a comparative study using quantitative methods to achieve the objectives. Participants came during the month of October 2006 (pre-season), February 2007 (in-season), and April 2007 (off-season) to have their body composition tested. Upon arrival, their height (in cm and inches) and weight (in kg and lbs) was measured. Then, the participants' hydration status was determined using a refractometer to ensure they were adequately hydrated before body composition measurement. Participants were scanned using a Hologic DEXA scanner (model QDR-4500A).

Skinfold thickness was measured in millimeters at seven sites (the triceps, subscapular, midaxillary, chest, suprailiac, abdomen, and thigh) with a Lange caliper by a trained assessor. Measurements were taken three times and averaged. Then, the Lohman equation was used to determine body density using three sites as recommended by the NFHS and OSSAA (Lohman, 1981; Housh et al., 1989; OSSAA, 2007)

- 3-site formula (triceps, subscapular, abdomen):

  Body density = [1.0982 - (sum of 3 skinfolds x 0.000815)] - [(sum of 3 skinfolds)^2 x 0.0000084]

From the calculated body density, percent body fat was then determined using the Brozek equation (Brozek et al., 1963):

- %BF = (4.57 / body density) – 4.142 x 100

Next, minimum wrestling weight was calculated using the following formulas (Utter et al., 2005):

- Weight at 7% BF:

  Weight at 7% BF = [[1 – (%BF/100] x current weight]/0.93

- Minimum wrestling weight with a 3% allowance:

  Minimum weight = 7% weight x 0.97

Last, body mass index (BMI) was calculated using the following formula (Ode et al., 2007):

- Weight (kg)/height (m^2)

Statistical Analysis

Analyses were performed using the SPSS Version 14 computerized statistical analysis package. Frequencies were tabulated. Comparisons were made using Student t-tests for paired comparisons. This statistic was used to compare values for the same individuals at different times. Significance was set at the $p \leq 0.05$ level.

CHAPTER IV

FINDINGS

Demographics

At the start of the study, there were 25 male participants. Twelve were from Stillwater High School and 13 were from Enid High School. Sixteen of the participants were white (64% of the sample), 7 participants were Native American (28%), one participant was African American (4%), and one participant was Asian/Pacific Islander.

A total of 24 out of 25 subjects (96% of the original sample) participated in the pre-season testing in October 2006. One subject could not participate in the pre-season testing due to a broken collarbone. The mean age during pre-season was 15.5 years. A total of 20 out of 25 subjects (80% of the original sample) participated during the in-season testing in February 2007. The mean age during in-season was 15.75. A total of 17 out of 25 subjects (68% of the original sample) participated in the off-season testing in April 2007. Participants were slightly older by this point in the study, with a mean age of 15.88. Overall, there was a 32% attrition rate.

Mean weight did not change significantly from pre- to in-season (p=.061), but mean weight did increase from in-season to off-season (p=.018) and from pre-season to off-season (p=.000). Height increased from pre-season to in-season (p=.000) and pre-season to off-season (p=.000) but not between in-season and off-season (p=.187).

Pre-season, in-season and off-season demographics of the participants, including race/ethnicity, age, weight, and height, are summarized in Table 4.1 below.

Table 4.1: Demographics, Weight, and Height Across Season

		Pre-season	In-season	Off-season
Valid	Mean age (y) ±SE	15.50±0.25	15.75±0.22	15.88±0.27
	Race/Ethnicity (n)			
	White	16	14	10
	Native American	7	5	6
	African American	1	1	1
	Asian/Pacific Islander	1	0	0
	Total N	24	20	17
	Weight (lbs.) ±SE	148.88±8.14[a]	149.62±8.84[a]	155.58±10.32[b]
	Height (in.) ±SE	66.54±0.52[a]	67.03±0.59[b]	67.15±0.57[b]

[abc] different superscripts indicate statistically significant difference at $p \leq .05$; SE = standard error

Percent Body Fat from DEXA and the Lohman 3-site Equation

Pre-season, in-season, and off-season %BF from DEXA and the Lohman 3-site equation 3 (L3) are shown in Table 4.2.

Table 4.2: Percent Body Fat Across Season

	Pre-season	In-season	Off-season
DEXA %BF ±SE	16.22±1.50[a]	15.10±1.60[a]	16.35±1.76[a]
L3 %BF ±SE	12.41±1.22[a]	12.67±1.29[b]	15.75±2.25[b]
Difference between DEXA and L3 ±SE	3.81±0.43	1.41±0.47	0.60±0.65

[abc] different superscripts indicate statistically significant difference at $p \leq .05$; SE = standard error

DEXA estimates of %BF were consistent over time. In other words, there were no statistical differences between pre-season, in-season, and off-season (p=.065, p=.241. and p=.429, respectively). Additionally, estimates of %BF were higher from DEXA than from L3.

On the other hand, L3 was not a consistent estimate of %BF over time. Percent body fat from L3 was statistically different between pre-season and in-season (p=.003) and between pre-season and off-season (p=.001); however, there was no statistical difference between in-season and off-season (p=.144).

The difference between %BF from DEXA and L3 was greatest during pre-season (3.8%) and smallest during off-season (0.60%). The wide range of difference between DEXA and L3 across time is attributed to the fact that L3 was not consistent over time. L3 resulted in %BF 3.8% lower than DEXA during pre-season, 1.4% lower than DEXA during in-season, and 0.6% lower than DEXA during off-season. This is consistent with previous literature that suggests that skinfolds often underestimate %BF compared to DEXA (Hart et al., 1993).

Percent body fat from DEXA and L3 for pre-, in-, and off-season are summarized in Appendix B. The data is divided into quintiles based on average weight for the season.

Minimum Weight Calculations from DEXA and L3

Table 4.3 displays minimum weight calculations from DEXA and L3.

Table 4.3: Comparison of Measured Body Weight to Minimum Weight Predictions

	Weight (lbs.) ±SE	Minimum Weight from DEXA (lbs.) ±SE	Minimum Weight from L3 (lbs.) ±SE
Pre-season	148.88±8.14[a]	127.79±4.70[b]	133.93±5.19[c]
In-season	149.62±8.84[a]	130.28±5.09[b]	129.04±3.99[c]
Off-season	155.58±10.32[a]	133.24±5.75[b]	133.35±4.87[b]

[abc] different superscripts indicate statistically significant difference at $p \leq .05$; SE = standard error

There were statistically significant differences between pre-season weight and minimum weight from DEXA (p=.000), pre-season weight and minimum weight from L3 (p=.000), and between pre-season minimum weights from DEXA and L3 (p=.000). Likewise, there were statistically significant differences between in-season weight and minimum weight from DEXA (p=.000), in-season weight and minimum weight from L3 (p=.000), and between in-season minimum weights from DEXA and L3 (p=.009). There were statistically significant differences between off-season weight and minimum weight from DEXA (p=.001) and between off-season weight and minimum weight from L3 (p=.003); however, there was no statistically significant difference between off-season minimum weights from DEXA and L3 (p=.938). This lends further evidence that L3 is not a reliable estimate of body fat compared to DEXA.

The mean pre-season minimum weight was higher using %BF from L3, approximately 134 pounds, than the pre-season mean minimum weight from DEXA, approximately 128 pounds. Therefore, a wrestler would have been asked to lose approximately 21 pounds (based on the mean pre-season weight, approximately 149 pounds), on average, if his minimum weight was calculated using DEXA compared to only 15 pounds if his minimum weight was calculated using L3.

In contrast to pre-season, the in-season mean minimum weight was higher with L3, approximately 129 pounds, than with DEXA, approximately 130 pounds. However, the difference is minimal. Compared to the in-season mean weight, approximately 150 pounds, a wrestler would have been asked to lose approximately 20-21 pounds, on average, using either DEXA or L3. This is similar to the amount of weight a wrestler would have had to lose in pre-season if %BF from DEXA was used (21 pounds).

Off-season mean minimum weight from L3 was higher than mean minimum weight from DEXA, but only by approximately 0.1%. Compared to the mean off-season weight (approximately 156 pounds), a wrestler would have been asked to lose approximately 23 pounds, on average, using either %BF from L3 or DEXA. This is slightly higher than the amount a wrestler would have had to lose in both pre-season (15-21 pounds) and in-season (20-21 pounds).

Weight and minimum weights from DEXA and L3 for pre-, in-, and off-season are summarized in Appendix A. The data is divided into quintiles based on average weight for the season.

BMI

In addition to %BF, BMI of mean weight was also evaluated along with BMI of predicted minimum weight from DEXA and L3. These results are summarized in Table 4.4.

Table 4.4: Comparison of Measured BMI to BMI of Minimum Weight Predictions

	BMI of mean weight (kg•m^2) ±SE	BMI of Minimum Weight from DEXA (kg•m^2) ±SE	BMI of Minimum Weight from L3 (kg•m^2) ±SE
Pre-season	23.55±1.19[a]	20.22±0.62[b]	21.20±0.71[c]
In-season	23.39±1.36[a]	20.35±0.72[b]	20.21±0.59[c]
Off-season	24.26±1.59[a]	20.77±0.86[b]	20.79±0.72[b]

[abc] different superscripts indicate statistically significant difference at $p \leq .05$; SE = standard error

There were statistically significant differences between pre-season BMI and BMI of pre-season predicted minimum weight from DEXA (p=.000), between pre-season BMI and BMI of pre-season predicted minimum weight from L3 (p=.000), and between BMI of pre-season predicted minimum weights from DEXA and L3 (p=.000). Likewise, there were statistically significant differences between in-season BMI and BMI of in-season predicted minimum weight from DEXA (p=.001), between in-season BMI and BMI of in-season predicted minimum weight from L3 (p=.000), and between in-season BMI of predicted minimum weights from DEXA and L3 (p=.008). There were statistically significant differences between off-season BMI and BMI of off-season predicted minimum weight from DEXA (p=.001) and between off-season BMI and BMI of off-season predicted minimum weight from L3 (p=.003); however, there was no statistically significant difference between BMI of off-season predicted minimum weights from DEXA and L3 (p=.922).

Throughout the season, all measures of BMI based on mean weight or minimum weights from DEXA or L3 were within the healthy range (between the 5^{th} and 85^{th} percentile) for boys age 2-20 years old (CDCb, 2008). In spite of the healthy mean BMI, some wrestlers were well above the healthy range. The maximum pre-season BMI was 43.08 $kg \bullet m^2$; the maximum in-season BMI was 42.79 $kg \bullet m^2$, and the maximum off-season BMI was 43.28 $kg \bullet m^2$. A case summary of BMI data divided by quintiles of average weight is displayed in Appendix C.

CHAPTER V

DISCUSSION

The purpose of this study was to evaluate the accuracy of skinfold measurements as a predictor of body fat in adolescent wrestlers by comparing the sum of three sites with DEXA whole-body scans, using DEXA as the reference model. Secondly, minimum wrestling weights were calculated to assess the practicability of current recommendations. The significance of our objectives was to assess one of the current methods of body composition being used in Oklahoma high schools.

Body weight, height, and body fat all increased throughout the season. This is understandable because the wrestlers were at an age of rapid growth, not only in height and weight but also in the composition of their bodies. Sex hormones during adolescence affect the distribution of fat (Bray et al., 2001). Another explanation for the increase in the wrestlers' weight and body fat during off-season is that they were no longer "cutting weight". This increase in weight may have an effect on body composition; however, it is possible that increase in weight and height is due to some of the shorter or lighter wrestlers dropping out.

Body composition is a vital part of predicting minimal wrestling weights; therefore, we want to ensure that wrestlers are being assigned a minimum weight that is both accurate and appropriate. Although the data from this study did not show a consistent pattern or trend, our findings lend evidence that L3 was not a reliable measure of body composition over time, compared to DEXA. It is unclear whether the inconsistency of the data for the skinfolds was due to an error in the measurements of skinfold thickness or an intrinsic fault within the Lohman equation. In other words, the Lohman equation may not be the most accurate anthropometric equation for this particular population, despite support from previous literature. For example, Stout et al. (1995) states that the Lohman equation is usually recommended for children and non-athletic adolescents; therefore, it may not be suitable for athletic adolescents. However, part of the error could also be associated with the HW criterion (2C model) from which the Lohman equation was created. The Lohman equation was developed before significant advancements in body composition research and technology, such as the discovery of multi-compartment models and the wide availability of DEXA (Clark et al., 2004). Based on these uncertainties, further research is warranted to validate the use of the Lohman equation for adolescent wrestlers. Even though DEXA may be a more reliable measure of body composition, it is not feasible to use in school settings due to monetary constraints; therefore, schools, such as the ones used in this current study, are limited to using skinfold measurements to estimate body composition.

Our second objective was to calculate and evaluate minimum wrestling weights. Again, results were inconsistent over time using both DEXA and L3. One of the ways minimum wrestling weights were evaluated was by assessing the BMI of the predicted minimum weights. First of all, the mean BMI of the wrestlers was evaluated throughout the season. The mean BMI throughout the season fell within the healthy range defined for boys of this age group (CDCb, 2008). However, some wrestlers had a very high BMI.

The maximum BMI in pre-season was 43.08 kg•m^2, 42.79 kg•m^2 during in-season, and 43.28 kg•m^2 during off-season. Previous literature claims that BMI is not a good measure of body fat in athletes because it does account for muscle mass; however, a high BMI is still a cause for concern, even among an athletic population, because it may be indicative of excess body fat, which may increase the risk for disease (Jonnalagadda et al., 2004; Watts et al., 2006, Freedman et al., 2005). Thus, BMI should be evaluated in conjunction with %BF to accurately assess overweight and obesity (Kyle et al., 2003). Secondly, BMI of the predicted minimum weights were evaluated. Similarly to the mean BMI, the BMI of all the predicted minimum weights from both DEXA and L3 also fell within the healthy range for boys of this age group (CDCb, 2008).

The second way that minimum wrestling weights were evaluated was by comparing them to the average body weight throughout the season. Despite the normal BMI of the predicted minimum weights, the predicted minimum weights were all well below the average body weight of the wrestlers throughout the season. Wrestlers would have been asked to lose, on average, 15-21 pounds to attain their pre-season minimum weight, 20-21 pounds to wrestle at their in-season minimum weight, and 23 pounds in order to wrestle at their off-season minimum weight. This is a significant amount of weight to lose, especially for growing adolescent boys. Losing this amount of weight in such a short period of time would not be possible unless drastic methods were taken, such as the harmful rapid weight loss methods that so many wrestlers often resort to. That being said, the minimum wrestling weight standard of 7% body fat ± a 3% allowance may be too low for adolescent males, especially considering the average body weight of the subjects throughout the study. Even in the lowest quintile, only two of the subjects were near 7% body fat during any point in the study (6.90% and 7.97%, measured by L3). Most subjects averaged within the range of 12-16 %BF, although some subjects were lower and some were higher. The normal range of body fat composition for most boys is 7-20%, with some variation (Perriello, 2001).

Although OSSAA has set the minimum weight standard at 7% body fat, Periello (2001) states that wrestlers compete best at their natural body weight, which is defined as off-season weight when eating and exercise are normal and healthy (OSSAA, 2007). Seven percent body fat is the minimum wrestling weight set by the ACSM and was adopted by the NFHS and OSSAA; however, this standard is considered the *minimum* for wrestlers to compete at and therefore, may not necessarily be the natural or ideal weight for all wrestlers (Oppliger et al., 1996, Perrierllo, 2001). Ethnicity and genetics play a considerable role in an individual's body composition; therefore, some wrestlers may naturally be higher or lower than the minimum weight standard (Perriello, 2001). In addition, the subjects in this study are adolescents, which is an age of rapid growth, not only in weight and height but also in body composition. Their bodies may be resisting fat loss due to increased sex hormones (Bray et al., 2001). Nevertheless, wrestlers still try to lose weight to gain a perceived competitive advantage. However, the theory that competing in a lower weight class will give a wrestler a higher advantage is a myth and misconception that has been a component of wrestling since as early as 1930 (Kiningham and Gorenflo, 2001). The wrestling community has developed a mentality of commitment, sacrifice, and self-discipline that is manifested through weight loss. Wrestling is a sport that thrives on the "no pain, no gain" philosophy but unfortunately at the expense of wrestlers' physiological and psychological health (Perriello, 2001).

Another issue of concern is the ambiguity of the OSSAA weight management regulations that may lead to misinterpretation by some wrestling coaches. For example, the guidelines state that "a 3% variance will be subtracted from the minimum weight for all males who are at or above 7% body fat" (OSSAA, 2007). According to Ed Sheakley ([esheakley@ossaa.com], email, March 13, 2008), who is a staff member of the OSSAA, the reason for this allowance is because skinfold calipers have a plus or minus margin of error of 2-4%. Additionally, the 3% allowance may account for potential human error in measuring skinfold thickness. However, some coaches may interpret this rule to imply that wrestlers can compete as low as 4% body fat. This seems dangerously low and unhealthy for growing boys. If the minimum weight standard were raised higher than 7% body fat, then the 3% allowance would not be as much of a concern.

Limitations

Since the sample size was small (25 subjects initially and only 17 subjects in the final test), this data may not be generalizable to the rest of the high school wrestling population. In addition, the use of a convenience sample also limits the generalizability of the results because this sample may not be representative of a larger population. Furthermore, there is incomplete data for some subjects who either dropped out of the study early or came into the study late. Finally, there were two different assessors who measured skinfold thickness during the study, which may affect the accuracy of the results. Even though both assessors were well trained and measured skinfolds in triplicate throughout the study, anthropometry in itself has many limitations. First of all, skinfold compressibility is inconsistent (Watts et al., 2006). Other potential sources of error include inter-tester, intra-tester, and equipment-related errors as well as possible interactions of these sources of error (Oppliger et al., 1992).

Despite these limitations, this data demonstrates that the minimum weight standard of 7% BF is too low for most adolescent wrestlers. This finding is true not only among the sample in this current study but more importantly across the high school wrestling population as a whole, thus allowing for the continuation of potentially dangerous weight loss behaviors within the sport.

Implications for Practice

Based on the results of this study, it is evident that minimum weight standards should be re-evaluated and more realistic recommendations should be established for adolescent wrestlers. Considering the average weight of this sample throughout the season, it would be unreasonable to recommend and expect wrestlers to lose such a significant amount of weight. Because the minimum weight standard is set so low, wrestlers are most likely resorting to harmful weight loss methods in an attempt to achieve an unrealistic goal. This is the behavior that the NCAA, ACSM, NFHS, and OSSA initially sought to eliminate. However, as evidenced by these results, the standards need to be raised to a more realistic and sustainable minimum weight.

Secondly, it is essential that a standardized training and testing protocol for measuring skinfold thickness be implemented in schools. In addition, testers who measure skinfold thickness need to be adequately trained and certified. Although the

OSSAA requires that assessors be medical professionals who are certified, it is difficult to ensure this in schools. Therefore, a standardized training and testing protocol would decrease potential error.

Moreover, wrestlers should be instructed further on steps to healthy weight loss and the importance of proper and adequate nutrition. Wrestlers should be educated on the difference between losing excess body fat and losing weight. The harmful weight loss methods currently being employed by wrestlers (i.e. excessive exercise and severe calorie restriction) promotes loss of lean body mass and water as opposed to fat. This is not only dangerous to the health of growing adolescents but also counterproductive for athletic performance. Unfortunately, is seems evident that wrestlers do not understand the difference between gradually losing fat and losing total body water quickly (Perriello et al., 1995). Therefore, further education is crucial. Adolescents need about 1,700 to 3,000 calories a day, depending on weight and metabolic rate, just to maintain physiological function and support healthy growth and development. Depending on the length and intensity of exercise, adolescents may need an additional 350 – 1,000 calories per day. Adolescents need to consume a balanced diet consisting of carbohydrates (55%), fat (20-25%), and protein (15-20%). Although many wrestlers forgo carbohydrates in order to lose more weight, a high carbohydrate diet may improve performance. In addition to food, wrestlers need to stay adequately hydrated by drinking ½ to 1 cup of water every 15 to 30 minutes of exercise depending on the intensity and the heat index. Wrestlers should exercise adequately to maintain their fitness level but not excessively. If wrestlers need to lose fat, they should be instructed to do so gradually in a healthy manner. Quick weight loss often leads to weight regain later. A general recommendation for healthy weight loss is to lose no more that one to two pounds per week. Since 3,500 calories are equivalent to one pound, one can achieve this goal by burning 500 to 1,000 additional calories a day. Finally, wrestlers should be encouraged to maintain their “natural” weight, which is defined as weight when diet and exercise are healthy, balanced, and adequate (Perriello, 2001). The goal is to teach wrestlers life long healthy habits that they can sustain throughout their life rather than promoting fast weight loss through unhealthy habits. It is important for coaches, parents, and physicians to work together to encourage healthy habits among wrestlers and to change the harmful traditions of the sport.

Implications for Future Research

More research needs to be done to determine the accuracy of skinfold measurements in determining body composition. Since this study only compared the Lohman 3-site equation to DEXA, future research should compare many different anthropometric equations to DEXA to determine the most accurate formula.

Since OSSAA also allows the Tanita Bioelectrical Impedance 300W machine in addition to skinfolds to test body fat in Oklahoma high schools, future research should compare skinfold measurements and bioelectrical impedance to DEXA to determine the most accurate measure of body composition.

As discussed previously, nutrition education is crucial for wrestlers. Therefore, future research should also evaluate the nutrition knowledge of wrestlers and coaches in order to determine how much education they need. Then, such a program can be developed and implemented in the schools.

It is also important to determine the accuracy of the skinfold assessors in the schools. Therefore, future research should compare school assessors to experienced testers (those who routinely test a variety subjects, including athletes and the general public, of all levels of fatness) to determine the accuracy of the skinfold measurements in the schools (Oppliger et al., 1992).

Based on the results of this current study, we also suggest that future research should evaluate wrestlers' performance at different %BF to determine a range of body fat in which wrestlers perform best. Then, perhaps a more realistic minimum wrestling weight can be established.

Additional research needs to be done to explore these topics since they were not objectives in this current study but rather issues that were recognized during the research process.

Conclusions

Based on the results of this study, we conclude that skinfold measurements (specifically the Lohman 3-site equation) were not a reliable measure of body composition compared to DEXA due to the inconsistency of the results over time. However, it was unclear whether the inconsistency of the skinfold data was a result of measurement error or a fault in the Lohman anthropometric equation. Therefore, further research needs to be done. Secondly, as evidenced by the significant difference between average weight and predicted minimum wrestling weight, we also conclude that the minimum wrestling weight standard of 7% body fat is an unrealistic, unsustainable recommendation and expectation for adolescent wrestlers. Therefore, the minimum wrestling weight standard should be re-evaluated, and a more realistic minimum weight should be established.

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APPENDICIES

Case Summaries[a]

		preseason wt lb	inseason wt lb	offseason wt lb	Pminwt Dexa	Pminwt L3	Inminwt Dexa	Inminwt L3	Offminwt Dexa	Offminwt L3
average wt 1.00	1	112.50	118.20	116.50	102.79	107.45	108.98	107.65	107.17	107.58
	2	100.60	101.20	-	89.92	95.77	90.99	94.41	-	-
	3	111.60	113.60	112.10	101.38	104.29	101.66	105.80	99.85	104.40
	4	108.00	-	-	99.80	103.67	-	-	-	-
	5	104.90	104.30	110.40	92.78	100.36	95.30	101.28	99.60	103.34
	Total N	5	4	3	5	5	4	4	3	3
2.00	1	129.70	-	133.60	112.15	121.41	-	-	119.42	118.11
	2	132.70	140.40	136.10	121.94	125.90	130.18	131.42	126.76	128.91
	3	137.00	138.80	140.60	120.89	124.78	123.34	126.41	125.09	128.94
	4	134.20	131.00	140.30	124.16	127.75	121.47	125.12	130.24	132.44
	5	138.90	135.20	-	131.11	132.67	128.04	129.13	-	-
	Total N	5	4	4	5	5	4	4	4	4
3.00	1	-	145.80	-	-	-	137.02	134.63	-	-
	2	139.10	141.20	142.90	128.98	133.75	132.99	132.40	131.91	133.76
	3	138.00	141.40	140.70	122.35	129.83	125.65	129.67	125.03	129.70
	4	137.50	144.90	152.20	127.64	131.77	131.33	135.41	141.28	141.99
	5	138.00	139.00	143.60	121.19	126.34	121.20	127.47	123.72	130.11
	Total N	4	5	4	4	4	5	5	4	4
4.00	1	163.30	163.50	-	152.78	152.65	153.99	151.23	-	-
	2	159.40	-	171.40	138.99	144.47	-	-	148.02	146.19
	3	147.40	-	-	128.68	135.50	-	-	-	-
	4	150.60	147.30	-	129.75	135.64	129.21	129.99	-	-
	5	149.00	153.40	157.90	140.33	141.37	144.80	143.84	148.22	147.40
	Total N	5	3	2	5	5	3	3	2	2
5.00	1	210.60	215.60	220.90	142.56	156.54	153.14	158.97	159.21	146.07
	2	172.20	169.10	168.50	128.60	140.76	131.57	130.51	128.47	126.76
	3	214.40	-	-	169.95	177.89	-	-	-	-
	4	163.50	170.00	172.60	150.58	152.53	154.26	156.44	155.54	157.47
	5	280.00	278.50	284.60	187.78	211.34	190.55	-	195.62	138.72
	Total N	5	4	4	5	5	4	3	4	4
Total N		24	20	17	24	24	20	19	17	17

[a] Limited to first 100 cases.

Preseason wt lb = pre-season mean weight in pounds
Inseason wt lb = in-season mean weight in pounds
Offseason wt lb = off-season mean weight in pounds
Pminwtdexa = pre-season predicted minimum weight using DEXA %BF
PminwtL3 = pre-season minimum weight using Lohman 3-site
InminwtDexa = in-season minimum weight using DEXA %BF
InminwtL3 = in-season minimum weight using Lohman 3-site %BF
OffminwtDexa = off-season minimum weight using DEXA %BF
OffminwtL3 = off-season minimum weight using Lohman 3-site %BF

Case Summaries[a]

		Pre-%BodyFat based on DEXA	PL3BF	In-%BodyFat based on DEXA	InL3BF	Off-%BodyFat based on DEXA	OffL3BF
average wt 1.00	1	12.40	8.43	11.60	12.68	11.80	11.47
	2	14.30	8.73	13.80	10.56	-	-
	3	12.90	10.41	14.20	10.71	14.60	10.71
	4	11.40	7.97	-	-	-	-
	5	15.20	8.27	12.40	6.90	13.50	10.25
	Total N	5	5	4	4	3	3
2.00	1	17.10	10.25	-	-	14.30	15.24
	2	11.90	9.04	11.10	10.25	10.70	9.19
	3	15.40	12.68	14.80	12.68	14.70	12.07
	4	11.30	8.73	11.10	8.43	11.00	9.49
	5	9.50	8.43	9.20	8.43	-	-
	Total N	5	5	4	4	4	4
3.00	1	-	-	9.90	11.47	-	-
	2	11.10	7.81	9.70	10.10	11.50	10.25
	3	15.00	9.80	14.80	12.07	14.80	11.62
	4	11.00	8.12	13.10	10.41	11.00	10.56
	5	15.80	12.23	16.40	12.07	17.40	13.13
	Total N	4	4	5	5	4	4
4.00	1	10.30	10.38	9.70	11.32	-	-
	2	16.40	13.10	-	-	17.20	18.23
	3	16.30	11.86	-	-	-	-
	4	17.40	13.64	15.90	15.39	-	-
	5	9.70	9.04	9.50	10.10	10.00	10.50
	Total N	5	5	3	3	2	2
5.00	1	35.10	28.74	31.90	29.31	30.90	36.60
	2	28.40	21.63	25.40	26.00	26.90	27.88
	3	24.00	20.45	-	-	-	-
	4	11.70	10.56	13.00	11.77	13.60	12.53
	5	35.70	27.64	34.40	-	34.10	38.11
	Total N	5	5	4	3	4	4
Total N		24	24	20	19	17	17

[a] Limited to first 100 cases.

Pre-%BodyFat based on DEXA = pre-season % body fat based on DEXA
PL3BF = pre-season % body fat based on Lohman 3-site equation
In-%BodyFat based on DEXA = in-season % bodt fat based on DEXA
InL3BF = in-season % body fat based on Lohman 3-site equation
Off-%BodyFat based on DEXA = off-season % body fat based on DEXA
OffL3BF = off-season % body fat based on Lohman 3-site equation

Case Summaries[a]

		PBMI	PminwtDexa BMI	PminwtL3 BMI	InBMI	InminwtDexa BMI	InminwtL3 BMI	OffBMI	OffminwtDexa BMI	OffminwtL3 BMI
average wt 1.00	1	18.61	17.00	17.77	19.15	17.66	17.44	18.86	17.35	17.41
	2	18.64	16.66	17.74	18.50	16.63	17.26	-	-	-
	3	17.62	16.01	16.46	17.93	16.05	16.70	17.66	15.73	16.45
	4	19.33	17.86	18.55	-	-	-	-	-	-
	5	19.50	17.25	18.66	18.93	17.29	18.38	19.46	17.56	18.22
	Total N	5	5	5	4	4	4	3	3	3
2.00	1	21.51	18.60	20.14	-	-	-	21.69	19.39	19.18
	2	19.97	18.35	18.95	20.77	19.26	19.44	20.51	19.10	19.43
	3	22.88	20.19	20.84	22.88	20.33	20.83	23.03	20.49	21.12
	4	21.85	20.22	20.80	21.33	19.78	20.37	22.71	21.08	21.44
	5	22.11	20.87	21.12	21.52	20.38	20.55	-	-	-
	Total N	5	5	5	4	4	4	4	4	4
3.00	1	-	-	-	20.59	19.35	19.02	-	-	-
	2	20.54	19.04	19.75	20.63	19.43	19.34	20.92	19.31	19.58
	3	19.51	17.30	18.36	19.53	17.36	17.91	19.35	17.19	17.84
	4	21.66	20.11	20.76	22.34	20.25	20.88	23.14	21.48	21.59
	5	24.09	21.15	22.05	24.05	20.97	22.06	25.04	21.57	22.68
	Total N	4	4	4	5	5	5	4	4	4
4.00	1	25.07	23.45	23.44	25.23	23.76	23.33	-	-	-
	2	24.02	20.95	21.77	-	-	-	25.53	22.05	21.77
	3	22.26	19.43	20.46	-	-	-	-	-	-
	4	22.43	19.33	20.20	21.86	19.18	19.30	-	-	-
	5	20.97	19.75	19.90	21.47	20.27	20.13	22.06	20.71	20.59
	Total N	5	5	5	3	3	3	2	2	2
5.00	1	35.59	24.09	26.45	36.01	25.58	26.55	36.64	26.41	24.23
	2	26.18	19.55	21.40	25.36	19.74	19.58	25.17	19.19	18.94
	3	31.76	25.18	26.35	-	-	-	-	-	-
	4	26.03	23.97	24.28	26.99	24.49	24.84	27.44	24.73	25.04
	5	43.08	28.89	32.51	42.79	29.28	-	43.28	29.75	27.94
	Total N	5	5	5	4	4	3	4	4	4
Total N		24	24	24	20	20	19	17	17	17

[a] Limited to first 100 cases.

PBMI = pre-season mean BMI
PminwtDexaBMI = BMI based on pre-season predicted minimum weight from DEXA
PminwtL3BMI = BMI based on pre-season predicted minimum weight from Lohman 3-site
InBMI = in-season mean BMI
InminwtDEXABMI = BMI based on in-season predicted minimum weight from DEXA
InminwtL3BMI = BMI based on in-season predicted minimum weight from Lohman 3-site
OffBMI = off-season mean BMI
OffminwtDexaBMI = BMI based on off-season predicted minimum weight from DEXA
OffminwtL3BMI = BMI based on off-season predicted minimum weight from Lohman 3-site

APPENDIX D

Oklahoma State University Institutional Review Board

Date:	Monday, October 01, 2007
IRB Application No	HE0754
Proposal Title:	Nutrition-Related Parameters, Dietary Intakes, and Food and Exercise-Related Attitudes Among Collegiate Athletes
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved   Protocol Expires: 9/30/2008

Principal Investigator(s

Lenka Humenikova	Nancy Betts	Brenda Smith
308 HES	301 HES	420 HES
Stillwater, OK 74078	Stillwater, OK 74078	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 219 Cordell North (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Sue C Jacobs

Sue C. Jacobs, Chair
Institutional Review Board

APPENDIX E

INFORMED CONSENT FOR PARTICIPANTS

Project Title: Nutrition-related Parameters, Dietary Intakes, and Food and Exercise-Related Attitudes among Collegiate Athletes

Project Leaders: Lenka Humenikova, PhD; Nancy Betts, PhD, RD; Brenda Smith, PhD

We are asking you to participate in a study measuring body composition, metabolic rate, food intake and attitudes about food and exercise in pre-season, season, and off-season. We are asking you to volunteer to participate because you are an OSU student athlete who is 18 years of age or older. The purpose of this study is to assess nutrition-related parameters, dietary intakes, and food- and exercise-related behaviors and attitudes among OSU collegiate athletes and monitor changes that occur throughout the year. The ultimate purpose of this research project is to make recommendations for dietary intakes that will optimize athletic performance of OSU male and female athletes. You must be 18 years old or older to be able to participate in this study.

You will be invited to make one visit to the Department of Nutritional Sciences during the preseason, season, and off-season (a total of 3 visits). Each visit will take approximately 1.5-2 hours. Your body composition and bone density will be measured using the Dual Energy X-ray Absorptiometry (DEXA). DEXA is currently the most accurate scan that measures body composition and bone density. You will be asked to dress in comfortable clothing (we will provide clothing if needed), removing any metal (excluding orthodontic braces). During the scan, you will lay on an examination table while a machine arm passes over your body. You will feel no discomfort. The X-ray exposure from DEXA is much smaller than exposure from a chest X-ray (approximately 10 times less). The scan will take approximately 10-15 minutes, including all the preparation procedures.

Your body composition will also be measured using standard skinfold thickness measurements. A trained researcher will measure your body fat using calipers in 7 different places on the body (arm, stomach, back etc.). This measurement will take approximately 5 minutes. Before the body composition measurement, we will measure your height and weight. Because body composition affects metabolic rate, we will measure your resting metabolic rate during each visit. You will sit in a semi-recumbent chair with a clear canopy placed over your head. You will be asked to rest as much as possible. We will measure the amount of oxygen you breathe in and the amount of carbon dioxide you breathe out with each breath for approximately 20-30 minutes.

In addition, during each visit, you will also be asked to remember what foods and beverages you ate during the previous day. This activity will take about 10-15 minutes. You will be also asked to complete two questionnaires that contain items related to your diet history, hydration, body weight, and other nutrition- and exercise-related topics. It will take approximately 10 minutes to fill out the questionnaires. Lastly, you will be instructed on how to complete a food record and you will be asked to complete a 3-day food record at home. To complete a 3-day food record, you will be asked to write down all foods and beverages you consume within the next 3 days immediately following your visit.

The measurements that will be completed are not medical procedures and no medical diagnoses will be made. However, you will benefit from the study by receiving results of the study through your athletic trainers. The results of these tests will be useful for determining the optimal nutrition for your sport. Your performance may be optimized as a result of this knowledge. If you are a male, there are no known risks associated with this research study which are greater than those ordinarily encountered in daily life. If you are a female, you must not be pregnant while participating in this study. Although the radiation dose from the DEXA scans is very low, there may be some risks to an embryo or fetus, including birth defects. If you become pregnant or suspect that you are pregnant during the course of this study, you will be asked to do a pregnancy test (urine test) prior to having a DEXA scan. If pregnancy is confirmed, you will not be allowed to have the DEXA scan performed, but may participate in the other assessment associated with the study.

We will protect your confidentiality during the project by assigning you an ID number. The list of all names and corresponding 10 numbers will be kept in a locked drawer and only the project leaders will have access to the list. Your measurements will be obtained in a separate room without the presence of other individuals. Any reports we prepare from the study will be for grouped data and no individual will be identified. None of the results of the measurements will be shared with your coach.

The OSU Institutional Review Board has the authority to inspect consent records and data files to assure compliance with approved procedures. The participation in the study is voluntary. If you feel uncomfortable while reporting any information, you can choose not to answer any question, or to withdraw completely from the study at any time. A decision to withdraw from the study will not result in any loss of benefits to which you are otherwise entitled.

If you have questions about the project, please contact Lenka Humenikova at (405) 744-8285 or lenka.humenikova@okstate.edu or Nancy Betts at (405) 744-5040 or nancy.betts@okstate.edu or Brenda Smith at 744-3866 or bjsmith@okstate.edu. If you have any questions about your rights as a research participant, you may contact Dr. Sue Jacobs, Institutional Review Board Chair, 219 Cordell Hall, Oklahoma State University, Stillwater, OK 74078 at (405) 744-1676.

DOCUMENTATION OF INFORMED CONSENT

You are voluntarily making a decision whether or not to participate in the research study. Your signature certifies that you have decided to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

I have read and fully understand the consent form. I, ______________________________(print name), agree to participate in the described research.

_______________________________________   ______________________

Signature   Date

I certify that I have personally explained this document before requesting that the participant sign it.

_______________________________________   ______________________

Signature of PI   Date

APPENDIX F

INFORMATION RELEASE FORM

Your signature certifies that the project leaders have your permission to send the results of your measurements to your team athletic trainer(s) who will then share the results with you. If the measurements collected during the study indicate that you may have any potential nutrition related problems, the project leaders will make nutrition recommendations through your athletic trainer(s) and suggest a referral to your team physician.

I fully understand the information release form. I, ________________________(print name), give permission to the project leaders to share the results of my measurements with my athletic trainer(s).

________________________________ Signature

____________________ Date

APPENDIX G

PARENT/GUARDIAN PERMISSION FORM

Project Title: Body Composition Changes in High School Wrestlers during Pre-season, Season, and Off-season

Project Leaders: Lenka Humenikova, PhD and Nancy Betts, PhD, RD

We are asking your son to participate in a research study conducted by Dr. Lenka Humenikova and Dr. Nancy Betts from the Department of Nutritional Sciences at Oklahoma State University. The main purpose of this research study is to assess body composition (body fat etc.) and resting metabolic rate, and determine whether changes in body composition and resting metabolic rate occur between pre-season, season, and off-season among high school wrestlers. The secondary purpose of this study is to evaluate wrestlers' dietary intakes and eating attitudes, and determine the association between body composition, metabolic rate, and dietary intakes among high school wrestlers.

Your son is being asked to participate in this study because he is a member of the wrestling team. Your son will have his body fat measured, as required by the new regulations from the Oklahoma Secondary School Activities Association (OSSAA), by an assessor designated by the high school wrestling coach/athletic director/principal prior to the wrestling season. Your son's participation in this study is completely voluntary and is not necessary for meeting the OSSAA's requirements.

During this research study, your son will be invited to visit the Department of NutritionalSciences at Oklahoma State University in Stillwater three times (during pre-season, season, and off-season). The length of time your son will be involved in actual measurements will be approximately 1-1.5 hours. However, each of the three visits may take up to 5 hours because several of his teammates may be evaluated during the same visit.

The following measurements will be conducted with your son during <u>each</u> of the three visits.

1. Your son's body composition will be measured using one Dual Energy X-ray Absorptiometry (DEXA) scan. DEXA is currently the most accurate scan that measures body composition and bone density. Your son will be asked to dress in comfortable clothing (we will provide clothing if needed) and he will be asked to remove any metal

that he may be wearing (excluding orthodontic braces). During the scan, your son will lay on an examination table while a machine arm passes over his body. The scan will take approximately 4-5 minutes (to allow for positioning and adjustment, we estimated 10-15 minutes per scan). Your son should feel no discomfort. The X-rays exposure from DEXA is much smaller than exposure from a dental or chest X-ray and is significantly lower than the amount of radiation individuals receive from natural background radiation.

2. Your son's body composition will also be measured using standard skinfold thickness measurements. A trained researcher will measure your son's body fat using calipers in at least three different places on the body (arm, stomach, back etc.). This measurement will take approximately 5 minutes. Before the body composition measurement, we will ask your son to provide a urine sample to evaluate his hydration status and we will measure his height and weight.

3. Because body composition affects metabolic rate, we will measure your son's resting metabolic rate during each visit. Your son will sit in a chair with a clear canopy placed over his head. Your son will be asked to rest as much as possible or even fall asleep. We will simply measure the amount of oxygen he breaths in and the amount of carbon dioxide he breaths out with each breath for 30 minutes.

4. During each visit, your son will also be asked to recall what foods and beverages he ate during the previous day. This activity will take about 10-15 minutes.

5. Lastly, your son will complete a 5-minute questionnaire about his dietary habits and attitudes related to food and weight.

During one of the three visits, your son will have an opportunity to tour the Wrestling Hall of Fame which is located on the OSU campus in Stillwater. In addition, popular movies and refreshments will be offered to your son while measurements are being taken from his teammates during each visit.

You and your son will benefit from the study by receiving results of the DEXA scan, resting metabolic rate, and skinfold thickness measurements. These results will be made available to you and your son within two weeks of each visit. The investigators will place the results of your son's measurements in a sealed envelope and deliver it to your son's wrestling coach within two weeks of each visit. The wrestling coach will be responsible for giving the sealed envelope to your son at school. You and your son will benefit from the study by obtaining specific information on your son's body composition and resting metabolic rate. We strongly encourage you to visit with your son's physician and discuss the results of the measurements with him/her. If requested by you or your son, we will offer individualized nutrition information to your son based on the findings of the study.

The records of this study will be kept private. The written results of this study will only refer to group findings and will not include information that will identify you or your son. Research records will be stored securely and only researchers and individuals responsible for research oversight will have access to the records. It is possible that the consent process and data collection will be observed by research oversight staff responsible for safeguarding the rights and wellbeing of people who participate in research. We will protect confidentiality during the project by assigning an ID number to your son. The list of all names and corresponding ID numbers will be kept in a locked drawer and only the project leaders will have access to the list. Your son's measurements will be obtained in a separate room without the presence of other individuals.

The results of the DEXA scans, resting metabolic measurements, and skinfold thickness measurements will be offered only to you and your son within two weeks of each visit. If any other individual wishes to obtain the results of your son's measurements, they will be required to contact you directly, receive your permission, and obtain those results directly from you.

Participation in the study is voluntary. If your son feels uncomfortable while reporting any information, he can choose not to answer any question, or he can withdraw completely from the study at any time. You have also the right to withdraw the consent for your son at any time by notifying the researchers. Your decision will not result in any loss of benefits to which you or your son is otherwise entitled.

If you have questions about the project, please contact Lenka Humenikova by phone at (405) 744-8285 or by email at lenka.humenikova@okstate.edu or Nancy M. Betts by phone at (405) 744-5040 or by email at nancy.betts@okstate.edu. If you have any questions about your son's rights as a research participant, you may contact Dr. Sue Jacobs, Institutional Review Board Chair, 219 Cordell North, Oklahoma State University, Stillwater, OK 74078 by phone at (405) 744-1676 or by email at irb@okstate.edu.

DOCUMENTATION OF INFORMED CONSENT

You are voluntarily making a decision whether or not to allow your son to participate in the research study. Your signature certifies that you have decided to allow your son to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

Parental Signature for Minor

I understand the risks associated with this study and voluntarily choose to participate. I understand that no funds have been set aside by Oklahoma State University to compensate me in the event of illness or injury."

I have read and fully understand the consent form. As parent or guardian I authorize ____________________________(print name) to participate in the described research.

___________________________ ________________
Signature of Parent/Guardian Date

____

____

I certify that I have personally explained this document before requesting that the participant sign it.

________________________ _______________
Signature of Researcher Date

APPENDIX H

ASSENT SCRIPT AND FORM

Project Title: Body Composition Changes in High School Wrestlers during Pre-season, Season and Off-season

Project Leaders: Lenka Humenikova, PhD and Nancy Betts, PhD, RD

We are conducting this study to measure your body composition and metabolic rate before, during and after the wrestling season. We have asked you to participate because we are conducting a research study involving male adolescent wrestlers and you are a member of the high school wrestling team. Our measurements will also allow us to determine your dietary intake and attitudes about food.

You will be invited to visit the Department of Nutritional Sciences at Oklahoma State University in Stillwater three times (during pre-season, season, and off-season). During each visit, you will be involved in several measurements that will take approximately 1-1.5 hours. If several of your teammates will be measured on the same day, each visit may take up to 5 hours, depending on how many wrestlers will be evaluated on that day.

During each visit, we will ask you to dress comfortably with no metal in your clothes or on you (except for orthodontic braces). To measure your body composition, we will ask you to lay still on an examination table while the body composition machine will scan your whole body. The scan will take about 4-5 minutes. You should feel no pain and you should not experience any discomfort. The scan uses 10 times less X-rays than what you get from a dental x-ray. We will also measure your body fat using skin-fold calipers in at least 3 different places on your body which will take approximately 5 minutes. Before these measurements, we will ask you to provide a urine sample to evaluate your hydration status and we will measure your height and weight. All of these measurements will be conducted one time during each visit (pre-season, season, off-season).

To measure your metabolic rate, we will ask you to sit in a comfortable reclining chair. We will place a clear canopy over your head and ask you to sit quietly or sleep for 30 minutes. This exam measures the amount of oxygen you breathe in and the amount of carbon dioxide you breathe out. You should feel no pain and you should not experience any discomfort. We will measure your resting metabolic rate during each visit.

We will also ask you to recall all foods and beverages you consumed during the previous 24 hours. This activity will take about 10-15 minutes. In addition, you will be asked to complete a 5-minute questionnaire containing questions about your dietary habits and attitudes related to food. We will complete one 24-hour recall with you and you will complete the questionnaire during each visit.

During one of your three visits, you will have an opportunity to tour the Wrestling Hall of Fame on OSU's campus. In addition, we will make arrangements for you to watch movies and enjoy refreshments while your teammates are being measured during each visit. You should feel no pain and you should not experience any discomfort during any of the measurements. You will be able to stop the measurements at any time by asking the attendant.

Your participation is completely voluntary. You have the right to withdraw from the study anytime. If you decide to withdraw from the study, you just need to inform your parents or one of the researchers involved in the study. If you choose not to participate or if you withdraw at any time, it will not affect your relationship with your team, your coach or anyone at the Oklahoma State University. If you have any questions, please feel free to contact Dr. Lenka Humenikova at (405) 744-8285 or Dr. Nancy M. Betts at (405) 744-5040.

By participating you will have a very accurate measure of your body composition (body fat), and resting metabolic rate. Knowing these measurements will help you and your parents/guardians make decisions about weight loss or weight gain for wrestling. You will benefit from the study by learning more about your body composition and metabolic changes during pre-season, season, and off-season.

If you sign this form it means that you have decided to participate and have read everything that is on this form. You and your parents will be given a copy of this form to keep.

Yes, I would like to participate in the study ______________ ____________________

Name (please print) Signature/Date

VITA

Megan Schrader

Candidate for the Degree of

Master of Science

Thesis: A COMPARATIVE ANALYSIS OF DUAL ENERGY X-RAY ABSORPTIOMETRY AND SKINFOLD MEASUREMENTS IN DETERMINING BODY COMPOSITION AND MINIMUM WRESTLING WEIGHT IN ADOLESCENT WRESTLERS

Major Field: Nutritional Sciences

Biographical:

Personal Data: Born in Bakersfield, California, on May 19, 1984, the daughter of Jeff and Collette Schrader.

Education: Graduated from Katy High School, Katy, Texas in May 2002; received Bachelor of Science degree in Nutritional Sciences from Texas A&M University, College Station, Texas in May 2006. Completed the requirements for the Master of Science in Nutritional Sciences at Oklahoma State University, Stillwater, Oklahoma in May 2008.

Experience: Completed the Dietetic Internship at Oklahoma State University in July 2007; passed the registration examination to become a registered dietitian in September 2007; employed by Oklahoma State University, Department of Nutritional Sciences as a graduate teaching assistant from August 2006 to present.

Professional Memberships: American Dietetic Association, Sports, Cardiovascular, and Wellness Nutritionists, Oklahoma Dietetic Association, Kappa Omicron Nu.

Name: Megan Schrader Date of Degree: May, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: A COMPARATIVE ANALYSIS OF DUAL ENERGY X-RAY ABSORPTIOMETRY AND SKINFOLD MEASUREMENTS IN DETERMINING BODY COMPOSITION AND MINIMUM WRESTLING WEIGHT IN ADOLESCENT WRESTLERS

Pages in Study: 72 Candidate for the Degree of Master of Science

Major Field: Nutritional Sciences

Scope and Method of Study: The purpose of this study was to evaluate the accuracy of skinfold measurements as a predictor of body fat in adolescent wrestlers by comparing the sum of three sites with DEXA whole-body scans, using DEXA as the reference model. Secondly, minimum wrestling weights were calculated to assess the practicability of current recommendations. The skinfold measurements were compared across the period of a wrestling season (pre-, in-, and off-season). The sample consisted of 25 male high school wrestlers (mean age=15.4 years) from Enid High School (13 participants) and Stillwater High School (12 participants) who were competing in the 2006-07 wrestling season. Participants were scanned using a Hologic DEXA scanner. Skinfold thickness was measured in millimeters at seven sites (the triceps, subscapular, midaxillary, chest, suprailiac, abdomen, and thigh) with a Lange caliper by a trained assessor. The Lohman 3-site equation was used to calculate body density. Body density was converted to percent body fat using the Brozek equation. Percent body fat from the Lohman equation was compared to DEXA to determine accuracy. Percent body fat from both methods was used to calculate minimum wrestling weight, which was then evaluated for practicability.

Findings and Conclusions: Based on the results of this study, we conclude that skinfold measurements (specifically the Lohman 3-site equation) were not a reliable measure of body composition compared to DEXA due to the inconsistency of the results over time. However, it was unclear whether the inconsistency of the skinfold data was a result of measurement error or a fault in the Lohman anthropometric equation. Therefore, further research needs to be done. Secondly, as evidenced by the significant difference between average weight and the predicted minimum wrestling weight throughout the study, we also conclude that the minimum wrestling weight standard of 7% body fat is an unrealistic, unsustainable recommendation and expectation for adolescent wrestlers. Therefore, the minimum wrestling weight standard should be re-evaluated, and a more realistic minimum weight standard should be established.

ADVISER'S APPROVAL: Dr. Nancy Betts