The Wisconsin Wrestling Minimal Weight Project: Cross-Validation of Prediction Equations

R. Randall Clark, Jacqueline M. Kuta, and Robert A. Oppliger

Wisconsin has mandated minimal weight (MW) testing for high school wrestlers. In preparation, six MW predictions were cross-validated on 69 Wisconsin wrestlers (age 15.7 ± 1.1 yrs, height 169.2 ± 6.3 cm, weight 63.3 ± 8.1 kg, percent fat 11.2 ± 4.7%, and MW 58.9 ± 6.9 kg). Minimal weight, defined as fat-free body/l.93, determined by hydrostatic weighing (HW) and residual volume using O2 dilution, served as the criterion. Analyzed using repeated-measures ANOVA, statistically significant but clinically small (<1.3 kg) differences were shown in four of six predictions. Lohman1, Lohman2, and Katch equations appear more appropriate with smaller mean differences, smaller total error, and higher correlations.

Historically the sport of wrestling has attracted the attention of medical and educational groups for the practices associated with “making weight” (1, 2, 27, 31). Typical behavior includes food and fluid deprivation as well as exercise in elevated thermal environments to induce dehydration (1, 2, 4, 10, 21, 25, 26, 31, 32). As many as 33% of school-age wrestlers might be using undesirable weight-loss practices and competing at excessively low body weights (19, 20, 25). Recognizing potential problems, both the American College of Sports Medicine and the American Medical Association have issued position statements regarding wrestling and weight control (1, 2). Despite a history of concern, the patterns of weight loss and regain appear to have changed little and the tradition of making weight continues today (25).

In response to these concerns, the Wisconsin Interscholastic Athletic Association (WIAA) has established the Wisconsin Wrestling Minimal Weight Project (WWMWP). The project follows the guidelines set forth by the American College of Sports Medicine, which include assessment of body composition for each wrestler several weeks in advance of the competitive season (1). The assessment employs WIAA-certified measurers to determine each competitor’s appropriate minimal wrestling weight based on 7% body fat.

Estimation of minimal weight (MW) based on a laboratory method such as
hydrostatic weighing (HW) is not practical on a statewide basis because of cost, the lengthy procedures involved, and the lack of available equipment and trained personnel. Alternatives to HW must be accurate, inexpensive, and widely available. Previous investigations have found that anthropometric prediction equations for minimal weight meet these criteria. Anthropometric measurements based on limb circumferences, skeletal diameters, or skinfolds are commonly used in clinical settings.

Using a sample of high school wrestlers at a state championship, Tcheng and Tipton (27) developed equations using skeletal dimensions to predict minimal weight. Their investigation assumed the participants were at MW, but they did not employ a criterion measurement such as HW. Subsequent studies by Clarke (6) and Landwer et al. (14) to cross-validate their MW predictions met with inconsistent results. Neither study employed an objective criterion. Sinning et al. (24) and Williford et al. (33) used densitometry as a criterion-referenced approach to examine the validity of the Tcheng–Tipton equations and found the equations to consistently overpredict wrestlers’ minimal weight.

Other anthropometric equations have been used to assess body composition in high school wrestlers, but Sinning recommended caution when selecting a prediction equation because accuracy may be limited to the population from which they were derived (7). However, several equations originally derived from young adults have been cross-validated on adolescent athletes (29). Michael and Katch (18) used hydrostatic weighing to develop a prediction equation for high school students based on skinfold and girth measurements. It was subsequently validated (13) and later used to assess the body composition of high school wrestlers (12). Equations developed by Forsyth and Sinning (7) on college athletes have also been used to assess high school and college wrestlers (23, 24).

More recently, investigators have developed new equations and cross-validated existing ones on populations specifically made up of wrestlers (9, 28). In a large sample of midwestern wrestlers pooled from five laboratories, Thorland et al. (30) evaluated many of the anthropometric equations available to predict MW. In an effort to improve accuracy, revised versions of selected equations were provided which demonstrated low mean differences, high correlations, and low total errors.

Of the many anthropometric equations available to predict percent fat and calculate MW in wrestlers, six were selected from the literature for the present investigation. These were selected based on previously demonstrated predictive ability and their reliance on skinfolds. Each equation employs skinfolds exclusively, as the WIAA had previously selected this as the method for predicting minimal weight in the WWMWP. The decision was based on cost effectiveness, availability of trained measurers, and an attempt to reduce measurement variables during large-scale field testing at the high schools during preseason.

The WIAA objective was to predict MW as accurately as possible with the minimum number of variables necessary. Recent work had demonstrated the ability of skinfolds alone (30) to predict MW in wrestlers. Consequently, modified equations by Lohman, Katch, and Thorland (30) and original equations by Lohman (16) and Oppliger and Tipton (20) were included in the present cross-validation study.

Establishing minimal weight for an entire high school wrestling population in a state called for a valid method of estimating body density. Because numerous skinfold predictions were available (11, 16, 20, 29), the purpose of our study
was not to derive new anthropometric equations but to cross-validate existing equations for Wisconsin high school wrestlers. In preparation for mandatory MW testing, six equations were cross-validated to quantify the error in a sample of Wisconsin high school wrestlers. These equations were Lohman 1 (16), Iowa (20), Katch, Thorland 1, Thorland 2, and Lohman 2 (30) (Figure 1).
Methods

Subjects

The subjects were 69 male Caucasian high school age wrestlers; all were residents of Wisconsin and participants in summer wrestling camps on the University of Wisconsin campus during the summer of 1989. Based on body weight at the time of investigation, each of the 13 National Federation of State High School Associations weight classes was represented. Subject testing was done at early morning sessions prior to workouts and following an 8-hour fast. Normal hydration was encouraged. Informed written consent was obtained prior to completing the testing protocols.

Measurements

Anthropometric measurements included height, weight, and nine skinfolds. Height was measured with a stadiometer to the nearest 0.64 cm. Weight was measured on a beam balance platform scale to the nearest 0.11 kg. Nine skinfold sites (Figure 1) were measured with a Lange skinfold caliper. All measurements were taken on the right side of the body in serial fashion by the same investigator. Skinfold thickness was based on the average of two trials within 0.5 mm. If the two skinfold measurements at the same site differed by more than 0.5 mm, a third measurement was taken and the mean value was used in all further analyses.

Body density was determined by HW at residual volume (RV) as described by Behnke and Wilmore (3). A Chatillon 9-kg autopsy scale was used to obtain underwater weights. Eight to 10 trials were obtained for each subject. The mean of the heaviest 3 trials was used as the underwater weight for calculating body density. Residual volume was measured by the oxygen dilution method described by Wilmore (34) using a modified Collins 13.5-liter respirometer and a Med Science model 505 N2 analyzer. It was measured outside the tank with the subject in a seated position similar to that used during HW. The mean of two trials within 75 ml was used as the RV. An additional correction of 100 ml, to account for gastrointestinal gas, was used in the HW calculation (3). Percent body fat (%BF) was estimated from body density using the equation of Brozek et al. (5). Minimal weight was computed to be the subject's weight at 7% BF (fat-free body from HW/0.93).

Statistical Analysis

Six equations (Figure 1) validated by Oppliger and Tipton, Lohman, Katch, or Thorland were cross-validated against the criterion measure of minimal weight from hydrostatic weighing. Criterion-referenced cross-validation included (a) computation of concurrent validity coefficients using Pearson correlations, (b) comparisons of group means for MW using repeated-measures ANOVA and Bonferroni pairwise post hoc tests when appropriate, (c) determination of total error, as computed by the formula described by Lohman (16), and (d) scatter plots of the predicted versus hydrostatic MW. Data were analyzed using SAS, fifth edition (22).

Results

The physical characteristics of the subjects and anthropometric data are summarized in Table 1. The mean ± SD minimal weight values, correlations, and total
### Table 1

**Characteristics of Subjects**

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>15.7</td>
<td>1.1</td>
<td>14.0 – 18.0</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>63.3</td>
<td>8.1</td>
<td>46.8 – 86.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.2</td>
<td>6.3</td>
<td>146.1 – 179.7</td>
</tr>
<tr>
<td>Body density (g · ml⁻¹)</td>
<td>1.0744</td>
<td>0.011</td>
<td>1.0252 – 1.0947</td>
</tr>
<tr>
<td>% body fat (Brozek)</td>
<td>11.2</td>
<td>4.3</td>
<td>3.3 – 31.6</td>
</tr>
<tr>
<td>Minimal weight (kg)</td>
<td>58.9</td>
<td>6.9</td>
<td>42.5 – 72.9</td>
</tr>
</tbody>
</table>

**Skinfolds (mm)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>M</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>6.0</td>
<td>2.9</td>
<td>3.5 – 23.7</td>
</tr>
<tr>
<td>Triceps</td>
<td>8.1</td>
<td>3.3</td>
<td>4.0 – 23.5</td>
</tr>
<tr>
<td>Subscapula</td>
<td>8.1</td>
<td>3.3</td>
<td>4.5 – 30.7</td>
</tr>
<tr>
<td>Mid axilla</td>
<td>6.7</td>
<td>3.8</td>
<td>4.0 – 32.2</td>
</tr>
<tr>
<td>Suprailliac</td>
<td>8.7</td>
<td>5.6</td>
<td>4.0 – 38.5</td>
</tr>
<tr>
<td>Anterior suprailliac</td>
<td>6.7</td>
<td>3.7</td>
<td>4.0 – 30.7</td>
</tr>
<tr>
<td>Abdomen</td>
<td>10.5</td>
<td>7.1</td>
<td>5.0 – 44.0</td>
</tr>
<tr>
<td>Thigh</td>
<td>10.7</td>
<td>4.2</td>
<td>5.5 – 28.0</td>
</tr>
<tr>
<td>Calf</td>
<td>8.1</td>
<td>3.7</td>
<td>4.5 – 27.8</td>
</tr>
</tbody>
</table>

### Table 2

**Comparison of Means, Standard Deviations, r, and TE for Minimal Weight**

<table>
<thead>
<tr>
<th>Method</th>
<th>Minimal weight (kg)</th>
<th>M</th>
<th>SD</th>
<th>r</th>
<th>TE (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic weighing</td>
<td>58.9</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa</td>
<td>60.1*</td>
<td>6.7</td>
<td>.966</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Lohman 1</td>
<td>59.6*</td>
<td>6.5</td>
<td>.968</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Lohman 2</td>
<td>59.3*</td>
<td>6.4</td>
<td>.968</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Katch</td>
<td>59.3</td>
<td>6.5</td>
<td>.969</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Thorland 1</td>
<td>60.0*</td>
<td>6.5</td>
<td>.961</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Thorland 2</td>
<td>59.3</td>
<td>6.3</td>
<td>.920</td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>

*Significance @ p < .05.

Error are shown in Table 2. Correlations between methods are described in Table 3. When comparing predicted MW to criterion MW the correlations were high (r = .920 to .969), as were the correlations between methods (r = .924 to 1.000).
Table 3
Correlations Between Methods for Minimal Weight

<table>
<thead>
<tr>
<th>Method</th>
<th>Iowa</th>
<th>Lohman 1</th>
<th>Lohman 2</th>
<th>Katch</th>
<th>Thorland 1</th>
<th>Thorland 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic weighing</td>
<td>.966</td>
<td>.968</td>
<td>.968</td>
<td>.969</td>
<td>.961</td>
<td>.920</td>
</tr>
<tr>
<td>Iowa</td>
<td>.995</td>
<td>.995</td>
<td>.997</td>
<td>.983</td>
<td>.924</td>
<td>.954</td>
</tr>
<tr>
<td>Lohman 1</td>
<td></td>
<td>1.00</td>
<td>.998</td>
<td>.995</td>
<td>.954</td>
<td>.954</td>
</tr>
<tr>
<td>Lohman 2</td>
<td></td>
<td></td>
<td>.998</td>
<td>.995</td>
<td>.954</td>
<td>.938</td>
</tr>
<tr>
<td>Katch</td>
<td></td>
<td></td>
<td></td>
<td>.990</td>
<td></td>
<td>.969</td>
</tr>
<tr>
<td>Thorland 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All methods underpredicted %BF as compared to HW in this sample. Consequently, when minimal weight is calculated at 7% body fat, the equations tested overpredicted MW relative to HW. Mean comparisons between predicted and criterion MW yielded differences of 0.4 to 1.2 kg (Table 2). Differences were significant ($p<.05$) in the mean values for all but Katch and Thorland 2. The intermethod differences when predicting minimal weight from skinfolds varied by less than 0.8 kg. Intermethod comparisons yielded significant differences between Iowa, Katch, and Thorland 2.

Total error for MW, as described by Lohman (16), ranged from 1.7 to 1.8 kg in the Katch, Lohman 1, and Lohman 2 equations to 2.6 kg in the Thorland 2 equation (Table 2). For all equations, the regression lines closely approximated the line of identity (slope of 1.0 and intercept of 0) and the differences over the weight range were consistent (Figure 2). In the Lohman 1, Lohman 2, Katch, Thorland 1, and Iowa predictions, the regression lines showed small deviations from the line of identity with slopes $>0.90$. The Thorland 2 equation yielded a slope of 0.85.

Discussion

An important consideration when using anthropometry in estimating minimal weight is the size of the error associated with the prediction equation. When predicting %BF and calculating MW, part of the error is associated with the criterion measure, HW. The hydrostatic weighing procedure assumes constant hydration and reference densities of 1.1 g•ml$^{-1}$ and 0.9 g•ml$^{-1}$ for the fat-free body and fat, respectively. Unfortunately, in the adolescent wrestler these assumptions may be inappropriate. Children and adolescents have a higher percentage of water in the fat-free body as well as a skeletal system that is not fully mineralized and therefore lower in density than that of adults (15). It has been suggested that equations adjusted for this chemical immaturity be used in the adolescent population (8, 15). However, Thorland et al. (30) found lower total error in the Brozek equation than in age-adjusted equations when evaluating school-age wrestlers.
Figure 2 — Scatter plots of predicted minimal weight vs. criterion minimal weight, including regression coefficient (slope), constant (intercept), and $r^2$. 
Another suggestion in accounting for the chemical immaturity of the adolescent is to use multicomponent equations that correct for the differences in bone mineral content and hydration. However, Horswill et al. (8) concluded that a multicomponent model did not significantly improve the estimates of MW in adolescent males compared to the two-component model. He demonstrated that correction for hydration and bone mineral content did not significantly improve predictions in his sample. It has been suggested that these athletes may have more advanced chemical maturity since their activity level may enhance bone mineralization as well as muscular development (15, 17). They may therefore appear to be more like adults than their less active peers.

As a check for bias based on the chronological age of the subjects and accuracy of the prediction, we regressed criterion density from HW on sum of skinfolds in our sample. The subjects were divided into three age groups (<16, =16, >16). The results showed no significant difference between regression lines. Though its limitations are recognized, the two-component model of calculating body fatness from density remains the criterion for predicting MW and was used in this investigation.

Our data suggest that the characteristics of the Wisconsin sample are similar to those of high school wrestlers in other states. The weight and %BF of the subjects were consistent with data on wrestlers from other states around the country (9, 30). The mean density (1.0744 g/mL) of the subjects in this investigation was similar to that reported by Housh et al. (9) (1.0748 g/mL) and Thorland et al. (30) (1.0733 g/mL). This corresponds to %BF of 11.15, 11.04, and 11.59, respectively, when using Brozek’s conversion (5). No peculiarities seemed unique to Wisconsin high school wrestlers that might invalidate equations available for predicting MW. This information was not only of interest to the investigators but also to the WIAA, coaches, parents, and athletes involved in the mandatory MW testing.

From the six equations, statistically significant differences were shown in four when comparing MW mean values. However, these mean differences were clinically small (<1.3 kg). In a cross-validation sample, the variability as well as the means of the predicted values must be comparable to the criterion (16). Standard deviation values noted in the predictions (6.3–6.7 kg) were similar to the criterion (6.9 kg) MW.

Correlations were high (0.920–0.969) between predicted and criterion MW. However, comparison of predicted %BF with criterion %BF revealed correlations in the range of 0.784 to 0.800. Correlations involving MW are higher due to the influence of body weight on the scatter.

Total error (TE) is an important measure for judging accuracy in cross-validations (16) and is considered by Thorland et al. (30) to be the primary means of evaluating prediction equations. Lohman describes it as a better measure of the accuracy of a prediction than either a standard error of estimate (SEE) or correlation (16). Whereas the SEE reflects deviations of predicted versus criterion minimal weight about a regression line that fits the scatter plot, TE is reflective of the deviations around the ideal line with intercept 0 and slope of 1.0. Five of the six equations showed a TE <2.3 kg and three demonstrated a TE <1.9 kg. The lowest TE values were noted in the Lohman1, Lohman2, and Katch equations.
Internmethod comparisons revealed small differences in predicting MW by these six equations. On average, all methods underpredicted %BF and overpredicted MW. If the opposite were true, an overprediction of %BF during MW testing would wrongly suggest to the wrestler that a greater amount of weight could be lost. This could adversely affect both performance and health (1). However, according to our results the lower predicted mean %BF indicates that the wrestler would have a correspondingly higher minimal weight. If the goal of MW testing is to prevent the athlete from dropping too much weight, error in this direction may provide an additional margin of safety.

On the basis of these results, we conclude that skinfold prediction equations provide a valid method for estimating minimal weight in Wisconsin high school wrestlers, with the best predictors coming from revised equations by Lohman and Katch. In our sample, all equations showed small clinical differences. Three of the six equations (Lohman 1, Lohman 2, Katch) appeared to be more appropriate because of smaller mean differences, comparable variability, smaller total error, and higher correlations when compared to hydrostatic weighing.

Each of the variables used to evaluate the results of this cross-validation study (mean ± SD, r, TE, and regression analysis) provides important information in regard to predicted MW accuracy, and each should be weighed carefully in selecting an appropriate equation. It is clear that even with the most skilled anthropometrist, quantifiable error exists. It is critical that this error be recognized and understood by those responsible for MW determinations.

Caution must be used and the limitations recognized before MW testing is implemented on a large scale. Initially it appears that accuracy of skinfolds may be the limiting factor in the success of the WWMWP. However, the prediction of MW is based not only on skinfold values but also on the athlete’s body weight at the time of measurement. A lower minimal weight could be achieved by a reduction in body weight at the time of the skinfold measurement through fasting or dehydration. If the wrestler’s goal is to achieve a lower minimal weight, the evaluation could lead to the rapid weight loss practices that MW testing was meant to deter. Thorland et al. (30) have suggested that a single preseason evaluation, with the wrestler hydrated, be used to deter this behavior.

Research findings of the last 20 years indicate that many of the problems identified with “making weight” in wrestlers still exist today. The WIAA feels that the potential physiological and psychological consequences of these practices for high school students justifies rule changes in the state of Wisconsin. They have employed the help of health professionals and research committees to implement MW testing statewide. The data from this study lend support to the use of skinfold prediction equations to calculate a valid minimal wrestling weight under controlled testing conditions.

References


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