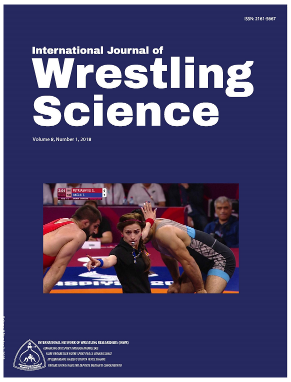

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DEFINING THE WRESTLER'S BODY – APPROPRIATE MEASURES FOR TARGETING WEIGHT CLASS

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ABSTRACT
Competition within a specified weight class is a fixture in the sport of wrestling to help prevent injury and allow equal opportunity among participants. Weight reduction to a lower than normal weight class is a common practice in the U.S. Because of adverse events with such practice, national governing bodies (NGB) in the states have established programs to guide wrestlers to safe weight classes based on body composition. For large teams of participants, the field assessments adopted by NGB's include anthropometry using skinfold thicknesses (SF) and bioelectrical impedance analysis (BIA) because of the validation testing and efficiency. The standard used to calibrate, or cross validate SF, BIA, and any other field methods has most often been densitometry that typically relies on hydrostatic weighing of the athlete (HW). Assumptions on which HW was developed include fixed constants for hydration and mineralization of the fat-free body. However, maturation level, gender, and ethnicity will alter these constants and leave densitometry to be erroneous regardless of whether HW or other methods (air displacement plethysmography) are applied as the validation standard. The biological variability of the wrestler body must be accounted for to develop accurate and reliable methods. In this way, fair and safe minimal weight programs can be implemented in the sport.

INTRODUCTION
Division of competitors in wrestling by weight class is a tenet of the sport for the purpose of equalizing opportunity and reducing risk of injury. The selection of weight class for a particular wrestler can be complex, particularly for the wrestler whose natural weight places him or her between two weight classes or the wrestler who cannot make the desired team at his or her current weight. The options are reducing body weight to the lower class or building up the body to reach the mass for the higher class. Given the genetic limitations of the latter and that the former is a function of behaviors – training and diet control – already occurring among participants, most wrestlers will reduce to the lower class.

In the U.S. and other Westernized cultures, the common yet unproven notion is that a competitive advantage can be acquired by reducing to a lower weight class or several weight classes below normal weight. The practice of weight reduction appears to have started at the intercollegiate level in the early 1900's (Horswill 1990) and has also been a common practice at the interscholastic level (Committee on Medical Aspects of Sports 1967). In 1997, though, three collegiate wrestlers died within six weeks of each other while attempting substantial weight loss in a short period of time. Hyperthermia was indicated as the cause of death (CDC 1998). As a consequence, the NCAA, main governing body of college wrestling in the U.S. moved quickly to develop and implement a program that assessed hydration status and body composition to project a safe minimal weight to reduce if not eliminate the chance of wrestlers succumbing to hyperthermia during weight reduction and training (Oppliger et al 2006). At the interscholastic level, the state of Wisconsin had implemented a minimal weight program in the late 1980's (Oppliger et al 1995) and, with the NCAA move in the 1990's, most if not all states did likewise for high-school wrestling.
While the two-pronged approach appears to have accomplished the goal, questions remain about the validity of both the hydration testing and the body composition assessment given the narrow population represented in the validation, i.e., late-adolescent and early adult Caucasian males. Missing from the validation studies are younger males (early puberty), African American and Hispanics in the U.S., ethnicities from elsewhere in the world, and females of all maturation levels and ethnicities. With the changing demographics in the U.S. and the practice of weight loss potentially migrating among wrestlers in other regions of the world, validation of the methods used in minimal weight programs is imperative. Yet, validation attempts continue for new field methods, but without sound consideration for accuracy of the criterion particularly when maturation level, gender, or ethnicity vary (Montgomery et al 2017).

This brief review will define minimal weight, describe the process for determining minimal weight and weight class, identify and discuss assumptions underlying measurement of body composition, provide examples of how the assumptions are violated in athletes and how they might be influenced specific to wrestlers, and provide recommendations for validating new technology that emerge and thereby ensure fair and equitable process through accuracy and reliability for all wrestlers. The focus is on body composition. The issues around hydration testing will not be covered. The papers selected for this review were those available through Pubmed and published between 1960 to the present.

The Application – Minimal Weight
Starting with the end in mind, having determined the body composition of a wrestler, i.e., the current percentage body fat, the fat-free mass (FFM), and fat mass, the minimal weight can be calculated. Minimal weight is defined as the leanest weight (lowest body fat) that still sustains health and performance of the wrestler. Figure 1 depicts the conceptual components and calculation leading to minimal weight. In this example, the current mass of a wrestler is 67.8 kg with 18% body fat. Multiplying the mass by the decimal 0.18 gives us the fat mass, which is then subtracted from the current whole mass to obtained FFM. In this example, the FFM is 55.6 kg (rounded). Dividing 55.6 kg by the decimal form of the fat portion of the minimum weight gives us a minimal weight of 58.5 kg. (In this case, 0.95 such that 0.05 proportionally, or 5% is allowed as fat; more on this below). With 58.5 being between the weight classes **57kg and** 61kg, the wrestler would complete in the 61 kg weight class so excessive weight reduction below 5% body fat could not occur.

The calculation of minimal weight is based on a theoretical, lowest value for the portion of fat. The goal is to reduce the current fat mass and leave FFM untouched. The guidelines for portion of fat vary depending on gender and age. The original minimum for males was stated to be 5% body fat based on the work of Tipton and Tcheng and observations of what appeared as the leanest levels in athletes (Tipton and Tcheng 1973). In the example in Figure 1, the measured FFM is divided by the theoretical portion of FFM (0.95) if 5% (0.05) is allowed for fat. Most sports-health care organizations in the U.S. agree on this percentage for male adult wrestlers (presumed fully grown). For adolescent wrestlers, though, the minimum body fat has been set at 7% to provide a safety margin for energy for growth and overestimates due to methodology (Oppliger et al 1996; Sammarone Turocy et al 2011; Carl et al 2017). For females, a minimum of 12% has been set regardless of age or maturation (Oppliger et al 1996; Sammarone Turocy et al 2011; Carl et al 2017). It should be noted that the publication by the American Academy of Pediatrics makes an error for adolescent males and females; FFM should be divided by 0.93 for adolescent males and by 0.88 for all females (Carl et al 2017).

To date, most of the validated methods for wrestlers rely on densitometry to determine body composition. The next section will address potential errors with this approach and potential benefits of the implementation of a multi-component model of assessment; introducing the direct measurement of body water and bone density in place of cadaver-derived anatomical constants.

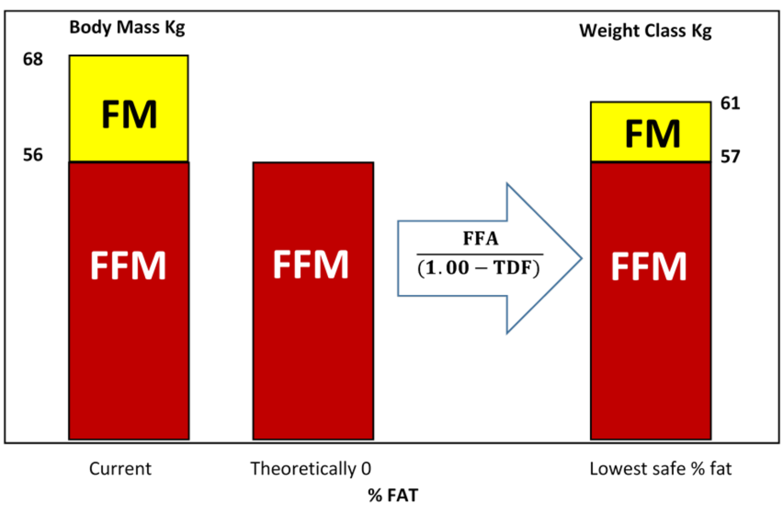

Figure 1. Process for calculating minimal weight (MW) using fat-free mass (FFM), fat mass (FM) and the theoretical decimal for fat (TDF). TDF for adult male wrestlers is 0.95 (5% allowed for fat), 0.93 for adolescent males (7% allowed for fat), and 0.88 for females of all ages (12% allowed for fat).

Chemistry and Physics of the Body No direct or complete method of assessing body composition exists. The original work for evaluating *in vivo* methods was based on cadavers that could be dissected and chemically analyzed (Siri 1961). From these analyses, assumptions were developed and are either accepted but not necessarily confirmed or testing protocols are set up to ensure they are close to being met. One of the underlying assumptions when assessing human body composition is that the body can be compartmentalized into two units:

FFM and fat mass. The goal for the wrestler is to determine how much of the fat can be lost with training and diet while not diminishing the FFM, which is composed of bone and muscle proteins needed for leverage and force production, respectively. The virtual dissection of the body into two components or compartments relies on the assumption that the density of the fat-free mass is 1.1 g/mL and that of fat is 0.9 g/mL (Brozek et al 1963; Siri 1961). Determination of the entire body density can then be used to quantify how much fat-free mass and fat mass exist using the equation of either Brozek et al or Siri.

Hydrostatic weighing (HW) has long been a prominent tool for measuring whole body density. More recently air displacement plethysmography has become popular and generally accepted as valid. While somewhat obtrusive, the methods are not invasive and impose low risks to the athletes. For some systems, the HW may be portable and can function as a field method (defined below). The accuracy, though, of converting to fat-free mass and fat mass is questionable. Because the fat-free mass is not a uniform composition, but varies based on mineral and water content, density of the FFM can be higher or lower than the assumed 1.1 g/mL. Under-mineralized bone in biologically immature adolescents and over or under hydration of the fat-free mass alter the FFM density and violate the assumptions for densitometric methods. This translates into an errors in the estimate of percentage of body fat and biases the calculation of minimal weight for the weight class determination. Use of hydrostatic weighing alone as the criterion predicted by skinfolds would lead to inaccurate anthropometric results (Lohman 1981; Slaughter et al 1984).

Additional Methods of Assessment Tables 1 and 2 summarize the various methods of assessing body composition and the requirements and limitations to wide spread use in wrestling. The field methods in Table 1 allow large numbers of participants to be measured fairly rapidly and reliably, and have been calibrated to one or more of the criterion methods. Obviously, the prediction equation would vary by study and criterion method. As described above, when field methods like anthropometry or bioelectrical impedance are calibrated to densitometry (two-compartment model), the prediction equation generated will have a greater prediction error particularly if the sample is of mixed gender, maturation level, and ethnicity. In addition, the accuracy could be questionable. The criterion methods (Table 2) provide the methods considered to be the gold standard. With the exception of DEXA and the multicomponent method, though, the densitometric methods and body water still fall short because of the limitations associated with relying on a two-compartment model.

Based on the initial calibration of densitometry with cadaver studies (Siri 1961), the body of the college-age athlete has been assumed to meet the required assumptions of the two-compartment model. However, even this population may violate the assumptions made for the FFM and bias percent fat estimation. Researchers at University of Georgia demonstrated this by assessing the body composition and compartments of the fat-free body in athletes participating in several sports (Modlesky et al 1996; Prior et al 1999). Unfortunately, because that university does not have a wresting program, no wrestlers were included. However, some of the categories of athletes might be reasonable proxies for wrestling and regardless of sport, their results will clearly demonstrate the potential errors when hydration and bone mineral of the fat free body are not considered (Table 3). For the U.S. football players and strength-trained males, body fat is overestimated due to the hydration of the fat-free mass being in excess of the cadaver-generated assumption. The contrast in female athletes is also interesting. Female gymnasts, who might have the closest physique and training style to female wrestlers, were found to be under hydrated and over mineralized in bone such that when hydrostatic weighing alone is used, their body fat was underestimated by ~4.5% (Prior et al 2001). Females swimmers in comparison went the opposite way, with over hydration and under mineralization of bone causing an over-estimate of body fat.

In the cases of overestimated % fat based on the two-compartment model, minimal weight would be underestimated. As a result, body weight may be unknowingly reduced below safe levels, posing a risk to athlete health. In the case where fatness is underestimated, the athletes would be more restricted in weight reduction when in fact they could afford to reduce more fat without undo harm. In addition to providing more accurate estimates of body composition with the compartment analysis, use of the multi-component approach as the standard for calibrating field methods would reduce the prediction error. A fairer, safer and more equitable method would be assured by eliminating the variability due to gender, maturation level and ethnicity. Currently, the main governing bodies of amateur wrestling in the U.S., the National Federation of High Schools and the National Collegiate Athletic Association, have adopted the skinfold method for prediction body composition and minimal weight in wrestlers. For males, the Lohman equation that uses the triceps, subscapular, and abdominal sites is applied because it has strong results in the validation and cross-validation work (Lohman 1981; Thorland et al 1981). For females, the equation presented by Slaughter et al is used since it incorporates tricep and subscapular sites that have been validated against the multi-component criterion. Both have limitations though because of the lack of ethnic diversity and accounting for maturation level in the research on male wrestlers and the lack of cross validation among female wrestlers for the Slaughter et al equation (Slaughter et al 1984).

Table 1. Field methods for assessing body composition for minimal weight in wrestlers.

<u>Method</u>	<u>Principles and Assumptions</u>	Applicability for <u>Wrestling</u>	<u>Requirements/Limitations</u>
Anthropometry - skinfolds	• Subcutaneous fat distribution is consistent in population of interest • Subcutaneous fat is proportional to total body fat • Total body fat is inversely related to body density	High	Inexpensive caliper Trained & experienced tester Confirm subject is euhydrated
Anthropometry – girth & skeletal widths	• Sites for circumferences and widths are consistent with fat-free mass in population of interest	Moderate	Calipers & tape measure Trained & experienced tester Confirm subject is euhydrated
BIA	• The body conducts electricity consistently like a wire • Conductivity of body is proportional to fat-free mass • Hydration fluctuation affects body fluid tonicity, which influences conductivity	High	Impedance instrument Instrument cost Confirm subject is euhydrated
BIS	• The body conducts electricity consistently like a wire • Conductivity of body is proportional to fat-free mass • Change in hydration will influence conductivity • Additional frequencies of current run through the body will differentiate intracellular and extracellular water compartments	High	Impedance instrument Instrument cost Confirm subject is euhydrated Not yet validated in in wrestlers
NIR	• Near-infrared energy is transmitted through the body in proportion to water content of tissues. • Site or sites measured for NIR are consistent and in proportion to the rest of the body	High	Confirm subject is euhydrated Instrument cost Not validated in wrestlers

Table 2. Criterion methods for assessing body composition for minimal weight in wrestlers.

Method	Principles and Assumptions	Applicability for Wrestling	Requirements/Limitations
Densitometry (D) – hydrostatic weighing	• Body can be divided into two compartments • Density of fat-free body is 1.1 g/mL and that for fat is 0.9 g/mL • FFM density is consistent in all people	Mod-to-high; often used as a criterion for wrestler studies	Access to technology Need maturation level Confirm subject is euhydrated Need Residual Volume assessment
Densitometry (D) – air displacement plethysmography	• Body can be divided into two compartments • Density of fat-free body is 1.1 g/mL and that for fat is 0.9 g/mL • FFM density is consistent in all people	Mod-to-high	Access to technology Need maturation level Confirm subject is euhydrated Need lung volume assessment
Total body water (TBW)	• Proportion of fat-free body is 73.8% in young adults. • The constant of 73.8% doesn't change • Little or no body water is found in adipose cells	Low	Time – 4-h test Access to technology & tracer Cost %fat biased by hydration state
X-ray Absorptiometry (DEXA)	• Ionizing energy is transmitted or attenuated as it moves through the body based on composition of the body tissues • The attenuation constants are known and fixed for mineral, protein, water, and fat	Low	Access to technology Confirm subject is euhydrated Some radiation exposure Cost
Multi-component	• Same principles as above for D, TBW, and DEXA • Density can be corrected for hydration (TBW) and mineral (DEXA) in the event that assumed constants vary due to maturation level of hydrate of the body	Very low; should be used as criterion for wrestler studies	Time Access to D TBW, DEXA, technologies Some radiation exposure Cost

Table 3. Impact of fluctuation in water and bone mineral content of fat-free mass on whole body density and percent body fat determination.

Variable	Assumed value[a]	U.S. Football[b]	Strength-trained males[c]	Female Swimmers[b]	Female gymnasts[b]
TBW/FFM, %	73.8	74.4	74.8	75.0	69.0
BM/FFM, %	6.8	5.8	5.3	5.7	6.6
FFM Density, g/mL[d]	1.100	1.092	1.059	1.090	1.114
% Fat – 2C model[e]	-NA-	15.6	17.3	23.5	16.4
% Fat – 4C model[f]	-NA-	12.6	13.2	20.1	20.8

[a]Assumed values based on cadaver analysis. [b]Mean values from Prior et al; [c]mean values from Modlesky et al. [d]FFM Density determined using hydrostatic weighing only. [e]2C: two compartment model of fat and fat-free mass only. [f]4C: four compartment model correcting for total body water and bone mineral density. NA: not applicable, % fat is calculated based on the model used.

Table 4. Summary of studies generating or validating methods of predictors of FFM or minimal weight (MW).

Study	Population	Criterion	Field Methods as Predictors	Results by Method	FFM, kg	MW, kg	*r*	SEE, kg
Thorland et al ‘91	Scholastic males, n=645	HW	SF	HW	57.8 ±10.7	-	-	-
			C+W	SF	-	-	0.97	2.45
				C+W	-	-	0.83	4.33
Clark et al ‘93	Scholastic males, n=95	HW	SF	HW	57.9 ± 9.0	-	-	-
			BIA	SF	60.3 ± 8.2	-		2.12
			DEXA	BIA	60.6 ± 9.1	-		2.62
			NIR	DEXA	56.7 ± 8.0	-		2.97
				NIR	54.8 ± 7.4	-		3.45
Clark et al ‘04	Collegiate males, n=53	MC	SF	MC	70.3 ± 7.4	-	-	-
			BIA	SF	70.5 ± 7.2	-	0.97	1.72
				BIA	70.6 ± 7.6	-	0.92	2.98
Clark et al ‘05	Collegiate males, n=57	MC	BIA	MC		72.2 ±10.0	--	
				BIA		72.9 ± 9.7	0.94	3.4
Utter et al ‘05	Scholastic males, n=129	HW	SF	HW	56.2 ±9.9	-	-	-
			BIA	SF	56.1 ±8.9	-	0.98	1.97
				BIA	56.9 ±8.4	-	0.93	3.64
Clark et al ‘07	Scholastic males, n=94	HW	DEXA	HW	-	59.8 ±9.0	-	-
			SF	DEXA	-	60.6 ±9.0	0.98	1.9
				SF	-	60.1 ±8.1	0.97	2.1
Utter et al ‘10	Scholastic males, n=72	HW	SF	HW	57.0 ±10.1	-		
			BIA	SF	56.4 ± 8.8	-	0.97	2.66
				BIA	57.2 ± 9.5	-	0.96	2.73

Potential Influence of Wrestling on Body Composition

Natural Selection. As with all sports, those who succeed are more likely to continue on with the sport. Those who do not succeed may withdraw from further participation at some point. This natural selection process will selectively screen out or in specific body types. In addition, because a wide array of body sizes is required to field a team, from smallest to largest weight class, the selection process can be fairly inclusive, although the assumptions made for the body composition of the small competitor may differ than those of the larger competitor. Part of this could include maturation variability since among 14-y-olds, the chance of having participants in lighter classes is greater than having 18-y-olds still in those classes. Part could be due to ethnicity.

Adaptation with Participation. Training, manipulation of the diet composition, dehydration, and general deprivation of calories and nutrients each could have varying and additive effects on the body composition of the wrestler. Most wrestlers engage in a mixture of anaerobic, aerobic, and resistance training. In one of the few published studies, wrestlers were reported to have greater bone mineralization than golfers or controls (Ackerman et al 2012). Of the extremes, resistance training and aerobic training are likely to have contrasting effects on bone mineralization (Dinç et al 1996). The coach's philosophy and emphasis will vary by program and could magnify the heterogeneity of mineral content and density of the FFM in wrestlers.

The macronutrient composition of the diet will have an effect on hydration status of the wrestler. Repletion compared to a state of depleted muscle glycogen can expand the total body water by ~2 L (Olsson and Saltin 1970). Under-hydration in the depleted state or overhydration when replete primarily occurs in the lean tissues and will alter the whole-body density and bias the estimate of percent body fat. Likewise, voluntary dehydration (sauna use, exercise in heavy gear) changes the water content of the lean tissues and alters the assumed value of 73.8%. This leads to an overestimate of density and an underestimate of percentage body fat (Girandola et al 1977). The menstrual cycle in females will do likewise. With water retention during specific phases of the menstrual cycle in females, the estimated percentage fat will increase as much as 3% units without a change in actual fat mass (Bunt et al).

Finally, repeated cycles of energy and nutrient restriction as a wrestler goes through his or her season can impact bone mineral content. Energy, protein, calcium, and vitamin D may all be compromised in the wrestler diet (Steen et al 1986) and are critical but not exclusive nutrients for bone health. Long term inadequacy or repeated inadequacy for several months during the competitive season could impact the bone density of wrestlers and alter assumptions made for measuring body composition. Currently, the influence of participation in wrestling on these factors and resultant impact of the fat-free body compartments is largely unknown.

SUMMARY AND RECOMMENDED APPROACH

Table 4 summarizes studies during the past three decades that compare field methods as predictors of an assortment of criterion variables in U.S. wrestlers. In some studies FFM is the outcome variable being predicted; in others minimal weight is used as the outcome variable. Because minimal weight is a direct conversion using FFM, the statistical results – the correlation coefficient and standard error of estimate – will be the same regardless of the outcome variable. The field methods include skinfold thicknesses, limb circumferences and skeletal widths, bioelectrical impedance analysis (BIA) and near infrared reactance (NIR). In several cases DEXA was included as a new method. The criterion variables consist of hydrostatic weighing or the multi-component model.

Unfortunately, all studies did not use uniform methods, thus making comparisons difficult between studies. It is worth noting that for those studies that used skinfold anthropometry (typically the Lohman equation), BIA (no one standard device) and one study using NIR, the correlation is always higher and prediction error lower (SEE) for skinfolds predicting the criterion than the BIA or NIR relationship with the criterion. In fact, the prediction errors are quite dramatically lower. To date, among scholastic wrestlers, only hydrostatic weighing has been used as a criterion variable. This is unfortunate since the multi-component criterion is likely to account for variability in younger, developing athletes and help reduce the prediction error and might further enhance the prediction strength of BIA and NIR. Yet, it is understandable due to a small amount of radiation exposure from the DEXA procedure; approval from the institution review board for minors, i.e., vulnerable populations, can be challenging.

Future work to calibrate new field methods and cross-validate existing methods should employ the multicomponent criterion variable, to account for and be inclusive of a wide array of maturation levels including early, mid, late pubescence, and young adult, male and female, and expand beyond the Caucasian race. With such an approach, field methods with the highest accuracy and reliability can be generated for fair and equitable assessment and performance among all competitors.

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