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Prediction of minimum wrestling weight in adolescent wrestlers by using anthropometric measures

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PREDICTION OF MINIMUM WRESTLING WEIGHT IN ADOLESCENT WRESTLERS BY USING ANTHROPOMETRIC MEASURES

by

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ABSTRACT

Fifty-five wrestlers from Tucson, Arizona were studied to develop equations using anthropometric measurements to predict a wrestler's minimum wrestling weight (MWW). This sample was also used to cross-validate seven equations that predict MWW by using anthropometric measures. All estimates of percent fat and MWW were validated by densitometry. The mean age, weight, percent fat and MWW for this sample, with standard deviations, were 16.8 $\pm$ 1.1 yrs, 63.7 $\pm$ 12.7 kg, 8.8 $\pm$ 5.49 percent, and 60.6 $\pm$ 9.49 kg. Using multiple regression analysis, the best combination of variables predicted MWW with an adjusted R^2 of .93 and standard error of estimate (SEE) of 2.45 kg. The next best equation from this sample predicted MWW with an adjusted R^2 of .91 and SEE of 2.8 kg. All seven of the equations from other samples were successfully cross validated on this sample. These equations predicted the criterion MWW with respective adjusted R^2's and SEE's ranging from .91 and 2.84 kg to .79 and 4.28 kg.

CHAPTER I

INTRODUCTION

Scientists and health practitioners have directed a considerable amount of effort toward alleviating the potentially unhealthy weight loss methods that are practiced commonly among wrestlers. The problems of weight loss techniques used commonly by adolescent wrestlers have been addressed by the medical community and numerous professional organizations. These include the American Medical Association, Alaskan Medical Society, Iowa Medical Society, N.C. Medical Society, Pennsylvania Medical Society, and the American College of Sports Medicine (5, 6, 7, 24, 26, 28, 43, 73). The most eagerly pursued solution to the problem of hazardous weight loss among wrestlers involves establishing a baseline limit of weight loss that would be allowed for any wrestler. Wrestlers would then be individually assessed and, by following a standardized protocol, their maximum allowable weight loss could be determined. The American College of Sports Medicine (ACSM) has taken the position that no wrestler should be allowed to lose an amount of weight that would result in a body composition that includes less than five percent body fat

(4). This has been termed a wrestler's minimum wrestling weight (MWW) and has been accepted as the baseline limit of weight loss for adolescent wrestlers (4).

It has been proposed that anthropometric measurements may be used in regression equations to predict MWW. Cureton and McCloy were among the first researchers to use regression equations based upon anthropometric variables to predict the physical characteristics in a sample (20, 40). Over a twenty year period, beginning in the 1940's, Hall used anthropometric measures in regression equations to estimate the optimal weight of large numbers of 4-H Club members (67). Tcheng and Tipton, the first researchers to investigate a means of assessing MWW, tested the accuracy of the Hall equation as a means of predicting MWW in a sample of wrestlers (67). From Tipton and Tcheng's study it became evident that regression equations based upon anthropometric variables might be applicable for predicting MWW. However, they concluded that new regression equations needed to be developed from samples of wrestlers and specifically for the purpose of predicting MWW. Several subsequent studies have been conducted to isolate the best combinations of anthropometric variables to use in regression equations for predicting MWW (14, 23, 24, 26, 33, 41, 44, 49, 56, 62, 63, 64, 65, 68) . In general, these studies have yielded regression equations that can predict MWW in a sample of wrestlers with a standard error of estimate (SEE) near 4.0 kg. Unfortunately, the equations that have been developed exhibit too much variability for predicting MWW to be accepted as a suitable means of assessing MWW in a certification process. Furthermore, only a few of these equations have been cross validated on other samples of wrestlers.

Purpose

The purpose of this study was to develop regression equations using anthropometric variables to predict minimal wrestling weight (MWW) in a sample of wrestlers from Tucson, Arizona. In addition, this sample was used to cross validate regression equations previously developed for predicting MWW based upon anthropometric measures.

It was hypothesized that MWW prediction equations derived from this sample of wrestlers from Tucson should yield correlation coefficients and standard errors of estimate (SEE) similar to those found in equations that have been published previously. Within this population, it was hypothesized that inclusion of a combination of skinfold and selected circumference measures in MWW prediction equations should decrease the SEE compared to equations using only skeletal measures. Finally, it was hypothesized that several previously published MWW prediction equations would be successfully cross validated on this sample.

Scope

Fifty-five, 12-18 year old wrestlers from five Tucson high schools were measured during the 1985-1986 wrestling season. All data were collected within a one and one-half month period with data from four of the five schools being collected within a seven day period. Height, weight, age, skinfolds, skeletal widths, limb circumferences and densitometric data were collected by the same investigators using the same instruments and apparatus. The sample was heterogeneous with respect to age, body weight, and level of success in wrestling.

Limitations

Body density and ultimately MWW values that were used as the criterion for comparison in this study were assumed to represent actual values within the accuracy of the densitometric technique. Since normal state of hydration and bone mineral content were assumed for these subjects, variations in total body water and bone mineral content may have limited the accuracy of body composition estimates from densitometry.

Because standardized techniques were used to obtain anthropometric measures, it was assumed that MWW prediction equations developed from other samples could be cross validated on this sample. However, failure to successfully cross validate other equations may, in part, be due to methodological factors.

The sample was comprised of 55 subjects from High Schools in Tucson, Arizona. Development of regression equations that may be generalizable to other samples was limited by the small size of this sample.

Definition of Terms

The following definitions of terms are used throughout the text.

Environment independent zone - the temperature range of the environment within which exercise can be performed without the environment adversely affecting the body's thermoregulatory mechanisms.

Essential fat - the portion of fat that is contained in cell membranes, as integral parts of functional organs.

Fat-free body - total body weight less total fat weight, i.e., essential and nonessential fat.

Lean body mass - total body weight less non-essential fat or fat-free body mass plus essential fat.

Minimum wrestling weight - the lowest body weight a wrestler in a normal state of hydration could obtain and be eligible to participate. At this weight the wrestler can have no less than five percent body fat.

Non-essential fat - fat generally stored in depots below the skin, in muscle, and around organs that is not essential to life.

Percent fat - the total of essential and non-essential fat given as a percentage of total body weight.

Physical work capacity 170 (PWC 170) - the intensity of exercise an individual can achieve without exceeding a heart rate of 170 beats per minute.

CHAPTER II

REVIEW of the LITERATURE

Wrestlers may use one or more methods to lose weight. The various weight loss techniques used among wrestlers have been studied from four main perspectives: (1) specific changes in physiologic parameters induced by the weight loss technique, (2) the effect various weight loss techniques have upon indices of performance such as cardiovascular function, exercise endurance, and oxygen uptake at various intensities and durations of exercise, (3) descriptive information on weight loss in the wrestling sample, the prevalence of various modes of weight loss used by wrestlers and the information sources from which wrestlers derive their knowledge about weight loss, (4) the direct effects that these weight loss techniques may have on the health of wrestlers.

Dehydration

The predominant form of weight loss among wrestlers is dehydration (3, 10, 13, 24, 26, 30, 43, 47, 50, 70, 74, 76, 77, 78). Dehydration is preferred among wrestlers because substantial quantities of weight can be lost rapidly and with relative ease in comparison to weight loss obtained through a well-planned diet and exercise program. For example, a 125 pound wrestler planning to wrestle at 120 pounds can begin dehydrating the day before competition and lose five pounds or four percent of his body weight--an amount of rapid weight loss that is common among wrestlers (68). In contrast, the same wrestler would need to start regulating his diet one to two weeks before the wrestling match in order to lose five pounds.

Dehydration is a method of weight loss accomplished by depleting the body fluid levels below normal values. Body fluids constitute approximately 64% of total body weight are stored in intracellular, intravascular and interstitial fluid compartments (39). Intracellular fluid is that which is contained within the cells, intravascular fluid is contained in the vascular system and interstitial fluid accounts for fluid not contained in cells or the vascular system (39).

The proportion of fluids lost from each of the fluid compartments appears to vary depending upon the method, extent, and interaction of the dehydration techniques used. Measuring fluid changes in each of the fluid compartments and determining the effects of a single contributor to total dehydration when combinations of dehydration methods are used is difficult.

Wrestlers may use either one method or combine several methods to dehydrate. The general practice involves restriction of fluid intake, exposure to a hot environment and exercise. The hot environment may be inside a suana, steam-room or hot bath. Rubber suits or layers of clothing may also be worn to increase the temperature and humidity around the body. Some wrestlers may also use diuretics for dehydration purposes (68). Although these methods of dehydration may be effective for losing weight rapidly and "easily," they warrant scrutiny in terms of health and performance-related effects.

The ingestion of diuretics sufficient to cause a two percent reduction in body weight will reduce plasma volume (PV) by seven to fourteen percent (7, 13). Dehydrating the body 5.8% by moderate exercise in a hot environment results in a 13.7 decrease in PV, a 14.5% decrease in interstitial fluids, a 6.5% decrease in intracellular fluid volume and a 9.1% change in total body water (TBW) when the normal fluid volumes of each of the spaces were estimated to be 3.4, 11.0, 28.9, and 43.4 liters respectively (18). With a four percent change in body weight from dehydration, by sitting in a hot environment, PV is reduced 10% to 13% or 0.42 liters on the average; the remaining loss of about 2.5 liters must come from other fluid spaces (13, 19, 55, 72). In contrast, a rapid weight loss of four percent induced solely by physical activity, does not decrease PV significantly (13).

In summary, when physical activity is used as the sole means of dehydrating, PV is not significantly affected and most of the fluid loss is from the intracellular and intercellular spaces. Dehydration of two to four percent through the use of diuretics reduces PV 7%-14%, but the majority of fluid is lost from the other fluid compartments. Dehydration of four percent by exposure to a hot environment will reduce PV 10%-13%, but the majority of water loss is from other fluid spaces. Dehydration due to four days of fluid and caloric restriction leads to an 11% decrease in PV (16).

Thermoregulation

Reductions in fluid volume are known to compromise the body's thermoregulatory mechanisms. Of particular concern are those occasions when wrestlers are dehydrated and exercising in a hot/humid environment. Being homeotherms, humans continuously generate heat. Our ability to survive during periods of thermal stress, e.g., severe exercise and/or exposure to a hot humid environment, depends primarily upon physiologic adjustments affected by a well-developed control system that regulates body temperature and protects tissues from overheating (49). Under conditions of heat stress, heat must be dissipated from the body by conduction, convection, radiation and/or evaporation. Environmental factors such as temperature, humidity, radiative heat and air flow may alter the effectiveness of the body's heat exchange mechanisms. Furthermore, biologic variations, such as the amount of fluid available for evaporative heat loss or the integrity of the cardiovascular system also can alter the effectiveness of the body's heat-exchange mechanisms. The heat balance equation explains the relationship of heat generated by the body and the transfer of heat from the body to the surrounding environment. The heat balance equation is given as $M \pm R \pm C \pm E \pm S = 0$, where: S is heat storage or loss, M is metabolic heat production, R is the heat lost or gained by radiation, C is the loss or gain of heat by conduction and convection, and E is the heat loss by evaporation of water.

At rest in a thermoneutral environment, most of the metabolic heat (65%) is dissipated by radiation. During exercise in a thermoneutral environment, evaporative heat loss is the major (70%) contributor to heat dissipation. In hot, humid environments the ability to dissipate heat by evaporation is impaired, and heat may be added to the body from radiation, conduction and convection. When exercising in a hot humid environment, metabolic heat may be stored in proportion to the intensity of exercise.

The thermoregulatory mechanisms of heat dissipation are compromised in a hot and/or humid environment. This holds true when the subject is in a normally hydrated state. When a subject is dehydrated, the mechanisms of heat dissipation are compromised even more. When a normally hydrated subject exercises in the environment-independent zone metabolically generated heat can be readily dissipated. However, in a dehydrated state, the thermoregulatory mechanisms of heat dissipation may be severely compromised during exercise in the environment-independent zone. Dehydration adversely affects the body's ability regulate core temperature. In an environment-independent bout of exercise, core temperature increases 0.3 to 0.4 degrees ^{o}C with dehydration of one percent of total body weight (21), and 0.5 ^{o}C with five percent dehydration (27). Core temperature has been found to increase 0.94 ^{o}C for each percent of TBW loss with exercise (39). These findings show that dehydration increases the body's heat storage rate and attenuates the mechanisms of heat dissipation. They also suggest that dehydration impairs the body's heat transfer ability, particularly by decreasing evaporative heat loss through sweating.

Sweat rate decreases during prolonged exercise in a dehydrated state (21, 27), stops completely at the onset of heat stroke (2). The proposed mechanisms of this decrease in sweat rate include: (1) an inadequate volume of interstitial fluid to supply the needs of sweat glands, (2) inhibition in the transfer of interstitial fluid to sweat glands due to increased interstitial fluid osmotic pressure, (3) possible interruption of the energy generating process in the formation of sweat, (4) impairment of stimuli, central and/or local, to the glands for discharge of sweat, (5) a decrease in osmotic gradient between the sweat gland and skin. Mechanisms 2 and 5 are thought to be the most likely choices (21, 22). In hot and humid environments such as inside a suana, steam-room or when a rubber suit is worn, the cooling effect caused by the evaporation of sweat is minimized, regardless of the subjects state of hydration. Humid air has a high moisture content which limits the amount of evaporation that can occur. In humid environments evaporation may be eliminated as a functional means of thermoregulation. In a sufficiently hot and humid environment conduction, convection, and radiation may transfer environmental heat to the body instead of dissipating metabolic heat.

The risk of heat trauma increases with the duration and intensity of exercise performed in a hot and/or humid environment (49). During hot and/or humid conditions metabolic heat cannot be adequately transferred from the body to the environment. In this situation, an increase in heat storage occurs, which is indicated by an increase in core temperature. An increase in core temperature of five degrees celsius can result in severe thermal distress (2).

The metabolic heat generated during vigorous exercise is enough to raise core temperature one ^{o}C every five minutes if it is not dissipated (39). Considering the effects of dehydration, exercise, and environment, it is evident that wrestlers who dehydrate by exercise in humid and/or hot environments may be at risk of experiencing thermal distress (49).

Urinary profiles

Studies of the urinary profiles immediately before competition verify that many of the wrestlers were dehydrated and some of them had been restricting caloric intake (76, 77, 78). An unexplained finding from these urinary studies was an elevation in urinary potassium levels of up to three times the amount found for non-wrestlers; a concomitant increase in leucine amino peptidase (LAP) has also been reported (77, 78). It has been proposed that acute renal ischemia may be occurring in wrestlers since total renal plasma flow is known to decrease with exercise and dehydration (46). Also, urinary potassium and LAP activity are known to increase in patients with renal ischemia (78). Unfortunately, this hypothesis has not been sufficiently tested. However, if renal ischemia is occurring, serious questions need to be addressed because a successful wrestler may dehydrate 200 times throughout high school and college. It is unknown and uncertain if pathologic changes in the kidneys of some of these wrestlers will occur with time.

Another finding from these urinary studies was increased levels of proteins and ketone bodies. This leads to the conclusion that the wrestlers had exercised vigorously and/or had restricted caloric intake before competition (77). Adding credence to this conclusion, from another sample of wrestlers, over a four month period during the season the average sum of six skinfold sites dropped from 58 mm to 37 mm and body weight decreased by six percent indicating that the wrestlers were experiencing a negative caloric balance and also a loss of lean body mass and fat (78). These findings are not surprising in the light of a previous study that evaluated the methods of weight loss used by 747 wrestlers. In the sample studied, 38% of the subjects used some caloric restriction, 32% used caloric restriction often and four percent used caloric restriction all of the time (68). In the same sample, exercise was used to lose weight "a little" by 24% of the subjects, "sometimes" by 22%, "often" by 32% and "always" by fourteen percent (68).

Caloric restriction is a common means of weight loss practiced by wrestlers. The two primary concerns with this practice are whether the wrestlers are meeting their nutritional requirements and how wrestlers determine the amount of weight they will lose. These questions are valid since wrestlers seldom consult the family physician or parents about their dietary goals or nutritional needs (70). Information on the methods of weight loss practiced by wrestlers, the extent of weight loss, and the general lack of knowledge of proper weight loss methods adds credence to the supposition that some wrestlers may be jeopardizing their performance and health.

Performance and weight control

Unequivocal evidence exists that dehydration, regardless of how it is achieved, impairs endurance on a graded exercise test (7, 13, 19, 30, 31, 47, 53, 72). Specifically, exercise time to exhaustion decreases, or time to complete an absolute task increases, when compared to a hydrated state (7, 13, 53, 54). Other studies of the effect of dehydration on performance as measured by the peak exercise performed at a given heart rate (HR), i.e. PWC 170, indicate that less exercise can be performed at a particular HR in the dehydrated versus hydrated state (3, 19, 27, 30, 47). Heart rate is elevated for a given workload and the HR to oxygen uptake curve is shifted upward in the dehydrated state. Because dehydration elevates HR for a given oxygen uptake, tests using HR as the criterion for exercise capacity may be inappropriate, particularly since maximal oxygen uptake does not seem to be affected by dehydration (7, 19, 53, 54).

It has been proposed that post-dehydration HR increases inversely to the reduction in PV (16, 54), but factors aside from decreased PV seem to affect HR in the dehydrated state. With rehydration, HR returns to normal during exercise although PV is still decreased eight to eleven percent (19). Although the mechanism is not completely understood, dehydration will cause a decrease in endurance at a given intensity of exercise.

The information on the effects of dehydration upon anaerobic work capacity, muscular strength and muscular endurance is unclear, and the results of studies are often contradictory. Research in this area is characterized by a lack of standardization with respect to muscles isolated and the exercise testing regimes. Four studies (3, 10, 53, 55) show no decrease in maximal isometric strength or endurance with dehydration while three studies (16, 53, 72) showed decreases in isotonic and isometric endurance of isolated muscle groups.

Caloric restriction

Although rapid weight loss from dehydration is most common among wrestlers, long term caloric restriction is also a means of weight loss used by some wrestlers. Wrestlers should be cautious when using prolonged caloric restriction as a means of weight loss. Along with the various nutritional concerns, caloric restriction can exaggerate the effects of dehydration (5). Since nutritional needs are known to peak during adolescence, it has been speculated that a failure to meet these nutritional needs may impair growth (12, 29, 38, 59, 73). Unfortunately, most wrestlers lack the knowledge and fail to seek professional guidance on proper weight loss techniques. Many wrestlers restrict calories as a means of losing weight to gain a position on the team instead of striving to attain an optimal body weight for competition. Considering the arbitrary selection of a target weight, the lack of skilled guidance in weight loss programs, the elevated nutritional needs of adolescents, and that participation in sports is secondary to health and education it is apparent that caloric restriction among wrestlers, in some cases, may be excessive.

The maximal velocity in linear growth occurs at age fourteen and remains elevated for several years afterwards (38). This period of rapid growth explains the increased nutritional needs of adolescents. Adolescent athletes have greater nutritional needs than non-athletes and failure to meet them may retard growth and delay sexual maturity (10, 29, 38). As a sub-population, wrestlers do not follow the normal growth curve during the season (24, 52). Freischlag found that a group of 104 wrestlers lost an average of four percent of their body weight during the wrestling season while 74 age matched controls gained about five percent body weight during the same season (24). Another study comparing the physical dimensions of wrestlers and controls found that the average body weight of the wrestlers was four kilograms less than that of the controls, and that the controls had an average of seven percent more body fat (52).

Weight loss by caloric restriction has been shown to decrease prolactin levels, testosterone levels, and percent body fat in wrestlers during the wrestling season (60). A relationship seems to exist between percent fat and reproductive hormone levels. In a group of subjects with less than five percent body fat, serum testosterone levels were found to be less than those normally expected (60). Evidently, inadequate nutrient intake may contribute to these low serum testosterone levels.

The typical standards used in prescribing weight loss for adults do not apply to adolescent athletes (68). Adults are generally instructed to maintain a 1200 Kcal per day diet which will provide enough nutrients and energy to meet their cellular maintenance and basal metabolic requirements. Because adolescents typically have higher metabolic rates, are experiencing rapid growth, have higher physical activity levels, and greater nutrient requirements than adults, a 45 kg adolescent requires in excess of 1500 Kcal per day to satisfy nutrient and basal energy requirements (12). The average caloric intake for a 16 year old male is approximately 3470 Kcal per day (38). Any diet providing less than 1500 Kcal per day may compromise the wrestler's nutritional and health status.

Nutritional deficiencies are more likely to occur as the proportion of calories coming from nutrient poor foods increases. In an effort to characterize the effect of nutrient poor snack-foods upon the nutritional status of American youth, it has been stated that American youth are overfed and undernourished (38). When wrestlers restrict caloric intake, it is essential for them to understand their nutritional requirements and the dietary means of meeting these requirements. Although a wrestler may experience strong pressure to lose weight, maintaining an adequate nutrient intake and a normal growth pattern is desireable (12, 17, 29, 38, 59).

When an individual decides to participate in wrestling, the possibility of failure at two levels must be faced: (1) failure to earn a position on the team, (2) failure to be successful at the sport (58). To some wrestlers, the pressure to succeed at either of these levels may be sufficient to create an obsessive behavior toward losing weight (58). The degree of weight loss documented in some wrestlers is sufficient to satisfy the major diagnostic criteria of anorexia nervosa. Some of these starving athletes may experience extreme feelings of guilt after eating, and binge eating may occur at the end of the season (58).

Performance and caloric restriction

One concern is the effect of caloric restriction upon mental health and academic performance. Because direct studies of this nature would be impractical, most of the information specific to wrestlers is anecdotal. Athletes have indicated that it was often difficult to concentrate on course-work or channel mental energy to tasks not related to wrestling (50, 58). A short term study investigating the effects of a five day weight loss program found that anxiety actually decreased following weight loss (42). Another study found that wrestlers in the lower weight classes experienced a significant decrease ($p \leq .001$) in emotional stability, and wrestlers in the upper weight classes experienced a significant ($p \leq .001$) decline in energy levels during the wrestling season when comparisons were made on the basis of weight classes (24). However, compared to controls, the wrestlers in this sample did not differ on the basis of frequency of illnesses (24). Because there is a lack of population specific studies on this topic, the results from the Minnesota Starvation Study (MSS) may be the best source of information available on the effects of caloric restriction (34). As semi-starvation progressed in the MSS, the subjects complained of an inability to concentrate for any period of time and the process of developing thoughts became exceedingly difficult (34). This supports the anecdotal evidence available from wrestlers. Toward the end of the MSS study, a large proportion of the men felt their judgement had been impaired and that their general alertness and concentration had declined (34).

Other changes that have been noted in semi-starvation that may affect health or performance are (15, 31, 61): (1) a decrease in basal metabolic rate, (2) a decreased in respiratory quotient, (3) decreased ventilatory rates during submaximal exercise, (4) a slowing of HR by 10-15 beats per minute, (5) abnormalities in the QRS complex of the electrocardiogram, (6) a negative water balance of one-half a liter per day, (7) failure of a 580 Kcal per day diet to maintain blood glucose levels, (8) a marked reduction of maximal oxygen uptake, (9) a decrease in grip strength when 10% of total body weight was lost, (10) increased feelings of fatigue at rest and during exercise, along with a feeling of dizziness when rising from a chair.

Minimum Wrestling Weight

By definition, this is a body weight that is comprised of no less than five percent fat. In a more general sense, it would be the lowest weight at which a wrestler could be eligible to wrestle. As proposed by Behnke, the fat contained within the body can separated into two categories, e.g., essential fat or non-essential fat. The names are descriptive because the body cannot function without maintaining essential fat levels. Essential fat is the portion that is included in the structure of cell membranes, organs, and biochemicals. It has been accepted that approximately three percent of the body is comprised of essential fat. Non-essential fat is generally stored in depots below the skin, in muscle, and around organs; and it is not required for the body to function.

The American College of Sports Medicine has issued a position stand which states that no wrestler should be allowed to wrestle with less than five percent fat, unless medical clearance is granted (4). Establishing five percent fat as the guideline for determining MWW involved considering Behnke's work, the weight loss practices of wrestlers, and the health of wrestlers. In a sense, the five percent fat requirement is arbitrary. However, at least three percent of the body's fat content is essential, and descriptive studies of successful wrestlers have shown that this healthy and competitive group maintains, on the average, about five percent fat (52, 63, 68).

Prediction of MWW by anthropometry

The concept of using anthropometric measures in regression equations to predict a physical characteristic of subjects from a population is not new. As early as 1936 Cureton and McCloy had completed the enormous task of hand calculating the regression coefficients of anthropometric variables to be used in a prediction equation (20, 40). By 1968, Hall had used anthropometric variables in regression equations to predict the optimal weight of 30,000-40,000 4-H Club members (67). The Hall method for predicting optimal weight was revised during the twenty year period of its use preceding 1968.

Because the Hall equation required using only five anthropometric measures, i.e., chest depth, chest width, hip width, height, and thigh circumference, its applicability for use on wrestlers was studied (67). In the sample studied, the predicted weights for wrestlers below 155 pounds tended to be higher than the actual weights by one to six percent. For wrestlers above 155 pounds, the predicted weights were, on the average, lower than the actual weights. These results indicated that wrestlers, as a group, may have different physical characteristics than the population from which the Hall prediction equations were derived. Also, because the accuracy of the equation varied substantially throughout the range of weight classes, it was concluded that a regression equation developed for the purpose of predicting optimal weight in a diverse population was not suitable for predicting MWW in a specific sample. It was also concluded that equations with less variability needed to be developed.

The physical characteristics of the wrestling population have been shown to differ significantly when compared to a general population of a similar age (24, 51, 52). When the wrestling population is categorized and compared on the basis of success in post-season competition, successful wrestlers have been found to have different physical characteristics than the unsuccessful wrestlers (33, 44, 56, 62, 63). Consequently, anthropometric prediction equations that are developed from samples of wrestlers, and perhaps from sub-groups of the wrestling sample, would be expected to predict body density and MWW among wrestlers with a lower standard error of estimate than would equations developed from other populations (8, 23, 33, 37, 56, 65). Prediction of body composition has been enhanced in other populations when circumferences, skeletal widths and skinfolds are used in the prediction equations (9, 45). This has not been conclusively demonstrated in the wrestling population for equations that predict MWW.

Anthropometric measures, e.g., skeletal widths, skinfold thickness and limb circumferences stay constant in comparison to weight under conditions of dehydration and rapid weight loss. Therefore, using anthropometric measures to determine MWW would make it difficult to "beat" the system. Presently a wrestler can attain a "false" body weight by dehydrating before certification. Using an anthropometrically based criterion for certification could eliminate this practice, since dehydrating would not affect the wrestler's certified weight; assuming the wrestler did not dehydrate to attain his MWW before competition.

Based upon the results from using the Hall equation on wrestlers, the considerations mentioned in the previous paragraphs, and growing support from the medical community, the desire to develop scientifically-based equations for use in certifying wrestlers has increased, as evidenced by the number of articles published on related topics since then. Typically, equations for predicting MWW have been developed from large samples. One of the landmark studies, deriving MWW prediction equations from a large sample, evaluated state finalists in Iowa between 1968 and 1971 (63). In this study it was assumed that state finalists would have body weights and percentages of fat representative of the lower limit that could be achieved while remaining successful. A correlation between actual and predicted MWW of r=.93 and a SEE of 3.7 kg was found (44). In another important study, samples of wrestlers from five states were studied (62). This study included MWW calculated from body density measurements as the criterion for comparison of MWW calculated from anthropometric measures. The equations that were developed have not been published yet, but they were made available for cross validation in this study (62).

Oppliger and Tipton published a MWW prediction equation in 1985 that had a correlation with actual MWW of r = 0.93 (44). However, the reported SEE of 4.0 kg for this equation is not optimal for widespread use. In contrast, within a specific population, prediction equations using skinfold values can generally estimate FFB with SEE's of two to three kilograms and percent fat can be estimated with a SEE of three to four percent (37).

A large amount of energy has been directed toward establishing the use of anthropometry as a workable method of estimating MWW in samples of wrestlers. While reviewing the products of this effort two points have become evident: (1) existing anthropometric regression equations for predicting MWW exhibit SEE's of a magnitude which are not ideal, (2) cross validation studies using these regression equations have been limited. This study was undertaken to develop regression equations for predicting MWW on a sample of wrestlers from Tucson and to cross validate seven regression equations selected from the literature.

CHAPTER III

METHODOLOGY

The purpose of this study was to develop multiple regression equations for predicting minimum wrestling weight (MWW) from anthropometric measures using a sample of high school wrestlers. Another aspect of this study was to cross validate anthropometric equations that predict MWW developed from other samples of wrestlers.

Fifty-five, 12 to 18 year old male wrestlers from five high schools in Tucson, Arizona were measured during the second half of the 1985-1986 wrestling season. All data were collected within a one-and-one-half month period and data from four of the five schools was collected within a seven day period. Standing height, body density, seven skinfolds, four circumferences and ten skeletal widths were assessed for each subject with four trained testers performing the same procedures.

The mean age of the sample was 16.8 years with a standard deviation (S) = 1.1. The mean weight of the sample was 63.7 kg S = 12.7. The sample distributions for age and weight, respectively, were: 12-13 yrs (n=1), 14-15 yrs (n=1), 15-16 yrs (n=6), 16-17 yrs (n=22), 17-18 yrs (n=18), 18-19 yrs(n=7), and 30-40 kg (n=1), 40-50 kg (n=4), 50-60 kg (n=20), 60-70 kg (n=15), 70-80 kg (n=9), 80-90 kg (n=5), 110-115 kg (n=1).

Body density

Underwater weight was measured in a modified hot tub using a Chatillon scale that was accurate to .005 kg. Subjects were weighed in a seated position following full immersion and expiration of air. Ten trials were recorded for each subject and the three highest weights were averaged. Body density was calculated from underwater weight using the following equation (11):

Body density = $(BW_{air} - BW_{water})/D_{water} - V_R + G_I$

where: BW_{air} is body weight in air

BW_{water} is body weight during complete submersion in water after a full exhalation

D_{water} is the density of water

V_R is the functional pulmonary residual volume at the time of underwater weighing

V_{GI} is a constant of 100 ml estimated to be the volume of gas trapped in the gastrointestinal tract.

Functional pulmonary residual volume was determined by the nitrogen dilution technique using a Hewlett-Packard nitrogen analyzer. The functional pulmonary residual volume represents the volume of air remaining in the lungs during underwater weighing. Residual volume (BTPS) was calculated according to the following equation:

$$V_R = [(\dot{V}O_2(EN_2 - IN_2) / (AiN_2 - AfN_2) - DS] \times \text{BTPS factor}$$

where: V_R is residual volume (BTPS)

$\dot{V}O_2$ is the initial volume of O_2 in spirometer system including dead space

EN_2 is the N_2 fraction at equilibrium

IN_2 is the N_2 fraction of initial VO_2

AiN_2 is the N_2 fraction in alveolar air when breathing room air

AfN_2 is the N_2 fraction in alveolar air when breathing room air

DS is the dead-space of the system

Minimum wrestling weight calculations

To predict percent fat and FFB for this sample, the expected FFB density value of 1.096 gm/cc was used as the constant for FFB density (35). The equation used to estimate percent fat in this population, using the expected density value for FFB, was:

$$\%fat = 503/\text{body density} - 459.$$

If too high a constant for FFB density were used, an over prediction of fat content would occur. MWW prediction equations generated on a population of this age must use the proper constant for FFB otherwise MWW will also be overestimated. Hence, a wrestler may be encouraged to lose an inappropriate amount of weight (35).

To develop MWW prediction equations from this sample and cross validate existing equations, the criterion MWW was calculated using body density measurements. First, percent fat was determined from body density using the modified Siri equation (57):

$$\%fat = 503/\text{body density} - 459.$$

Next, FFB was calculated for each subject with the following equation:

$$FFB = Weight - Weight \times (\%fat / 100).$$

Finally, MWW was calculated as:

$$MWW = 1.05 \times FFB.$$

Minimum wrestling weight, calculated from body density values and the preceding equations, was used as the criterion MWW for all comparisons.

Anthropometry

Standardized procedures outlined in the "Inter-University Research Project for Estimation of Minimal Weight in High School Wrestlers from Anthropometric Dimensions" were followed in this study to facilitate a meaningful cross validation (62). Investigators conducting research in this area are encouraged to use these standardized measures. Standardization of methodology will enhance the ability of researchers to compare the results of studies and conduct cross validation studies.

Standing height was measured with subjects standing maximally erect with heels together against a wall mounted stadiometer. Hands were placed upon the hips, thumb and index finger in superior position directly posteriorly and anteriorly respectively. The head was held in the Frankfurt plane, the eyes and nose directed straight forward and, at maximal inspiration, height was recorded. Three trials were performed on each subject and the average value of the trials was used for calculations.

Skeletal widths

Chest width, chest depth, bitrochanteric width, and bi-iliac width were measured with a Martin type Anthropometer manufactured by GPM and accurate to 0.5 mm. Elbow, wrist, knee and ankle widths were measured using a spreading caliper with rounded ends, also manufactured by GPM and accurate to 0.5 mm. Each site was measured three times and the mean value was used for calculations.

Chest width was measured with the subject standing erect and both arms were abducted slightly for placement of the Anthropometer. The thin edges of the Anthropometer were placed in the axillary region with the ends being placed on the second or third rib. The subject was instructed to continue breathing normally and the measurement was taken at the end of a normal expiration.

Chest depth was measured with the subject standing with the right arm abducted and right hand behind the head. One blade of the anthropometer was place on the tip of the xiphoid process while the other was placed over the vertebra of the twelfth rib. The measurement was taken at the end of a normal expiration. Hip width was measured with the subject standing erect, back to the examiner and body weight evenly distributed on both feet. The iliac crests were palpated and the blade ends of the anthropometer were placed on the lateral sides of the crests at the point resulting in the greatest width. The Anthropometer was held with the ends pointing slightly upward.

Bitrochanter width was measured as the distance between the most lateral projections of the greater trochanter. The subject stood with feet spaced six inches apart and weight evenly distributed between feet.

Wrist widths (right and left) were measured with the subject in a standing position, the right arm pronated and the elbow flexed to form a right angle. The width was measured across the styloid processes, oblique to the long axis of the arm. The procedure was repeated on the left arm.

Elbow width was measured with the subject in a standing position and the supinated arm raised forward to approximately the level of the shoulder joint. The elbow was then flexed to form a right angle. The most lateral points on the distal end of the humerus were palpated and the ends of the caliper were applied against these points so that the plane of the caliper bisected the angle of the elbow joint.

Knee width was measured from a standing position and the subject placed the right foot on a bench forming a right angle at the knee--the thigh horizontal and the leg vertical. The most lateral points on the distal end of the femur were palpated and the ends of the caliper were applied against these points so that the plane of the caliper bisected the angle of the knee joint.

Ankle widths (left and right) were measured while the subject's foot was placed on a bench with a right angle existing between the thigh and the heel. The caliper ends were placed on the internal and external malleolus at the angle of 45°--between the sole of the foot and the caliper. The procedure was repeated on the left foot.

Circumferences

All circumference measurements were taken on the right side of the body using a retractable, laminated cloth tape accurate to 0.5 mm. The tape was carefully positioned in a horizontal plane or at right angles to the length of the segments. Sufficient tension was applied for the tape to be in continuous contact with the skin but not depressing it. Care was taken to avoid allowing the fingers holding the tape to be allowed in the measurements.

Upper arm (contracted) circumference was measured with the subject standing erect and flexing the right elbow until the thumb touched the acromion process of the shoulder. The tape measure was positioned around the brachium and the subject was then asked to clench the fist and contract the biceps as strongly as possible. The tape measure was then repositioned so that the measurement was perpendicular to the long axis of the brachium at the location of maximal circumference.

Forearm circumference was measured with the subjects' elbow flexed at a 90^{o} angle, with the forearm parallel to the floor, the hand supinated, and the fist clenched. The biceps were relaxed and the measurement was taken immediately distal to the elbow joint, at the maximal girth.

Middle thigh circumference was measured with the subject standing erect and feet slightly apart with the weight evenly distributed. The tape was placed horizontally, midway between the trochanterium and the proximal border of the patella on the anterior of the thigh. The musculature of the thigh was relaxed.

Calf circumference was measured with the subject standing erect with the feet slightly separated and the weight evenly distributed on both feet. The horizontal circumference of the calf was taken at the level of maximal girth.

Skinfolds

Skinfold measurements were taken using an Harpenden caliper accurate to 0.5 mm. The sites were marked and each site was measured three times in a rotation sequence. A fold of skin and subcutaneous fat was taken with the thumb and index finger. The caliper was placed one half of an inch from the tip of the fingers and a reading was taken two seconds after caliper pressure was applied.

Triceps (upper arm) skinfold was taken vertically midway between the olecranon and acromion processes on the posterior of the brachium. The subjects were instructed to bend their arm before the midpoint was located. The skinfold was picked up one centimeter above the midpoint and the measurement was taken at the midpoint with arm extended.

Subscapular skinfold was measured one centimeter below the inferior angle of the right scapula, inclined downward and laterally in the natural cleavage of the skin. The subject stood erect with arms relaxed at the sides of the body.

The chest skinfold was taken diagonally between the shoulder and opposite the hip--over the lateral border of the pectoralis major just medial to the axilla.

The anterior supra-iliac skinfold was taken diagonally above the crest of the ilium at a spot where an imaginary line would come down from the axillary line.

An abdominal skinfold was taken two centimeters to the right of the umbilicus. The skinfold was lifted at the level of the umbilicus and the caliper was applied below the site.

The thigh skinfold was measured with the right foot placed on a bench with the knee slightly flexed and the thigh muscles relaxed. The skinfold was raised midway on the anterior of the thigh between the trochanterium and the proximal border of the patella. The fold was lifted parallel to the long axis of the thigh.

A medial calf skinfold was taken with the right foot placed on a bench with the knee slightly flexed. The vertical skinfold was raised on the medial side of the right calf just above the level of the maximal calf girth. Thus the fold was measured at the maximal girth.

<u>Cross validation of equations</u>

Seven equations were selected for cross validation on this sample. They were:

Inter-University Study Equation 2 (IU eq2) (62);

MWW kg = (.3846 x height + 2.3165 x bitroch. width
+ 3.301 x chest width
+ 14.777 x right wrist diameter
+ 2.6702 x chest depth
- 221.7804) / 2.2046

Inter-University Study % Fat (IU %fat) (62);

% body fat = .640995 x tricep skinfold
+ .232076 x supra-iliac skinfold
+ 3.294335.

MWW kg = (weight - %fat x weight) x 1.05

Inter-University Study 14 variables (IU 14) (62);

MWW kg = (1.556928 x right ankle diameter
-1.088152 x tricep skinfold
+ 0.165731 x thigh skinfold
+ 0.227912 x height
+ 1.063765 x right knee diameter
+ 2.130262 x chest Depth
+ 1.758881 x chest Width
+ 0.069762 x calf skinfold
+ 2.825395 x right wrist diameter
+ 1.548422 x bitrocanter width
+ 0.379225 x subscapular skinfold
+ 1.363826 x calf circumference
+ 1.503164 x bi-iliac width
+ 2.033428 x forearm circumference
- 219.506201)/2.2046

Oppliger-Tipton 1985 (O-T 85), (44):

MWW kg = (1.672 x Height in
+ 3.809 x chest diameter
+ 4.109 x chest depth
+ 1.966 x bi-iliac diameter
+ 5.243 x sum of both wrist diameters
- 0.248 x supra-iliac skinfold
-263.824)/2.2046

Tcheng-Tipton 1972 long form (T-T 72lf), (63):

MWW kg = (1.84 x height in
+ 3.28 x chest diameter cm
+ 3.31 x chest depth cm
+ 0.82 x bi-iliac diameter cm
+ 1.69 x bitrochanter diameter cm
+ 3.56 x both wrists cm
+ 2.15 x both ankles cm
- 281.72)/2.2046

Tcheng-Tipton 1972 short form (T-T 72sf), (63):

MWW kg = (2.05 x height in
+ 3.65 x chest diameter cm
+ 3.51 x chest depth cm
+ 1.96 x bitrochanter diameter cm
+ 8.02 x left ankle diameter cm
- 282.18)/2.2046

Tcheng-Tipton 1972 circumference (T-T 72c), (63):

MWW kg = (2.51 x height in
+ 1.17 x chest diameter cm
+ 1.25 x chest depth cm
+ 0.70 x bi-iliac diameter cm
+ 3.00 x thigh circumference cm
- 252.028)/2.2046

Statistics

Mean values, ranges and standard errors of estimate (SEE's) of physical characteristics were calculated for the sample as a group and also by school. Regression equations were developed using body density as a dependent variable and anthropometric data as independent variables in a step-up multiple regression analysis. Criterion MWW determined from densitometry was used as the dependent variable with the best predictors of body density being entered as the independent variables through forced regression.

Cross validation procedures included sample comparisons of mean values, ranges and SEE from criterion MWW and MWW predicted from the cross validation equations. With actual MWW as the dependent variable and equations to be cross validated as independent variables linear regression was performed.

Principles of Cross Validation

When cross validation studies are performed certain principles should be noted. A general list of these has been outlined (37):

> 1. Because random sampling is not utilized in developing anthropometric equations for predicting body composition equations correlations are likely to be affected by the degree of variability of body fatness from one sample to another (Norton, 1968). Thus standard errors of estimate are always

preferred over correlation coefficients when comparing one equation with another derived on different samples. Furthermore, as the number of independent variables increase, a further bias is introduced into the sample estimate of the population multiple correlation.

2. An equation used to predict body density on another sample when compared with the actual density measurement should produce comparable mean values. A large difference between predicted and measured means points to a systematic effect between studies due to technical or biological factors.

3. Most regression equations assume a linear relation between skinfolds and density while it has been demonstrated that the actual relation is curvilinear over a wide range of densities. The slope of the regression line of density on skinfolds decreases as body density decreases, thus accounting for some of the difficulty of utilizing linear equations developed from relatively homogeneous samples.

4. The total error of an equation derived from one sample and cross validated on another combines the standard error estimate (SEE) and the mean difference between the predicted and actual density. This total error is expressed by the statistic E, such that

$$E = \sqrt{\Sigma(\hat{Y} - Y_i)^2/N]}$$

And where $\hat{Y}$ is the predicted density values from the skinfold regression equation derived from another sample and Y_i is the measured density in the cross validation sample. This statistic is not a standard deviation or a SEE, but rather the square root of the mean of the squared deviations of predicted minus measured observations.

5. An important property of a regression equation is the variability in the predicted density values as compared to the measured densities in the cross validation sample. Important to the establishment of a valid equation is similar standard deviation between predicted and measured densities.

6. Large sample sizes are essential to develop and cross validate regression equations.

7. Non-random samples often deviate from the population distribution of body densities and effect the precision of estimates of various statistics.

These general principles were adhered to in this study and further explanation or clarification can be found in reference (37).

Adjusted R^2

When multiple regression analysis is performed the amount of variation in the dependent variable that is accounted for by the independent variables is determined by squaring the correlation coefficient (R) giving the coefficient of determination (R^2). Under certain conditions, e.g. those mentioned in cross validation principles one, two and seven, R^2 is inflated because a statistical phenomenon called shrinkage occurs. The magnitude of inflation of R^2 is affected by the sample size and number of independent variables in the regression equation. Therefore, a more accurate estimation of variation in the dependent variable accounted for by the independent variables is obtained by using an R^2 value which is adjusted to correct for shrinkage--called the adjusted R^2. The adjusted R^2 is calculated by using the following formula (25):

$$\text{Adjusted } R^2 = 1 - (1 - R^2) \times (n-1)/(n-k-1)$$

where: R^2 = correlation coefficient squared

n = number of subjects in sample

k = number of independent variables

Since the adjusted R^2 compensates for shrinkage and does not inflate estimates of variation accounted for by the independent variable, only adjusted R^2 values were used in this study.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to develop multiple regression equations for predicting minimum wrestling weight (MWW) from anthropometric measures including skinfolds, skeletal widths and circumferences based upon a sample of high school wrestlers. In addition, this sample was used to cross validate anthropometric equations for predicting MWW developed from other samples of the same population.

Characteristics of Subjects

Fifty-five subjects were measured and in two cases data on one variable was not obtained. One subject did not have height recorded on any of the data sheets and the other subject had too large an abdominal skinfold to be measured with the Harpenden skinfold caliper. Data from these two subjects were omitted from all phases of multiple regression procedures that required input of a missing data point as an independent variable. However, when possible, data for these two subjects were included while deriving normative data upon the sample. Raw data on all measures obtained from this sample can be found in Appendix A.

The mean age of the sample was 16.8 ± 1.06 yrs, mean height was 169.2 ± 7.72 cm, mean weight was 63.7 ± 12.7 kg, mean density was 1.07554 ± 0.0120 kg and mean percent fat was 8.8 ± 5.49 (Table 1). Ranges for these measures are also included in table 1 and it is evident from these values that the sample is diverse with weights ranging from 37.0-111.6 kg. Table 2 shows the mean values, standard deviations and ranges for the skinfold, skeletal width and circumference measures obtained from this sample.

Table 1 DESCRIPTIVE DATA ON SAMPLE

VARIABLE	n	MEAN	S	RANGE
AGE, yrs	55	16.8	1.06	12.6 - 18.5
HEIGHT, cm	53	169.2	7.73	146.3 - 185.4
WEIGHT, kg	55	63.7	12.69	37.0 - 111.6
DENSITY, gm/cc	55	1.0755	0.0120	1.0347 - 1.0930
% Fat[1]	55	8.8	5.49	1.2 - 27.2

[1]Calculated as: %fat = 503/body density - 459 (35).

TABLE 2 ANTHROPOMETRIC DIMENSIONS ON THE HIGH SCHOOL WRESTLERS

VARIABLE	N	MEAN	S	RANGE
SKINFOLDS, mm:				
TRICEP	55	6.9	2.25	4.2 - 18.3
SUBSCAPULAR	55	8.2	3.74	4.5 - 27.3
CHEST	55	5.0	1.92	2.8 - 16.5
SUPRA-ILIAC	55	7.9	4.81	4.4 - 35.9
ABDOMINAL	54	8.7	4.24	4.2 - 29.7
THIGH	55	8.7	2.88	4.7 - 17.0
CALF	55	7.2	3.10	3.4 - 23.2
WIDTHS, cm:				
CHEST WIDTH	55	26.1	2.06	20.8 - 31.5
CHEST DEPTH	55	17.5	1.80	15.0 - 23.3
BI-ILIAC	55	26.4	1.78	22.1 - 31.0
BITROCHANTRIC	55	30.3	2.09	25.4 - 34.9
RIGHT WRIST	55	5.5	3.05	4.7 - 6.2
RIGHT ELBOW	55	6.8	0.42	5.8 - 7.7
RIGHT KNEE	55	9.2	0.52	7.9 - 10.4
RIGHT ANKLE	55	7.3	0.42	6.2 - 8.3
LEFT ANKLE	55	7.4	0.40	6.3 - 6.2
LEFT WRIST	55	5.5	0.37	4.4 - 6.2
CIRCUMFERENCES, cm:				
UPPER ARM	55	32.0	3.08	24.9 - 41.7
FOREARM	55	27.9	2.18	21.8 - 33.3
THIGH	55	48.6	4.70	38.7 - 64.6
CALF	55	34.9	2.98	28.1 - 44.3

Prediction of Body Density

Initial analysis involved predicting body density from age, height, weight, skinfolds, circumferences and then skeletal widths. Because the SEE for predicting body density from each of these measures was known for other populations, the objective was to determine if the SEE's from this sample were comparable.

Step-up regression was performed using age, height, and weight as the independent variables, with body density as the dependent variable. Age alone accounted for none of the variance in body density in this sample, age plus height accounted for six percent of this variation, and when all three were combined they accounted for seventeen percent of the variation (Table 3).

The best combination of skinfolds in this sample were calf, abdomen, and tricep (Table 4). Using one regression coefficient for the sum of three variables makes equations simpler, generally without affecting accuracy, than when three separate regression coefficients are used. Further regression analysis was performed with the sum of these three sites being entered as one independent variable (Table 4) to compare coefficients of determination and SEE's. As shown in table 4, use of the sum of three skinfolds as an independent variable slightly decreases the adjusted R^2 value and increases the SEE 0.0007 gm/cc. The effect of including age with skinfolds as independent variables for predicting body density is shown in Table 4. As an independent variable, age entered the step-up regression analysis following four skinfold measures and was not significant ($p \leq .05$). Including age in the regression equation did not affect the adjusted R^2 value. An age effect of 0.00076 gm/cc per year was found in this sample. That is, for a given skinfold thickness, body density increased less than 0.001 gm/cc for each year of age in this select sample.

Table 3 **REGRESSION ANALYSIS OF BODY DENSITY WITH AGE, HEIGHT AND WEIGHT**

	Regression Coefficients Body Density = Dependant Variable		
Independent[1] Variables — Equation	1	2	3
Age, yrs	.00376*	.00242	.00132
Height, cm	.00018	.00044*	
Weight, kg	-.00062*		
Adjusted R^2	.17	.06	0
SEE, gm/cc	.010	.011	.011
Intercept	1.02	1.11	1.05

*Significant at $p \leq .05$ level
[1]N = 54

Table 4 **REGRESSION OF BODY DENSITY ON SKINFOLDS AND AGE**

Independent[1] Variables:	Regression Coefficients Body Density = Dependant Variable					
	Eq. 1	2	3	4	5	6
Age, yrs		.00076				
[2]Sum 7						.0005*
[3]Sum 3					-.0011*	
Calf	-.00158*	-.00148	-.0016*	-.00210		
Abdominal	-.00148*	-.00152*	-.0009*	-.00010*		
Tricep	-.00148	-.00134	-.0014			
Supra-iliac	.00105	.00097				
Adjusted R^2	.53	.53	.52	.50	.48	.46
SEE, gm/cc	.00768	.00772	.00780	.00793	.00804	.00827
Intercept	1.1023	1.0889	1.105	1.100	1.100	1.103

* $p \leq .05$
[1]N = 53
[2]Sum7 = Sum of all skinfolds
[3]Sum3 = Sum of tricep, abdominal and calf skinfolds

Comparing estimates of body density from a set of skinfolds on specific populations of young male adults, the values from this study were slightly higher than the average SEE of 0.0070 gm/cc, found in a number of previous studies (37). As shown in table 4, the SEE for predicting body density from calf, abdomen, and tricep skinfolds was 0.0078 gm/cc, and for the sum of these three it was 0.0080 gm/cc.

The best combination of skeletal widths for predicting body density in order of selection using step-up regression analysis (Table 5) were chest depth, age, right knee, right elbow, and left wrist. Skeletal widths represent bone diameters and relate to FFB mass rather than percent fat. Thus, the relation of body density to skeletal widths was not expected to be very high. Since bone size may affect body density, one could expect the regression coefficient to be positive. However, large bone size often is related to higher body weight and fatness. And thus, an inverse relation of skeletal widths to body density was found (Table 5). The SEE's were, in general, about 0.011 gm/cc for various combinations of skeletal widths. Inclusion of right elbow and left wrist width in the regression equation accounted for additional variability in body density, although the SEE was still quite large (Table 5).

Table 5 **REGRESSION ANALYSIS OF BODY DENSITY ON SKELETAL WIDTHS AND AGE**

	Regression Coefficients Body Density = Dependent Variable		
Independent[1] Variables / Equation	1	2	3
Age, yrs	.0047*	.0034*	.0036*
Skeletal Widths:			
Chest depth	-.0039*	-.0025*	-.0031*
Right knee	-.0096*	-.0058	-.0124*
Right elbow	.0206*		.0127*
Left wrist	-.0146*		
Adjusted R^2	.34	.21	.28
SEE, gm/cc	.010	.011	.011
Intercept	1.0923	1.1144	1.0971

*Significant at $p \leq .05$ level
[1]N = 53

Step-up regression using age, height, and circumference measures as independent variables to predict body density was performed. The sum of all circumferences--upper arm, forearm, thigh and calf--and age accounted for 23% of the variability in body density with a SEE of 0.01093 gm/cc (Table 6). When age, height, the sum of all circumferences and its square were entered as independent variables to check for a quadratic effect, the sum squared was entered into the step-up regression second to the sum of circumferences. Addition of the sum of circumferences squared to the sum of circumferences increased the coefficient of determination from 0.14 to 0.36 (36% of the variation accounted for) and decreased the SEE from 0.1159 gm/cc to 0.00997 gm/cc (Table 6), suggesting a quadratic effect of circumferences (45). When circumferences were entered individually, thigh circumference was the only one contributing significantly ($p \leq .05$) to the prediction of body density (Table 6). The regression equation yielding the highest adjusted R^2 and lowest SEE used the sum of four circumferences and the sum of seven skinfolds as two independent variables (Table 6). This regression equation had an adjusted R^2 of 0.50 and a SEE of 0.0080 gm/cc (Table 6).

Table 6 **REGRESSION OF BODY DENSITY ON CIRCUMFERENCES, SUM OF CIRCUMFERENCES SQUARED AND SKINFOLDS**

Independent[1] Variables:	Regression Coefficients Body Density = Dependent Variable Eq. 1	2	3	4	5
Age, yrs			.00414*	.00430*	
Circumferences:					
[2]Sum	.00028*	.00659*		-.00056*	-.0004
Sum^2		-.00002*			
Thigh			-.00158*		
Skinfolds:					
[3]Sum	-.00064*				
Adjusted R^2	.50	.36	.28	.23	.14
SEE, gm/cc	.0080	.0099	.0106	.0109	.0116
Intercept	1.069	0.623	1.083	1.084	1.132

*Significant at $p \leq .05$ level
[1]N = 53
2Sum = forearm, upper arm, thigh and calf circumferences summed
[3]Sum = tricep, subscapular, chest, supra-iliac, abdominal, thigh, and calf skinfolds summed

Table 7 **REGRESSION OF BODY DENSITY ON WIDTHS AND SKINFOLDS**

Independent[1] Variables:	Regression Coefficients Body Density = Dependent Variable Equation
SKINFOLDS, mm:	
Calf	-.0020*
Abdominal	-.0009*
Tricep	-.0020*
SKELETAL WIDTHS, cm:	
Right elbow	.0151*
Left wrist	-.0095*
Adjusted R^2	.64
SEE, gm/cc	.00670
Intercept	.0164

*Significant at $p \leq .05$ level
[1]N = 53

Height, all skinfolds and all skeletal widths were entered as independent variables to predict body density using step-up regression analysis. The best combination was calf, abdominal and tricep skinfolds with right elbow and left wrist widths. Using these independent variables gave and adjusted R^2 of 0.64 and SEE of 0.0060 gm/cc (Table 7).

When all circumferences, skeletal widths and skinfolds were entered as independent variables with body density as the dependent variable in a step-up regression analysis, the best equation using at least one variable from each of these three types is given in table 8. Skinfolds included were calf, abdominal and tricep. Skeletal widths included were right elbow, right knee and left wrist. The only circumference included was calf. The final equation using these seven independent variables had an adjusted R^2 of 0.68 and SEE of 0.00635 gm/cc (Table 8).

Table 8 **REGRESSION OF BODY DENSITY ON SKINFOLDS, SKELETAL WIDTHS AND CIRCUMFERENCES**

Independent[1] Variables:	Regression Coefficients Body Density = Dependent Variable Equation
SKINFOLDS, mm:	
Calf	-0.00185*
Abdominal	-0.00100*
Tricep	-0.00235*
SKELETAL WIDTHS, cm:	
Right elbow	0.01650*
Left wrist	-0.00793*
Right knee	-0.00647*
CIRCUMFERENCES, cm:	
Calf	0.00094
Adjusted R^2	0.68
SEE, gm/cc	0.00635
Intercept	1.07193

*Significant at $p \leq .05$ level
[1]N = 53

Prediction of Minimal Weight

The next phase of statistical analysis was to determine the combinations of independent variables that best predicted MWW (i.e. highest adjusted R^2 and lowest SEE). Skinfolds, circumferences and skeletal widths were entered alone and in combinations in the step-up regression with MWW as the dependent variable. Age and height were included in all regression analysis as independent variables because of the ease of assessing these variables. The best combinations of independent variables for predicting criterion MWW were then used in the final MWW equations. The best combinations of independent variables were height, the sum of four circumferences, right elbow and left wrist diameter, and the sum of 3 skinfolds (Table 9), with the adjusted $R^2 = 0.92$ and the SEE = 2.59 kg. The next best group of independent variables were forearm, calf upper arm and thigh circumferences, height, right elbow width, and calf skinfold, having an adjusted $R^2 = .92$ and SEE = 2.62 kg. The third best combination was age and height, forearm, calf and upper arm circumferences, and right elbow and left wrist widths, adjusted $R^2 = .91$ and SEE = 2.82 kg (Table 9). Other combinations of independent variables for predicting MWW are also given in table 9, arranged with best on the left and worst on the right.

Table 9 **REGRESSION OF MINIMUM WRESTLING WEIGHT ON ANTHROPOMETRIC VARIABLES**

Independent[1] Variables:	Regression Coefficients Minimum Wrestling Weight = Dependent Variable Eq 1	2	3	4	5	6
Age, yrs			1.3445*		1.7113*	2.7840*
Height, cm	.2414*	.2911*	.2657*	.3267*	.3927*	.7187*
CIRCUMFERENCES:						
[2]Sum	.6365*					
Forearm		.0319	-.2377*	.6619*		
Calf		.8485*	1.2960*	1.1057*		
Upper arm		.7108*	1.0581*	1.1242*		
Thigh		.6672*				
WIDTHS, cm:						
Chest depth					1.0103*	
Chest width					1.5768*	
Right elbow		4.3317*	5.9680*		6.2848*	
Left wrist			-3.2400*			
[3]Sum	.2394*					
SKINFOLDS, mm:						
[4]Sum	-.2552*					
Chest						1.9800*
Calf		-.8140*				
Adjusted R^2	.92	.92	.91	.89	.85	.70
SEE, kg	2.59	2.62	2.82	3.13	3.65	5.12
Intercept	-99.60	-97.97	-102.04	-87.51	-125.66	-118.04

*Significant at $p \leq .05$ level
[1]N = 53
[2]Sum = sum of calf, upper arm, thigh and forearm circumferences
[3]Sum = sum of chest depth, chest width, bi-iliac and bitrochanteric widths
[4]Sum = sum of tricep, abdominal and calf skinfolds

Table 10 **REGRESSION OF MINIMUM WRESTLING WEIGHT ON BEST COMBINATIONS OF VARIABLES FROM SAMPLE**

INDEPENDENT[1] VARIABLES:	REGRESSION COEFFICIENTS Minimum Wrestling Weight = Dependent Variable Equation 1	2
Age, yrs		1.2858*
Height, cm	.2748*	.2654*
CIRCUMFERENCES:		
Calf		1.2502*
Upper Arm		.9715*
[2]Sum 3	.7958*	
WIDTHS:		
Left Wrist		-3.2928*
Right Elbow	4.4085*	5.7681*
SKINFOLDS:		
[3]Sum 3	-.3016*	
Adjusted R^2	.93	.91
SEE, kg	2.45	2.80
Intercept	-100.88	-101.63

*Significant at $p \leq .05$ level
[1]N = 53
[2]Sum 3 = sum of calf, thigh, and upper arm circumferences
[3]Sum 3 = sum of tricep, abdominal, and calf skinfolds

The final step in the process of developing equations for predicting MWW involved using selected independent variables from the previous step, best predictors of MWW, in a forced regression analysis with the criterion MWW. The resulting regression analysis revealed the final MWW prediction equations for the sample. The first included height, the sum of three circumferences, right elbow width and the sum of three skinfolds to predict criterion MWW with an adjusted R^2 of .93 and SEE of 2.45 kg (Table 10). The second equation used age, height, upper arm and calf circumferences, and right elbow and left wrist circumferences to predict criterion MWW with an adjusted R^2 of .91 and SEE of 2.80 kg (Table 10).

Cross Validation

The mean MWW of the sample was calculated using the sample derived and also the cross validation equations. The values obtained were compared with those obtained when MWW was calculated via the criterion method; allowing for a simple comparison of mean values and standard deviations (S). As shown in table 11, the mean MWW from the criterion method was 60 kg with S = 9.49 kg. The two sample derived equations predicted a mean MWW of 60 kg with S near nine kg. The cross validation equations all predicted MWW within 3 kg (Table 11). A list of the equations included in the cross validation follows. For each equation listed, the mean difference ($D_{\hat{y}-\hat{x}}$) of the mean MWW calculated from the criterion method less the mean MWW estimated from the equation is given (Table 12). The difference between the standard deviation of the criterion measure and each of the cross validation equations ($S_{\hat{y}-\hat{x}}$), from table 11, are also included in the following list: (1) IU eq2, $D_{\hat{y}-\hat{x}}$= 2.4 kg and $S_{\hat{y}-\hat{x}}$= 1.2 kg, (2) IU 14, $D_{\hat{y}-\hat{x}}$= -0.1 kg and $S_{\hat{y}-\hat{x}}$= 0.4 kg, (3) IU %fat, $D_{\hat{y}-\hat{x}}$= 0.5 kg and $S_{\hat{y}-\hat{x}}$= -0.1 kg, (4) O-T 85, $D_{\hat{y}-\hat{x}}$= 3.1 kg and $S_{\hat{y}-\hat{x}}$= 0.6 kg, (5) T-T 72lf, $D_{\hat{y}-\hat{x}}$= 2.6 kg and $S_{\hat{y}-\hat{x}}$= 0.2 kg, (6) T-T 72sf, $D_{\hat{y}-\hat{x}}$= 1.6 kg and $S_{\hat{y}-\hat{x}}$= 0.1 kg, (7) T-T 72c, $D_{\hat{y}-\hat{x}}$= 0.9 kg and $S_{\hat{y}-\hat{x}}$= -0.4 kg.

Table 11 **SUMMARY OF MEAN CRITERION MWW AND MWW ESTIMATED FROM CROSS VALIDATION AND SAMPLE DERIVED EQUATIONS**

Equation	Mean	S	Min	Max
CRITERION	60.55	9.49	34.0	78.7
SAMPLE SPECIFIC:				
[1]BHCWS	60.49	9.53	34.6	79.9
[2]BAHWC	60.54	9.19	32.8	78.5
[3]CROSS VALIDATION:				
IU eq2	58.12	8.28	34.9	75.3
IU 14	60.64	9.11	34.0	79.9
IU %fat	60.03	9.58	35.5	81.8
O-T 85	57.42	8.84	31.8	76.6
T-T 721f	57.98	9.34	31.0	78.0
T-T 72sf	58.60	9.44	31.5	79.8
T-T 72C	59.64	9.87	31.2	80.5

[1]BHCWS - sample derived equation using height, Sum 3 circumferences, right elbow width and Sum 3 skinfolds to predict MWW

[2]BAHWC - sample derived equation using age, height, calf and upper arm circumferences, and left wrist and right elbow widths to predict MWW

[3]Selected cross validation equations

Table 12 **REGRESSION ANALYSIS OF CRITERION MWW ON CROSS VALIDATION EQUATIONS**

	Minimum Wrestling Weight			
Independent Variables	Adjusted R^2	SEE, kg	Intercept	Mean Difference
IU %fat	.91	2.84	3.74	-0.5
IU 14	.88	3.36	1.41	0.1
T-T 72c	.87	3.47	7.11	-0.9
O-T 85	.81	4.06	4.74	-3.1
T-T 721f	.81	4.17	7.53	-2.6
T-T 72sf	.80	4.20	7.59	-1.9
IU Eq2	.79	4.28	0.92	-2.4

The subsequent step in the cross validation procedure was to perform linear regression using the criterion MWW as the dependent variable and MWW from the equation to be tested as the independent variable. In table 12, when the equations are ranked by adjusted R^2 and SEE, they appear in the following order: (1) IU %fat, (2) IU 14, (3) T-T 72c, (4) O-T 85, (5) T-T 721f, (6) T-T 72sf, (7) IU eq2.

The IU %fat equation which ranked the highest for predicting MWW had an adjusted R^2 of .91 and SEE of 2.84 kg while the lowest ranked equation (IU eq2) had an adjusted R^2 of .79 and SEE of 4.28 kg (Table 12).

Discussion

Age effect upon body density

Evidence suggests that adolescents in this sample's age range, 12.6-18.5 years, have not attained chemical maturity (35). Chemical maturity is the age at which FFB has a density 1.100 gm/cc, as assumed in the Siri equation (57). The Siri equation uses a constant for FFB that is based upon the reference adult composition of 73.8% water, 6.8% mineral and 18.8% protein (57). Evidence suggests that these component proportions of FFB are not attained until post-pubescence (35, 36). Therefore, in subjects that have not attained chemical maturity, it may be inappropriate to use a FFB density constant of 1.100 gm/cc. Using the Siri equation developed for predicting the body density of adults on a sample of adolescents could result in an overestimate of percent fat (36, 75).

As stated earlier, a modified Siri equation using 1.096 gm/cc as the density of FFB was selected on the basis of the samples mean age (35, 36). A crucial consideration in using this constant for FFB was the effect of age upon body density. If a large age effect on body density existed in this sample, holding skinfold thickness constant, then using one constant to calculate body density across the sample would provide inaccurate body density and percent fat estimates in some wrestlers. Through regression analysis the age effect on body density in this sample was estimated to be 0.0014 gm/cc per year. Using the FFB density of 1.096 gm/cc assumed for a 16-17 year old, and 0.0014 gm/cc as the estimated deviation in body density per year, a 12-13 year old in this sample would be expected to have a FFB density of 1.091 gm/cc. The magnitude of error introduced by using 1.096 gm/cc as the constant for FFB density was less, because most of the subjects in this sample were between 15 and 17 years of age. Much of the data supporting the concept of chemical maturity comes from non-athletic samples. Thus, if this sample deviated from the expected FFB composition of non athletic youths, i.e., percent water, percent bone mineral and percent protein in FFB, then a systematic error could be introduced into the MWW prediction equations.

Prediction of body density with skinfolds

The best combination of skinfolds for predicting body density were calf, abdominal, tricep and supra-iliac with SEE = 0.0077 gm/cc and adjusted R^2 = 0.53 (Table 4). When this combination was used, neither tricep or supra-iliac skinfolds were significant ($p \leq .05$). Since the purpose of this study was to develop potential equations for application, the decision was made to use the sum of calf, abdominal and tricep skinfolds as one independent variable, called Sum 3 in the regression equation. This provided two advantages. The first was that only one regression coefficient was needed for Sum 3, rather than three. The second was that three skinfolds combined into one independent variable reduced the effect of multicolinearity upon the regression analysis. This can occur when independent variables such as skinfolds are highly related, and could result in less accurate regression coefficients. When Sum 3 was entered as an independent variable, with body density, the SEE = 0.00800 gm/cc and adjusted $R^2 = 0.48$. These results compared well with other skinfold regression equations, derived in both the non-athletic and athletic samples, where the SEE's generally range from 0.006 gm/cc to 0.009 gm/cc (37).

Prediction of body density with skeletal widths

Measures of skeletal widths represent bone structure which is a component of FFB. As such, skeletal widths are not expected to relate well to body density, a measure of fatness. As shown in table 5, various combinations of skeletal widths and age failed to relate well to body density. This was expected since body density is mainly affected by fluctuations in body water and fat content.

Prediction of body
density with circumferences

In this study, all of the anthropometric measurements were used to estimate body density before regression equations for estimating minimum wrestling weight were developed. This procedure allowed the validity of circumferences as a measure of fatness to be tested. Furthermore, the results could also be compared against those of many investigations using body density as a criterion variable.

One intention of this study was to explore the effect of including circumference measures in the regression equations. The summed effect of bone diameter, muscle mass, and fat should be accounted for by circumference measures. The postulated result of including circumferences in a regression equation would be to increase the equation's validity; as would be observed by an increased adjusted R^2 and a decreased SEE. Circumferences should provide information, not supplied by skeletal widths or skinfolds, that would enable a better prediction of minimal weight. Presumably, circumferences should provide information on a component of muscle mass that is not provided by skeletal widths or skinfolds. Skinfolds measure subcutaneous fat which is related to total fat. Skeletal widths indicate bone diameter which is a gross index of skeletal mass. In essence, the information on muscle mass that is provided by circumference measures was expected to enhance MWW prediction equations.

In some investigations, selected circumference measures have been shown to gauge a component of body fatness not accounted for by skinfold thickness. In leaner samples, circumference measures should relate more to FFB mass and show less relation to body density as the subjects become leaner. In comparison to adult and non-athletic populations, wrestlers are leaner and circumference measures alone may not relate well to body density. This was seen in this sample (Table 4 and Table 6), where the sum of four circumferences yielded a lower adjusted R^2 and higher SEE than when the sum of four skinfolds were used to predict body density.

Of the equations cross validated in this study, those equations that included circumference measures tended to predict MWW better than equations using combinations of other anthropometric variables. Two equations, i.e. the IU 14 and T-T 72c that required a circumference measure were included in the cross validation. These two equations ranked second and third in comparison to the five other equations; the equation that was ranked highest used only skinfold measures. This is evidence that circumference measures can enhance regression equations for predicting MWW.

Combining measures to predict body density

The best equations for predicting body density generally result when combinations of anthropometric measures are used (45). Inclusion of various measures may improve the prediction equation by accounting for a greater portion of the variation in the dependent variable. Skinfolds generally account for the greatest variation in body density, although addition of circumferences and skeletal widths may enhance the prediction equation. For example, in this sample, use of four skinfold measures to predict body density yielded an adjusted R^2 of .53 and SEE of .00768 gm/cc (Table 4). Use of three skinfolds and two skeletal widths to predict body density yielded an adjusted R^2 of .65 and SEE of .00670 gm/cc (Table 7). Combining three skinfolds, three skeletal widths and one circumference yielded the best formula for predicting body density using anthropometric variables, with an adjusted R^2 = .68 and a SEE = .00635 gm/cc (Table 8). In this sample, prediction of body density was enhanced when the prediction equation included a combination of anthropometric variables.

Prediction of MWW

In this sample, the equations for predicting MWW were developed by using the measured body density value to estimate FFB mass and FFB mass plus five percent fat, or MWW. This value for MWW was then used as the dependent variable in the regression analysis. With MWW as the dependent variable, different combinations of independent variables were selected than when body density was the dependent variable. Since MWW was calculated as FFB plus five percent, those variables which were related to FFB should have contributed most to the prediction of MWW, although the variables may not relate well to body density. Minimum wrestling weight should relate more to FFB , and less to percent fat, in comparison to body density. This could be shown if skeletal widths and circumferences, measures of FFB, contributed more to the prediction of MWW than skinfolds. Table 9 shows the relationship of MWW and FFB. Skeletal widths and circumferences, compared to skinfolds, have a low adjusted R^2 when predicting body density, but have a higher adjusted R^2 when predicting MWW. As can be seen in table 9, combinations of skinfolds, circumferences and skeletal widths provide the highest adjusted R^2 and lowest SEE when predicting MWW. This was also seen with prediction of body density.

The best predictors of MWW included height, the sum of three circumferences, and right elbow width, which were all positively related to MWW; and also the sum of three skinfolds which had a negative relation to MWW as seen by the regression coefficients in table 10. These regression coefficients are further evidence of the positive relationship of FFB to MWW.

Cross validation equations

Table 11 shows the average MWW, standard deviation, and range of MWW's found from each of the equations tested in this sample. The mean MWW predicted from each of the cross validation equations was compared to the mean MWW calculated by the criterion method. From the criterion method, the mean MWW was found to be 60.6 kg with S = 9.49 kg. This initial test is important in cross validation studies since differences from the criterion mean of more than three percent, when standard deviations are comparable, may indicate technical error, biologic error or a low validity of the equation being cross validated (37, 45). The IU 14 variable equation, IU %fat equation and T-T 72c equation worked well in this comparison. The IU eq2, O-T 85 equation, T-T 72lf and T-T 72sf all predicted mean MWW to be at least two kilograms or, three percent less than the criterion method--indicating that a systematic error occurred when these equations were compared to the criterion method.

Since the T-T 72lf and T-T 72sf equations were not originally validated by densitometry, the discrepancy with the T-T 72lf and T-T 72sf equations in this cross validation study was probably due to methodological factors. These equations were developed based upon the assumption that the body weights of state finalists would represent the minimum body weight a wrestler could attain while remaining competitive. This assumption suggests that state finalists may differ from non-finalists when the two groups are compared on the basis of physical characteristics; this difference has been shown (63). Because the state finalists represented a select sample of the wrestling population, and the weights of the state finalists were used as the dependent variable for developing these prediction equations, it would be reasonable to expect a systematic error when the equations were cross validated using MWW determined from densitometry measures from a sample that included average wrestlers. The equations were tested against a different dependent variable than that from which they were developed, and a more general sample was investigated.

The systematic error that occurred with O-T 85 cross validation equation was also the result of methodological differences between studies. Oppliger and Tipton assessed body composition by densitometric methods and these estimates were used as the criterion in their study. However, they used the Brozek equation, (e.g., % body fat = 457/body density - 414.2) to calculate body fat (9, 44). In the present study, however, a modified form of the Siri equation, e.g., % body fat = 503/body density - 459 was used to derive the criterion MWW values in an attempt to provide a more accurate estimate of body composition within this sample (35, 36, 75). These equations use different constants for FFB density to determine percent fat. A systematic difference would be observed in a sample if the estimates of percent fat or MWW from each of these equations were compared. The amount of discrepancy can be shown by using the average body density from this study, 1.07554 gm/cc, to calculate percent fat and MWW with both methods. When this was done, the Brozek equation estimated body fat to be 10% and MWW to be 59.7 kg, whereas the modified Siri equation estimated body fat to be 8.7% and MWW to be 61.1 kg. The Brozek equation will systematically provide higher estimates of percent fat and lower estimates of MWW. Using the Brozek equation results in an over-estimate of percent fat and an under-estimate of MWW, assuming the concept of chemical maturity held true for this sample (35, 36, 75).

It is difficult to explain the systematic error observed with the IU eq2 equation. Two other equations developed from the same sample did not exhibit systematic errors when cross validated on this sample. In fact, these equations, i.e., the IU %fat and IU 14, were the best predictors of MWW in this study. Upon reviewing the IU eq2 equation, it is striking that the regression coefficient for right wrist diameter (14.77), is disproportionately larger than any of the other regression coefficients in the equation; right wrist was the third independent variable to enter the step-up regression analysis. The error found with this equation may be due to the disproportionate emphasis placed upon right wrist diameter.

In the final step of the cross validation, regression analysis was performed and each of the cross validation equations was entered as the independent variable with the criterion MWW as the dependent variable. The IU %fat equation had the highest adjusted R^2 and lowest SEE of the equations cross validated (Table 12). This equation used a new approach for estimating MWW. In contrast to the traditional approach of correlating anthropometric measures to FFB mass, this equation used two skinfolds to estimate the subject's percent fat. Fat weight was calculated by multiplying percent fat and body weight, then fat weight was subtracted from total body weight, yielding the estimated FFB weight from skinfolds. Minimum wrestling weight was computed as 1.05 times FFB weight, the estimated body weight with five percent fat when FFB was held constant.

This new approach estimated criterion MWW with a lower SEE (2.84 kg) and higher adjusted R^2 (.91) than the traditional approaches tested within this sample, or reported in other samples. Since this approach uses few measures, two skinfolds and weight, it would be practical in application because little equipment is needed, measurers could be trained easily, and the necessary information could be collected rapidly.

The next best equation was the IU 14, with adjusted R^2 = .88 and SEE = 3.36 kg (Table 12). In the sample from which the IU 14 equation was originally derived, similar values were obtained, with adjusted R^2 = .90 and SEE = 2.9 kg. Because fourteen independent variables were used in the IU 14 equation, it represents the lowest errors possible using anthropometry. However, the large number of variables and measures required for each wrestler make this equation impractical for widespread use in a certification process.

The T-T 72c equation (63), was the next best predictor of MWW in this sample (Table 12). It requires height, three diameters and one circumference measure as independent variables. In the sample of 582 state finalist wrestlers from which it was developed, an R^2 (not the adjusted R^2) of .95 and SEE of 2.8 kg were reported. Body weight during the state championships was the dependent variable. In the reported study MWW was not calculated for each wrestler, rather it was assumed that the actual weight of each wrestler was optimal for success, since the subjects were state finalists (63). The use of actual body weight instead of MWW as the dependent variable in the sample from which the equation was derived may explain the difference in reported values and those found in this study.

Two other equations, the T-T 721f and T-T 72sf were developed from the same data (63) and under the same assumptions. The T-T 721f was reported with an R^2 (not adjusted R^2) of .87 and SEE of 4.0 kg with the wrestler's actual weight (assumed MWW). In this sample, the adjusted R^2 was .81 with an SEE of 4.17 kg when predicting the criterion minimum wrestling weight. The T-T 72sf equation was originally reported with an R^2 (not adjusted R^2) of .85 and SEE of 4.4 kg. Comparing the original findings of these two equations to the results of this cross validation (Table 12) supports the assumption that state finalists were near their respective MWW. These two equations were also studied, with a sample of college wrestlers, using MWW determined by densitometry as the dependent variable. The

T-T 72lf and T-T 72sf yielded r = .90 and .90 with SEE's of 4.0 kg and 4.0 kg respectively (56). These values are similar to those reported in the original study and also in this study.

Advocate further study
of the new equation

Although the IU %fat uses body weight in the calculations to predict MWW, further investigation of this equation needs to be conducted with other samples. Opposition to using body weight directly to predict MWW is centered around the contention that a wrestler in a state of dehydration would have a lower, incorrect estimated MWW. Therefore, if such an equation were used, the problem of dehydration among wrestlers would not be resolved. Defending an equation that uses weight to predict MWW requires one to consider the accuracy of alternate methods of determining MWW, and equally important, the extent of resolution to the problem of dehydration that would be effected if equations that did not use body weight were used as a means of determining a wrestlers certified MWW. The unusually high level of accuracy demonstrated by this equation for predicting MWW in this sample was addresed previously. However, if part of the purpose of establishing a MWW certification process is to prevent wrestlers from losing too much weight by caloric restriction, then it would be favorable to predict each subject's MWW with the lowest possible amount of error. So far, the other equations developed to predict MWW with anthropometric variables have had SEE's that are too large to meet this requirement. Moving to the second point of defense, even if a system of predicting MWW by using anthropometric measures without including body weight in the calculations was implemented, the problem of dehydration would not be resolved. For example, a wrestler weighing 135 pounds that is deemed to have a MWW of 130 pounds could still dehydrate before competition and wrestle in the 130 pound weight class. Determining a wrestler's MWW will not regulate the means of weight loss that wrestler will use. Simply prohibiting a wrestler to wrestle below his MWW does not preclude that wrestler from dehydrating to attain his MWW; regardless of how MWW is determined. Establishing a MWW certification procedure would prevent a wrestler from dehydrating to a body weight below the certified MWW, but dehydration will continue to be a preferred method of weight loss unless a check can be integrated into the MWW certification system.

Statement addressing the
abuses of weight loss by wrestlers

As Oppliger and Tipton have indicated, there is a lack of scientifically generated data to support the contention that losing fat, fluids and/or lean mass below five percent fat will improve performance. In fact, the data in this area indicates otherwise (44). Bearing in mind the potential hazards of some weight loss practices, the problems associated with weight loss among wrestlers need to be rectified. Most of these problems can be attributed to two factors: (1) excessive weight loss among wrestlers, (2) rapid weight loss generally achieved by dehydration. The most viable solution entails a multifaceted approach that focuses upon education, regulation of weight loss and dehydration, and the increased role of a physician.

To solve the problem of excessive weight loss by wrestlers, body composition needs to be assessed at the beginning of the season to determine the wrestlers minimum wrestling weight. Wrestlers, their parents, and coaches need to be educated about establishing weight loss goals, proper diet regimes and the selection of proper foods. The role of the team physician in supervising the weight loss programs also needs to be increased (6, 12, 17, 48, 58, 59, 66, 68, 69, 70, 71). This could be achieved by having a provision in the certification process that allows a wrestler to seek medical clearance if he wants to wrestle below his certified MWW (4). Of the feasible options available, the most accurate method of predicting MWW should be implemented in the MWW certification process for three reasons: (1) to reduce the frequency and magnitude of error in the determination of MWW; such errors could result in wrestlers being encouraged to lose an inappropriate amount of weight, (2) to assist the wrestler in determining a reasonable amount of weight loss, (3) to make the physician's decision of granting or denying medical clearance defensible on the basis of an objective and accurate estimate of MWW.

As a solution to the problem of dehydration among wrestlers, it has been proposed that the limits of an acceptable urine specific gravity could be established and the specific gravity of a wrestler's urine could be checked at the time of certification and before selected matches during the season (32, 77). By using a hydrometer with a floating ball, the specific gravity of urine can be checked more quickly than weight (32). In a study of over 300 wrestlers participating in the Illinois State High School Wrestling Tournament in 1975, Hursh found that the wrestlers that placed first or second were better hydrated than the other wrestlers, having an average urine specific gravity of 1.015 in comparison to the mean urine specific gravity of

1.020 found for the other wrestlers in the tournament (32). Checking the specific gravity of a wrestler's urine would provide a simple means of verifying hydrational status. With such a check, it would be reasonable to use a MWW certification equation that used body weight directly in the calculations. Based upon the findings of this study, such an equation would be considerably more accurate than the other anthropometric methods tested, and estimates of MWW could be improved. Furthermore, if this simple test was included in the pre-match weigh-in procedure, wrestlers would be forced to discontinue the practice of dehydrating to lose weight before competition. None of the methods that have been proposed as a means of predicting MWW can verify or eradicate the practice of wrestlers dehydrating to lose weight before competition. Therefore, to solve this problem, the process of implementing a MWW certification procedure should incorporate a means of verifying hydrational status.

CHAPTER V

SUMMARY and CONCLUSIONS

This study was undertaken to investigate the applicability of anthropometric regression equations for predicting minimal wrestling weight (MWW) on a sample of 55 high school wrestlers from Tucson, Arizona. Regression equations for predicting MWW were developed from this sample and seven other prediction equations were cross validated on this sample.

The criterion MWW was calculated using body density values and 1.096 gm/cc as the constant for FFB. Based upon estimates of chemical immaturity in adolescent males the constant for FFB of 1.100 gm/cc was deemed inappropriate for use with this sample (37). Anthropometric measures included selected skinfolds, circumferences, skeletal widths and height. All anthropometric measures were taken by the same testers and repeated three times on each subject. The mean of these three measures was used in a step-up multiple regression analysis to assess the relationship of the anthropometric measures and MWW. It was hypothesized that this sample would be comparable to others within the wrestling population, inclusion of circumference measures would enhance the predictability of regression equations, and regression equations derived on this sample should exhibit only slightly less variability in predicting MWW when compared to those equations derived from other samples.

Summary of Results

Mean age, height, weight, body density and percent fat, with the standard deviations for the sample were 16.8 ± 1.1 yrs, 169.2 ± 7.7 cm, 63.7 ± 12.7 kg, 1.0755 ± 0.012 gm/cc and 8.8% ± 5.6, respectively. When entered as independent variables in a step up regression analysis age, height and weight predict body density with an adjusted R^2 of 0.17 and SEE of 0.01023 gm/cc. The best combination of skinfolds, i.e., calf, abdominal, tricep and supra-iliac, predict body density with an adjusted R^2 of 0.53 and SEE of 0.0077 gm/cc. Age and four skeletal widths, i.e., chest depth, right knee, right elbow, and left wrist predicted body density with adjusted R^2 = 0.34 and SEE of 0.01013 gm/cc. The sum of forearm, upper arm, thigh and calf circumferences, and their sum squared predicted body density with an adjusted R^2 of 0.36 and SEE of 0.00997 gm/cc. Through step-up regression analysis the best combinations of skinfolds, skeletal widths and circumferences were found to predict body density with an adjusted R^2 of 0.68 and SEE of 0.00635 gm/cc.

Two equations for predicting MWW using different combinations of independent variables were selected with adjusted R^2 and SEE of 0.93 and 2.45 kg and 0.91 and 2.80 kg respectively. These equations represent the best combinations of independent variables for predicting MWW in this sample. Of these two equations, the one predicting MWW with the least amount of variability included height, the sum of three circumferences (i.e, calf, thigh and upper arm), right elbow width and the sum of three skinfolds (i.e., tricep, abdominal and calf) as independent variables. The other equation included age, height, calf and upper arm circumferences and, left wrist and right elbow widths as independent variables.

In the cross validation portion of this study an equation using two skinfolds and body weight to estimate MWW had the highest adjusted R^2 of 0.93 and lowest SEE of 2.84 kg; this was a new approach for predicting MWW. Of the equations deriving FFB and MWW through the usual approaches the IU 14 and T-T 72c equations worked best on this sample with adjusted R^2 of 0.88 and 0.87 and SEE of 3.36 kg and 3.47 kg respectively.

Conclusions

Within the stated limitations, the following conclusions are based on the results of this study:

1. Several equations with skinfolds and circumferences were found to produce SEE's similar to those previously found in other investigations estimating body density and minimal weight. This sample was comparable to other samples within the stated population.

2. Inclusion of circumference measures with other anthropometric variables enhanced regression equations for predicting minimum wrestling weight.

3. Several anthropometric formulas previously published for predicting minimum wrestling weight were successfully cross validated on this sample. The IU %fat equation that uses triceps and supra-iliac skinfolds and weight was the most accurate of the equations cross validated.

APPENDIX A

RAW DATA FROM SAMPLE

				Skinfolds						
Subject	Age, yrs.	Height, cm	Weight, kg	Tri., mm	Sub., mm	Chest, mm	Supra, mm	Abd., mm	Thigh, mm	Calf, mm
1001	16.5	165.3	55.6	7.8	6.1	4.5	5.4	8.2	10.0	8.2
1002	12.6	146.3	37.2	7.0	5.2	4.7	5.8	7.0	10.4	8.6
1003	16.7	174.6	63.9	7.6	6.6	4.6	7.2	7.0	7.2	8.3
1004	15.1	165.6	53.3	7.5	7.0	5.4	6.0	8.8	7.4	7.6
1005	17.2	171.1	65.2	10.6	9.1	4.4	7.4	11.9	15.6	8.0
1006	15.4	167.5	63.7	7.4	7.6	5.3	8.0	10.2	10.3	9.9
1007	18.5	175.0	77.2	7.7	8.7	5.5	13.3	12.5	10.6	6.7
1008	14.7	167.4	62.4	7.2	9.0	6.0	9.8	13.3	14.4	6.4
1009	16.5	170.2	62.0	8.1	7.2	6.4	9.4	14.2	12.2	8.6
2010	18.4	164.3	66.7	4.6	7.8	5.0	5.6	7.2	6.4	4.4
2011	16.6	178.0	111.6	18.3	27.3	16.5	35.9		17.0	23.2
2012	16.1	171.1	58.2	5.5	6.4	4.1	5.6	5.5	6.2	6.2
2013	17.6	163.9	58.5	4.8	7.4	4.1	4.6	6.5	6.6	5.9
2014	16.0	165.8	52.6	6.4	7.6	3.7	5.3	4.5	7.2	5.2
2015	18.3	169.4	62.9	5.4	5.6	3.6	4.7	5.7	4.8	4.6
2016	17.9	166.8	51.6	4.8	6.6	4.0	5.8	5.1	5.1	4.3

				Skinfolds						
Subject	Age, yrs.	Height, cm	Weight, kg	Tri., mm	Sub., mm	Chest, mm	Supra, mm	Abd., mm	Thigh, mm	Calf, mm
2017	17.8	169.9	81.8	6.9	8.3	6.9	9.8	14.6	7.0	5.6
3018	17.5	166.3	67.2	7.3	9.4	4.7	7.8	8.3	10.5	11.4
3019	16.5		45.4	4.6	4.5	2.8	6.1	4.4	7.8	3.4
3020	17.8	174.9	79.8	7.7	9.0	4.1	8.1	10.4	9.6	8.9
3021	17.4	174.7	71.7	6.2	10.4	5.2	12.6	10.7	9.2	7.2
3022	16.2	178.0	63.8	5.6	6.0	3.8	7.8	5.4	6.2	4.6
3023	16.3	160.6	54.5	6.1	6.7	4.4	6.0	7.0	7.5	8.3
3024	16.8	165.6	54.6	5.2	6.1	3.8	6.5	6.1	6.1	5.2
3025	17.4	156.0	49.8	4.8	6.8	3.0	4.4	4.2	6.4	4.0
3026	16.9	181.0	69.6	6.2	7.2	4.0	11.2	6.8	10.5	7.0
3027	16.9	165.0	55.6	5.4	6.3	4.9	4.8	5.4	7.4	4.5
4028	17.3	169.7	60.4	5.4	6.3	4.9	4.8	5.4	7.4	4.5
4029	17.3	171.0	62.3	6.4	6.6	4.9	5.1	5.3	6.0	4.0
4030	17.4	157.8	55.6	6.4	8.0	5.2	7.5	8.5	6.8	5.6
4031	18.0	170.4	66.6	6.0	8.1	4.4	6.1	7.1	6.8	6.3
4032	17.7	158.8	56.6	5.4	7.4	4.3	5.4	6.0	7.0	5.1
4033	15.8	161.2	58.0	7.5	9.4	5.4	6.7	7.4	6.6	5.8
4034	18.4	174.9	89.8	7.8	24.1	8.3	21.3	29.7	14.6	14.2
4035	16.9	174.2	74.6	9.7	10.9	7.2	10.4	16.1	14.1	10.3
4036	16.4	166.9	54.1	8.0	7.9	4.6	6.7	9.4	9.6	6.8
4037	15.5	166.5	54.7	8.3	7.2	6.4	6.4	12.0	11.0	9.6
4038	15.8	180.7	81.4	10.9	8.7	6.2	9.5	14.1	11.1	8.8
4039	17.7	176.0	70.7	6.9	11.6	5.4	11.4	12.9	9.5	9.6

				Skinfolds						
Subject	Age, yrs.	Height, cm	Weight, kg	Tri., mm	Sub., mm	Chest, mm	Supra, mm	Abd., mm	Thigh, mm	Calf, mm
5040	16.7	162.9	47.0	4.6	5.3	4.0	5.4	6.9	8.4	7.4
5041	17.2	179.5	73.3	5.8	7.6	4.2	5.5	6.8	9.2	9.0
5042	18.2	177.5	72.4	5.2	7.0	4.5	5.6	6.6	6.2	6.4
5043	15.5	165.4	49.2	5.0	5.6	3.2	5.0	5.1	8.7	7.3
5044	16.7	181.9	80.6	10.2	9.0	4.9	10.4	5.1	12.1	8.3
5045	16.9	164.9	59.6	7.2	9.4	5.3	9.8	11.6	7.2	6.0
5046	17.3	182.9	86.1	9.3	9.9	7.6	9.6	14.4	11.1	11.3
5947	16.6	156.5	52.8	6.4	6.8	4.9	4.8	8.0	5.4	6.8
5048	17.5	163.8	55.9	4.2	5.9	4.0	4.8	5.0	5.0	3.9
5049	16.3	159.6	54.2	6.4	7.2	5.3	6.8	6.4	8.1	6.6
5050	16.1	178.0	72.7	8.6	9.0	5.4	8.3	9.1	11.9	8.5
5051	18.4	175.1	65.6	7.6	7.2	4.1	6.6	8.2	9.0	6.4
5052	17.2	167.5	59.1	4.7	6.8	3.8	4.6	6.6	5.8	6.1
5053	16.4	174.5	74.4	6.8	7.8	5.4	6.9	8.4	7.3	5.7
5054	17.4	185.4	66.1	7.2	9.2	4.8	6.4	7.6	9.2	6.8
5055	16.3	166.0	54.3	4.2	6.4	4.2	5.4	6.4	6.0	5.5

Subj	Chest Width	Chest Depth	Bi-il	Bitroch.	Right Wrist	Right Elbow	Right Knee	Right Ankle	Left Ankle	Left Wrist
	Skeletal Widths, mm									
1001	23.6	16.3	25.7	28.8	5.6	7.0	9.2	7.2	7.4	5.5
1002	20.8	15.4	23.5	25.4	5.0	6.2	8.2	6.6	6.7	4.6
1003	26.0	17.1	26.9	32.3	5.8	7.2	9.8	7.8	7.8	5.8
1004	25.6	16.8	24.6	28.4	5.6	7.2	9.4	7.2	7.4	5.6
1005	24.3	19.0	24.8	29.6	5.4	6.6	8.9	6.8	7.1	4.5
1006	26.6	16.9	26.8	29.6	5.8	7.2	9.2	7.2	7.4	6.0
1007	28.7	17.4	27.6	33.6	6.2	7.4	9.6	7.8	7.8	6.1
1008	25.7	17.0	28.0	30.2	4.5	7.1	9.4	7.4	7.2	5.4
1009	24.6	18.2	27.2	30.8	5.6	7.1	8.8	7.2	7.0	5.6
2010	27.0	18.4	26.4	28.9	5.4	6.3	8.4	7.3	7.2	5.5
2011	31.5	21.9	29.5	33.7	5.7	7.1	10.4	8.3	8.2	5.4
2012	25.8	16.6	29.0	32.6	5.9	6.7	8.9	7.6	7.6	5.7
2013	26.6	16.5	25.4	30.4	5.6	6.5	9.0	7.2	7.1	5.1
2014	26.4	15.0	27.2	29.0	5.3	6.4	8.9	7.1	7.1	5.4
2015	25.8	18.2	26.4	31.0	5.6	6.6	9.0	7.6	7.7	5.5
2016	23.8	15.7	27.0	30.5	5.6	6.4	9.5	7.5	7.4	5.6
2017	29.2	19.6	28.3	66.0	6.0	7.7	9.6	7.7	7.5	6.1
3018	26.1	20.4	26.6	30.4	5.8	7.3	9.3	7.9	7.8	5.6
3019	21.9	15.3	24.1	26.6	5.5	6.5	9.0	7.3	7.4	5.3
3020	28.1	23.3	25.5	29.3	5.5	7.2	10.1	7.2	7.3	5.1
3021	29.8	18.7	25.5	31.2	6.0	7.4	10.0	8.0	8.0	5.9
3022	25.5	16.8	25.5	28.8	5.2	6.7	9.1	7.1	7.5	5.2
3023	23.4	17.0	24.3	28.2	5.6	6.6	8.6	7.0	7.0	5.4

	Skeletal Widths, mm									
Sub	Chest Width	Chest Depth	Bi-il	Bitroch.	Right Wrist	Right Elbow	Right Knee	Right Ankle	Left Ankle	Left Wrist
3024	25.8	17.4	24.1	29.0	5.0	6.4	7.9	6.7	6.8	4.7
3025	24.7	16.3	22.1	26.2	4.7	5.8	8.0	6.2	6.3	4.4
3026	26.9	19.1	31.0	34.9	5.7	7.3	9.5	8.0	8.0	5.7
3027	23.9	18.1	24.8	28.2	5.2	6.7	9.0	7.1	7.0	5.1
4028	27.0	16.8	26.5	32.2	5.9	7.2	9.8	7.7	7.7	6.0
4029	26.3	16.3	26.4	30.4	5.4	6.8	9.3	7.4	7.4	5.5
4030	26.3	16.4	24.8	28.5	5.3	6.5	8.8	6.9	6.9	5.4
4031	26.3	19.1	27.0	31.9	5.9	6.8	9.2	7.2	7.6	6.2
4032	25.6	17.5	24.1	28.3	5.4	6.4	8.6	7.2	7.2	5.4
4033	27.2	17.6	25.1	28.8	5.5	6.6	9.2	7.2	7.2	5.6
4034	28.9	19.4	28.9	33.6	5.7	7.0	9.9	8.0	7.7	6.0
4035	28.5	19.6	25.7	30.4	5.8	7.4	9.7	7.5	7.4	5.8
4036	24.1	16.4	23.4	28.4	5.2	6.2	8.9	7.0	7.0	5.1
4037	24.6	17.6	23.5	28.9	5.4	6.2	9.1	7.5	7.5	5.4
4038	28.6	19.3	26.3	32.3	5.5	7.0	9.3	7.2	7.6	5.6
4039	26.6	18.8	27.1	30.6	5.6	7.0	9.4	7.2	7.6	5.6
5040	21.9	16.4	25.2	28.0	5.1	6.5	8.9	6.7	6.9	5.3
5041	24.9	17.4	27.6	31.7	5.5	6.9	9.7	7.5	7.5	5.4
5042	25.5	18.9	28.7	33.6	5.6	7.0	9.8	7.2	7.5	5.5
5043	26.1	16.0	27.5	30.4	5.0	6.0	9.0	6.0	6.7	5.1
5044	28.3	19.6	29.6	33.8	6.0	7.5	10.0	7.6	8.1	6.1
5045	24.5	15.8	26.2	30.2	5.4	6.9	9.4	7.1	7.2	5.6

Sub	Chest Width	Chest Depth	Bi-il	Bitroch.	Right Wrist	Right Elbow	Right Knee	Right Ankle	Left Ankle	Left Wrist
	Skeletal Widths, mm									
5046	28.2	21.9	28.4	34.0	5.9	7.3	9.7	7.7	8.0	5.8
5047	24.7	15.8	26.1	28.8	5.3	6.5	8.4	6.5	6.7	5.1
5048	26.4	16.8	25.4	28.3	5.3	6.4	9.2	7.3	7.4	5.3
5049	27.7	15.8	26.9	29.0	5.2	6.3	8.8	6.7	7.0	5.2
5050	28.1	15.0	27.0	32.2	5.8	7.0	9.5	7.4	7.5	5.7
5051	27.9	15.3	26.6	30.3	5.6	6.7	9.3	7.3	7.6	5.7
5052	25.3	16.9	26.6	29.6	5.3	7.0	9.3	7.3	7.2	5.6
5053	28.8	16.3	27.7	30.6	6.1	7.0	10.0	7.7	7.7	6.0
5054	26.6	15.5	28.6	31.9	5.7	7.2	9.3	7.5	7.5	5.7
5055	23.9	16.5	25.1	29.5	5.6	6.6	9.0	6.9	7.0	5.3

	Circumferences, cm							
Subj.	Upper Arm	Forearm	Thigh	Calf	Residual Volume	Body Density	%fat	MWW
1001	30.8	27.5	46.2	34.8	0.87480	1.08022	6.6	54.5
1002	24.9	21.8	38.7	28.1	0.50340	1.06580	13.0	34.0
1003	32.4	28.0	47.8	36.1	1.00190	1.06580	8.0	61.7
1004	28.5	26.9	44.6	32.9	0.82210	1.07523	8.8	51.0
1005	31.0	28.2	51.1	36.6	1.17420	1.07124	10.6	61.2
1006	32.8	28.2	50.0	35.5	1.17210	1.07594	8.5	61.2
1007	34.5	31.0	51.4	38.9	1.00090	1.07110	10.6	72.5
1008	32.6	27.1	49.0	34.8	0.85720	1.07955	6.9	61.0
1009	31.0	27.4	46.5	33.5	0.94860	1.07228	10.1	58.5
2010	33.9	29.1	50.8	36.7	1.35931	1.08258	5.6	66.1
2011	41.7	33.3	64.6	44.3	0.72651	1.03466	27.2	85.4
2012	29.4	26.9	44.7	32.9	0.97656	1.08960	2.6	59.5
2013	33.0	27.9	47.4	35.2	0.90429	1.08472	6.0	57.7
2014	29.0	26.0	44.8	33.2	1.07205	1.08573	4.3	52.9
2015	33.0	27.4	49.5	33.0	1.15212	1.07886	7.2	61.3
2016	27.6	25.9	43.4	29.8	1.15709	1.08493	4.6	51.7
2017	38.2	32.2	58.2	38.0	0.95629	1.07611	8.4	78.7
3018	33.5	30.0	53.4	36.2	1.16020	1.07900	7.2	65.5
3019	26.5	23.6	39.6	32.0	0.52620	1.06900	11.5	42.2
3020	35.3	30.7	54.9	37.7	1.37370	1.07200	10.2	75.2
3021	35.5	30.5	50.5	38.6	1.53710	1.08300	5.4	71.2
3022	31.7	27.3	47.4	32.8	0.71720	1.07900	7.2	62.2
3023	30.1	26.2	45.3	32.6	1.03120	1.08600	4.2	54.8
3024	28.6	26.2	45.2	32.4	1.80240	1.09300	1.2	56.6

	Circumferences, cm							
Subj.	Upper Arm	Forearm	Thigh	Calf	Residual Volume	Body Density	%Fat	MWW
3025	30.4	25.5	48.0	33.9	0.76170	1.09300	1.2	51.7
3026	34.1	28.6	48.4	35.0	1.87280	1.08900	2.9	71.0
3027	32.0	26.8	45.8	33.6	1.22820	1.09200	1.6	57.4
4028	28.8	26.6	46.0	34.1	1.22058	1.08113	6.2	59.5
4029	32.6	28.2	47.8	34.2	1.22094	1.08521	4.5	62.5
4030	31.4	26.6	47.0	32.4	1.63205	1.08106	6.3	54.7
4031	35.0	29.1	50.5	35.8	1.21008	1.05928	15.8	58.8
4032	30.2	26.1	48.6	34.9	0.70682	1.08475	4.7	56.6
4033	32.0	29.8	48.4	35.5	0.81652	1.07398	9.4	55.2
4034	37.8	31.4	59.0	39.5	0.88022	1.04359	23.0	72.6
4035	33.0	29.0	54.9	37.0	1.17434	1.06982	11.2	69.6
4036	29.2	25.4	44.2	30.5	1.69531	1.05426	18.1	46.5
4037	28.5	25.6	47.4	32.9	0.37888	1.04532	22.2	44.7
4038	35.1	29.5	53.8	39.8	0.97056	1.05937	15.8	72.0
4039	33.4	29.8	49.0	35.6	1.12694	1.05849	16.1	62.3
5040	27.5	24.2	41.0	30.5	0.92060	1.07461	9.1	44.9
5041	34.2	29.4	51.1	38.6	1.37950	1.08187	5.9	72.4
5042	33.6	29.0	51.4	36.8	1.25130	1.06614	4.1	72.9
5043	27.9	24.8	41.8	30.5	1.25130	1.06614	12.8	45.0
5044	33.9	29.6	52.8	40.1	1.94030	1.07435	9.2	76.9
5045	33.4	28.1	46.8	33.0	0.85840	1.07677	8.1	57.5
5046	36.6	31.0	56.2	37.3	1.14320	1.05497	17.8	74.3
5047	30.6	27.2	45.1	32.0	0.66370	1.07947	7.0	51.6
5048	31.3	27.9	46.1	33.8	0.90790	1.09219	1.5	57.8

Subj.	Circumferences, cm Upper Arm	Forearm	Thigh	Calf	Residual Volume	Body Density	%Fat	MWW
5049	30.1	26.0	48.0	33.0	0.82790	1.07719	8.5	52.4
5050	34.1	29.0	50.9	37.4	0.93260	1.06707	12.4	66.9
5051	32.6	28.0	46.2	34.2	1.05480	1.07734	7.9	63.4
5052	31.7	27.8	46.0	33.7	0.75030	1.08366	5.2	58.8
5053	34.4	29.1	53.4	38.3	0.83020	1.08327	5.3	74.0
5054	32.0	29.0	50.5	36.0	1.13290	1.07548	8.7	63.4
5055	29.0	25.1	45.0	31.6	0.93800	1.07800	7.6	52.7

APPENDIX B

SUBJECTS CONSENT FORM FOR ARIZONA WRESTLING STUDY

You are being invited to participate in the above-titled research project. The purpose of this project is to develop an equation to predict a wrestler's minimal wrestling weight. You have been invited to participate because of your success in the sport of wrestling. We hope to enroll at least 300 subjects in this study over a three-year period.

If you agree to participate, you will be asked to agree to the following:

1. Have my height and weight measured as well as the following:

   (a) 10 bone diameters using a caliper

   (b) 5 limb circumference measurements using a tape measure

   (c) 7 skinfold thicknesses using a skinfold caliper

   It will take about 15 minutes to complete these measurements.

2. Have my body composition (percent fat) determined by being weighed while completely underwater and after exhaling all my air. This will require approximately ten trials and 15 minutes to complete. I realize that there is some discomfort due to complete exhalation, but I am free to surface for a breath at any time.

3. Have my residual lung volume measured by exhaling all of my air, followed by breathing from a bag that contains 100% oxygen, and, finally, exhaling all of my air again. This test measures the amount of air that was trapped in your lungs when you did the underwater weighing test. It takes about 10 minutes to complete.

4. Provide a urine sample prior to competition when competing at divisional and state wrestling championships.

As a participant in this study, you will obtain valuable information about your own percent fat and lean body weight. This will be helpful to both you and your coach.

The information obtained about your body composition and the composition of your urine will be kept confidential. Only the scientists involved with this study and your head coach will have access to these data.

Your involvement in this research project will not cost you any money, nor will you receive any money for your participation.

I have read this subject's consent form. The nature, demands, risks, and benefits of the project have been explained to me. I understand that I may ask questions and that I am free to withdraw from the project at any time without incurring ill will or affecting my medical care. I also understand that this consent form will be filed in an area designated by the Human Subjects Committee with access restricted to the principal investigator or authorized representatives of the particular department. A copy of this consent form will be given to me.

____ _______________
Subject's Signature Date

____ _______________
Parent/Guardian Signature (if necessary) Date

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