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Summary

This report summarizes the research findings that led to the policy decisions for development of the body fat content screening procedures and equations that are currently under consideration for inclusion in the Department of Defense (DoD) Instruction (DoDI) 1308.3, Physical Fitness and Body Fat Programs.

At a DoD meeting on 21 May 1998, results of a review by the Committee on Body Composition, Nutrition and Health, Military Nutrition Committee, Institute of Medicine were presented. It was recommended that a tiered body fat content standard be adopted. A weight-for-height screen would be adopted based on the recommendations of the Healthy People 2000 Committee: Healthy weights are represented by body mass index (BMI) values between 19 and 25, irrespective of gender. Service members exceeding the weight-for-height standards would have their body fat content determined. Men with body fat content values less than 20% body weight and women with values less than 30% body weight would be considered within standards. Men with values greater than 20% fat, but less than or equal to 26% fat, would be in a "cautionary zone" and acceptability of their body fat content would depend on performance on the Service's physical fitness test. For women, the cautionary zone values would be 30 to 36% fat.

Results of work performed at the Naval Health Research Center (NAVHLTHRSCHCEN) also were presented at the meeting. The use of a four-compartment model to determine body fat content was shown to reduce the error variance associated with body fat content measurement by 13 to 20%. Additionally, the use of a four-compartment model eliminates a systematic difference in body fat content estimation associated with ethnicity, which is inherent in the two-compartment model.

A variety of equations predicting four-compartment body fat content from body circumferences and height was presented. Prediction was shown to improve slightly by utilizing a non-linear equation form involving logarithms. It also was found that prediction of four-compartment body fat content from circumferences, as currently used by most of the Services, and in the logarithmic transform equations currently used, did not differ significantly ($p < 0.05$) in predictive accuracy from a variety of other model forms. It was recommended that work continue on equation development and, further, among the equations presented, the current

circumference measures would be retained. It also was recommended that a research group from outside DoD be contracted to conduct a parallel investigation to determine the best predictive equations from circumference values.

On 9 October 1998, a second meeting was held to review progress. At this meeting, researchers from Wright State University, Yellow Springs, OH, presented findings from the parallel equation development. Their final model was judged too complex to be used. In addition, the equations developed at NAVHLTHRSCHCEN were reviewed. Concern was raised about the form of the four-compartment analysis used at NAVHLTHRSCHCEN, specifically about the use of whole-body bioelectrical impedance analysis (BIA) to predict total body water (TBW). The group decided to recommend retention of the equations currently in use by the Navy and the Air Force. The rationale was that development of these equations has been documented in technical reports. Thus, a review of their development and validity was possible.

In their original development, body density was predicted, and then converted to percent fat. These equations were reformulated to allow direct prediction of percent body fat. Additionally, predicted percent fat values were analyzed for the influence of moderating variables. None were identified. The equations recommended for use by DoD were:

Men:

$\%\text{ body fat} = 86.010 \times \log_{10}(\text{abdomen II} - \text{neck}) - 70.041 \times \log_{10}(\text{height}) + 36.76$

($n = 594$, $R = 0.903$, SEE = 3.52 % fat)

Women:

$\%\text{ body fat} = 163.205 \times \log_{10}(\text{abdomen I} + \text{hip} - \text{neck}) - 97.684 \times \log_{10}(\text{height}) - 78.387$

($n = 202$, $R = 0.856$, SEE = 3.61 % fat)

Purpose

This report summarizes the research findings that led to development of the body fat content equations currently under consideration for inclusion in the next Department of Defense (DoD) Instruction (DoDI) 1308.3, Physical Fitness and Body Fat Programs.

Background

The Under Secretary of Defense (Personnel & Readiness), and Assistant Secretary of Defense (Force Management Policy) sponsored a meeting at the Pentagon on 21 May 1998 to review on-going research related to development of body fat content standards and prediction equations.

A proposal for new body fat content standards derived, in part, from the findings of a review conducted by the Committee on Body Composition, Nutrition and Health, Military Nutrition Committee, Institute of Medicine, under the Defense Women's Health Research Program (1998). LTC Karl Friedl of the U.S. Army Medical Research and Materiel Command presented these findings. The principal features of the proposal were that: (1) a tiered approach to body fat content standards be taken; (2) allowed levels of body fat content be tied to performance on the Service's physical fitness tests, and (3) the weight-for-height screening values be based on the recommendations of the Healthy People 2000 (i.e., that healthy weights correspond to body mass index [BMI] values between 19 and 25 $kg \cdot m^{-2}$, irrespective of gender or age) (Abernathy and Black, 1996). The tiered body fat content standards consisted of three levels: first, a lower boundary of 20% fat for men and 30% fat for women, at or below which body fat content is judged satisfactory irrespective of performance on the physical fitness test. Second, a cautionary zone of 20% < fat < 26% for men, and 30% < fat < 36% for women within which body fat content is judged satisfactory only if the person "performs well" on the Service physical fitness test. Determination of what constitutes performing well was to be left to the Services. Third, an upper boundary of 26% fat for men and 36% fat for women above which body fat content is judged to be unsatisfactory, irrespective of performance on fitness tests. This proposal differs from current Service practices in that there is no adjustment of the standards for age and that there is a tiered structure to the standards. Those in attendance at the meeting tentatively accepted the proposal or said they would take it under advisement.

Researchers at the Naval Health Research Center (NAVHLTHRSCHCEN) in San Diego were undertaking most of the on-going work in development of body fat content prediction for the Services. This work focused on use of percent body fat, derived from a four-compartment analysis of body fat content, as the criterion measure for equation development. Equations currently in use by the Services used a two-compartment analysis of body fat content as the criterion.

Dr. James Hodgdon presented the findings of the NAVHLTHRSCHCEN researchers. The first presentation dealt with an explanation of four-compartment body fat content measurement. The principal points were: first, that the assumption of equal fat-free mass density across individuals, which is part of the commonly employed two-compartment model, is invalid. The principal sources of deviation from this assumption, water and bone, can be measured and are used with determination of the fat and non-fat components of the non-bone, non-water body to make up a four-compartment analysis of body fat content. In the NAVHLTHRSCHCEN analysis, bone mineral content of the body was measured by dual-energy x-ray absorptiometry (DXA), and total body water (TBW) was estimated from bioelectrical impedance analysis (BIA). Second, the deviations from the assumption of equal fat-free mass density differ systematically across ethnic groups (e.g., African-Americans tends to have greater bone densities than Caucasian-Americans). Predictions based on equations developed using a two-compartment analysis will have systematic over or under estimation of body fat content associated with ethnicity. Estimations from equations based on a four-compartment analysis of body fat content will not have this systematic over or under prediction. Third, a four-compartment analysis yields a more precise estimate of body fat content. Based on the reliability coefficients presented by Friedl and coworkers (1992) the four-compartment analysis leads to a 13% reduction in error variance, compared with a two-compartment analysis. Comparison of the variances of the two- and four-compartment body fat content values in the NAVHLTHRSCHCEN data set revealed a 20% reduction in variance when the four-compartment analysis was used. Since the "true score" variance should be the same (the analyses were conducted on the same set of individuals), the reduction was attributed to the error variance.

Dr. Hodgdon also provided a presentation on prediction of body fat content from anthropometric variables. In his presentation, Dr. Hodgdon presented equations utilizing a variety of circumference measures and stature to predict four-compartment body fat content. Some of the predictive equations for men are provided in Table 1. In the NAVHLTHRSCHCEN data set, abdominal circumference is the best predictor of body fat content; therefore, it was always the first variable entered in the development of these comparative models. The multiple correlations for these equations do not differ significantly (*p* > 0.05), and they are reasonably equivalent models. Note that stature only contributes to the model when relaxed arm girth or neck girth is included.

Table 1. Equations to Predict Four-compartment Body Fat Content of Men from Circumferences and Height*

	Var1	Var2	Var3	Const.	R	SEE
Eq. 1	Abdomen	Forearm				
	0.622	-0.629		-18.887	0.90	2.99
Eq. 2	Abdomen	Ankle				
	0.624	-0.833		-18.691	0.89	3.05
Eq. 3	Abdomen	Wrist				
	0.614	-1.419		-11.982	0.90	3.02
Eq. 4	Abdomen	Shoulder				
	0.619	-0.144		-20.296	0.89	3.10
Eq. 5	Abdomen	Relaxed Arm	Height			
	0.608	-0.209	-0.064	-17.832	0.89	3.09
Eq. 6	Abdomen	Neck	Height			
	0.613	-0.306	-0.058	-14.629	0.89	3.11

* Numbers below the variable names are the regression weights.

Table 2 provides a similar comparison among equations to predict the body fat content of women. For women, waist circumference was the best predictor of body fat content, and was entered first in each of the modes. Again, these equations all represent equivalent

Table 2. Equations to Predict Four-compartment Body Fat Content of Women from Circumferences and Height*

	Var1	Var2	Var3	Var4	Const.	R	SEE
Eq. 1	Waist	Hip	Height	Neck			
	0.499	0.413	-0.167	-0.701	-0.169	0.89	3.08
Eq. 2	Waist	Hip	Height	Shoulder			
	0.492	0.448	-0.161	-0.256	-1.007	0.89	3.10
Eq. 3	Waist	Hip	Height	Wrist			
	0.412	0.437	-0.151	-1.119	-4.538	0.88	3.14
Eq. 4	Waist	Thigh	Neck	Height			
	0.549	0.492	-0.731	-0.123	1.264	0.86	3.12
Eq. 5	Waist	Thigh	Shoulder	Height			
	0.547	0.542	-0.277	-0.112	0.813	0.88	3.13
Eq. 6	Waist	Thigh	Wrist	Height			
	0.460	0.520	-1.147	-0.104	-3.319	0.88	3.19

* Numbers below the variable names are the regression weights.

models. For these regression models, the 4th variable accounts for approximately 1% of the variance and would not be included in most final equations.

The point of displaying these models was to show that once the initial predictor was selected (abdomen girth for men and waist girth for women), the models were equivalent, irrespective of the variables chosen later. This implies that the variables used currently by the Navy, the Marine Corps, and the Air Force (those in Eq. 6 for men and Eq. 1 for women) are as good as any other combination. Therefore, there was no compelling reason to select a set of variables different from those now in use by three of the four Services.

In the presentation of alternative predictive models, it was also shown that using the log transforms of the variables or logs of linear combinations of variables improved the fit of the model, but not significantly. Again, the point was that there was no compelling reason to change the form of the current equations, which involve logs of linear combinations of circumference values.

Dr. Hodgdon also showed the cross-validation of the equation currently used by the Marine Corps on the more-recent segment of the NAVHLTHRSCHCEN data set. The Marine Corps equation has the form of the current Navy equations, but was developed using the NAVHLTHRSCHCEN four-compartment analysis data set. The equations (men's and women's) cross-validated well, but were not the best model for the entire data set.

Comments on the NAVHLTHRSCHCEN presentations focused on the question of when sufficient data would be collected to decide when the "final" equation would be developed and concern over whether BIA as the method of measuring TBW was suitably accurate or precise to justify thinking of the analysis as being truly a four-compartment model.

From this meeting, it was concluded that (1) the proposed body fat content standards would be taken under advisement, and (2) NAVHLTHRSCHCEN would continue to collect data until August, 1998 with their findings evaluated in September, 1998.

Subsequent to the May, 1998 meeting, LTC Karl Friedl and Mr. Frank Spencer from Office of the Secretary of Defense (Personnel & Readiness) decided that an independent development of an anthropometry-based equation for prediction of body fat content be carried out. The objectives of the development were to determine whether an anthropometrically based equation could be developed that was sensitive to small changes in body fat content. A U.S. Army data set was provided as the basis for this development. This dataset contained body fat content, determined from DXA and anthropometric variables recorded prior to and following Army Basic Training on a sample of female Army trainees. The NAVHLTHRSCHCEN data set was to be used for cross-validation. Additionally, NAVHLTHRSCHCEN was tasked with determining whether the suggested equations were subject to any moderating influences that might show gender differences and lead to unequal application of the predictive equations between genders.

Meeting of 9 October 1998

On 9 October 1998, a meeting was held at NAVHLTHRSCHCEN to review progress on the development of a body fat prediction equation for the Services. Present were Mr. Frank Spencer from OSD (P&R), LTC Karl Friedl from USAMRMC, MAJ Neal Baumgartner from U.S. Air Force School of Aerospace Medicine, Dr. James Hodgdon and LCDR Kathleen Kujawa from NAVHLTHRSCHCEN, and Dr. Shumei Guo and Dr. W. Cameron Chumlea from Wright State University (contractors carrying out the independent equation development).

LTC Friedl gave a status review, and Dr. Guo provided a presentation of findings (Guo, 1998). Wright State Univeristy investigated the range of possible equations for body fat content prediction in the U.S. Army data set using the all-sets regression technique (Guo & Chumlea, 1996). The final model presented was judged too complex to be used practically.

There followed a discussion of the NAVHLTHRSCHCEN equations presented at the May meeting. The group had sufficient discomfort with the use of BIA as a predictor of TBW and the fact that the study findings had not yet been published or peer reviewed, that it was decided to use the current Navy equations (Hodgdon & Beckett, 1984a, 1984b) as the DoD body fat content prediction equations. The development of these equations was published in technical report form and had been presented before the American College of Sports Medicine, where it was favorably reviewed. The equations also have been cross-validated in several research studies, with suitable predictive accuracy (correlation coefficients of 0.85 or greater).

<u>Moderators of Percent Fat Prediction</u>

A variety of variables were examined to determine whether they influenced the prediction of four-compartment fat from the Navy equations. Two analysis schemes were used. For category variables (e.g., race and gender), the influence of the variable on the regression between Navy-predicted fat and four-compartment fat were tested using Analysis of Variance. This analysis determines whether there are significant differences in the slope or intercept of the regression model associated with category membership. For continuous variables (e.g., stature, weight, and neck size), a regression analysis was used. Percent fat from the Navy equations was forced in as the first step in the regression to predict four-compartment fat. The moderator being tested was

Table 3. Results of Analysis of Variance for Category Moderators of Percent Fat Prediction*

Variable	Effect on Intercept			Effect on Slope		
	$F_{501,1}$	Significance	% of variance	$F_{501,1}$	Significance	% of Variance
Gender (male/female)	1.35	NS		1.97	NS	
Race (black/white)	12.15	$p < 0.01$	0.3	8.09	$p < 0.01$	0.2

* With significant effects, the percentage of the total variance accounted for is displayed

then allowed to enter using stepwise criterion. This analysis determines whether a variable accounts for a significant increment in the accounted-for variance in the regression. Because the sample size was approximately 500 individuals, a variable did not have to account for much more than 0.15 percent of the variance to be a significant predictor.

Table 4. Results of Analysis of Variance for Continuous Moderators of Percent Fat Prediction

Variable	Effect on Regression		
	$F_{502,1}$	Significance	% of variance
Height	15.67	$p < 0.01$	0.5
Weight	7.951	$p < 0.01$	0.2
Waist circumference		NS	
Abdomen circumference	6.16	$p < 0.01$	0.2
Hip circumference	6.71	$p < 0.01$	0.2
Neck circumference		NS	
Age		NS	
BMI		NS	
Bone Mineral Content		NS	
Resistance at 50KHz	70.23	$p < 0.01$	1.8
Estimated TBW		NS	

Table 3 shows the effect of category moderator variables upon the predictions. Table 4 provides the analysis of the effects of continuous moderator variables upon the predictions.

As can be seen in Table 3, neither gender nor race has a meaningful effect on the prediction of four-compartment fat for the Navy equations. The lack of a significant gender moderating effect implies that the models fit equally well for both genders. Although there is a "significant" effect on the regression associated with race, the total percentage of the variance accounted for by the slope and intercept effects is less than 0.5%.

As was the case with the category variables, none of the continuous variables examined had a meaningful effect on the prediction of four-compartment fat using the Navy equations (see Table 4). Whole-body electrical resistance from BIA accounted for an additional 1.8% of the variance when added to the prediction model. Two percent of the variance or greater explained is a common criterion for inclusion in a regression model. Therefore, whole body electrical resistance has a "nearly meaningful" effect on the regression and should be investigated as a meaningful variable for inclusion in body fat predictive equations. In conclusion, it does not appear that there are biases in prediction of body fat content associated with the variables examined in these analyses.

Reformulation of the Navy equations.

Prior to inclusion in the DoDI, it was requested that the form of the Navy equations be changed from prediction of body density (the form that was originally developed) to prediction of percent body fat. Additionally, it was requested that the equations be expressed in English, rather than metric units (inches rather than centimeters). The mathematics involved in achieving these changes is difficult. Therefore, it was decided to calculate the desired regressions from the original Navy sample. However, the sample upon which the density prediction equations were developed could not be matched exactly. A few individuals appear to have been dropped from the sample after the original data analysis. The equations to predict body density from metric measurements on this subset of the original sample are virtually identical to those in the original technical reports (Hodgdon and Beckett; 1984a, 1984b), and they produce virtually the same results when they are rounded to the nearest percent fat. In the subsample:

Males: (n = 594 vs. 602 in the original development)

$$\% \text{ body fat} = 86.010 \times \log_{10}(\text{abdomen II} - \text{neck}) - 70.041 \times \log_{10}(\text{height}) + 36.76$$

(R = 0.903, SEE = 3.52 % fat)

Females: (n = 202 vs. 206 in the original development)

$$\% \text{ body fat} = 163.205 \times \log_{10}(\text{abdomen I} + \text{hip} - \text{neck}) - 97.684 \times \log_{10}(\text{height}) - 78.387$$

(R = 0.856, SEE = 3.61 % fat)

where all measurements are in inches.

Tables of estimated percent body fat utilizing these equations are attached as Appendix A of this report.

Predicted percent fat values from the equations provided above have been compared with percent fat values from four-compartment analysis in the current NAVHLTHRSCHCEN data set. For men, the correlation coefficient was 0.885 and the standard error of measurement is 3.15% fat. The mean difference between measured and predicted values is -0.833% fat, the predicted values being greater, on average, than the measured four-compartment percent fat. Comparisons with two-compartment fat values reveal a correlation coefficient of 0.89, a standard error of measurement of 3.37% fat, and a mean difference of –1.25% fat; again, with the predicted value being greater than the measured. For women, comparisons with four-compartment fat provide a correlation coefficient of 0.89, a standard error of measurement of 3.12% fat, and a mean difference of –2.00% fat. Comparisons with two-compartment fat produced a correlation coefficient of 0.82, standard error of measurement of 4.15% fat, and a mean difference of –3.22% fat. It is noteworthy that, in this newer sample, the Navy equations are better predictors of the percent fat values from four-compartment analysis than they are of values from a two-compartment analysis.

When compared with the current Marine Corps equations, the reformulated Navy equations are correlated almost perfectly ($R \cong 1.0$). This is to be expected since both sets of equations involve the same variables organized in the same fashion. However, the mean differences between percent fat values predicted by the Navy equations and those predicted by the Marine Corps equations are 1.09% fat for men and 3.04% fat for women. This means that, with the implementation of these Navy equations, Marines will be predicted to have greater percent fat values than at present.

Summary and Recommendations

The method of body water estimation from BIA needs to be validated for use in the estimation of multicompartment models of body fat content. Further, the Marine Corps equations based on this approach should be further validated against the Navy sample or against another sample to determine which of the equations (Navy or Marine Corps) has the greater validity. The need for comparative cross-validation is not justification for delaying implementation of a new DoDI. The two sets of equations are based on the same measurements and of the same general form. Therefore, changes in the equation can be implemented simply by substitution of a new body fat table.

References

Institute of Medicine (1998). *Assessing Readiness in Military Women.* Washington, DC. National Academy Press.

Abernathy, R.P. and D.R. Black (1996). Healthy body weights: an alternative perspective. *American Journal of Clinical Nutrition.* 63(suppl):448S-451S.

Friedl, K.E., J.P. DeLuca, L.J. Marchitelli, and J.A. Vogel (1992). Reliability of body-fat estimations from a four-compartment model by using density, body water, and bone mineral measurements. *American Journal of Clinical Nutrition.* 55:764-770

Guo, S, and W. C. Chumlea (1996). Statistical methods for the development and testing of predictive equations. In: *Human Body Composition.* AF Roche, SB Heymsfield, TG Lohman (eds.). Human Kenetics Books, Champaign, IL pp. 191-202.

Guo, S. and W.C. Chumlea (1998). Prediction equations for percent body fat. Interim Report for Consortium Research Fellows Program, Contract Number DASW01-97-C-0077. Wright State University School of Medicine, Yellow Springs, OH.

Hodgdon, J.A. and M.B. Beckett (1984a). Prediction of percent body fat for U.S. Navy men from body circumferences and height. Report No. 84-11, Naval Health Research Center, San Diego, CA

Hodgdon, J.A. and M.B. Beckett (1984b). Prediction of percent body fat for U.S. Navy women from body circumferences and height. Report No. 84-29, Naval Health Research Center, San Diego, CA

Appendix A

Tables for the Estimation of Body Fat Content from Circumferences and Stature

PERCENT FAT ESTIMATION FOR MEN

Circumference Value*	Height (in) 60.0	60.5	61.0	61.5	62.0	62.5	63.0	63.5	64.0	64.5
13.5	9	9								
14.0	11	11	10	10	10	10	9	9		
14.5	12	12	12	11	11	11	11	10	10	10
15.0	13	13	13	13	12	12	12	12	11	11
15.5	15	14	14	14	14	13	13	13	13	12
16.0	16	16	15	15	15	15	14	14	14	14
16.5	17	17	16	16	16	16	15	15	15	15
17.0	18	18	18	17	17	17	17	16	16	16
17.5	19	19	19	18	18	18	18	17	17	17
18.0	20	20	20	19	19	19	19	18	18	18
18.5	21	21	21	20	20	20	20	19	19	19
19.0	22	22	22	21	21	21	21	20	20	20
19.5	23	23	23	22	22	22	22	21	21	21
20.0	24	24	24	23	23	23	23	22	22	22
20.5	25	25	25	24	24	24	24	23	23	23
21.0	26	26	25	25	25	25	24	24	24	24
21.5	27	27	26	26	26	26	25	25	25	25
22.0	28	27	27	27	27	26	26	26	26	25
22.5	29	28	28	28	28	27	27	27	27	26
23.0	29	29	29	29	28	28	28	28	27	27
23.5	30	30	30	29	29	29	29	28	28	28
24.0	31	31	30	30	30	30	29	29	29	29
24.5	32	31	31	31	31	30	30	30	30	29
25.0	32	32	32	32	31	31	31	31	30	30
25.5	33	33	33	32	32	32	32	31	31	31
26.0	34	34	33	33	33	33	32	32	32	32
26.5	35	34	34	34	34	33	33	33	33	32
27.0	35	35	35	35	34	34	34	34	33	33
27.5	36	36	36	35	35	35	35	34	34	34
28.0	37	36	36	36	36	35	35	35	35	34
28.5			37	37	36	36	36	36	35	35
29.0					37	37	37	36	36	36
29.5								37	37	36
30.0										
30.5										
31.0										
31.5										
32.0										
32.5										
33.0										
33.5										
34.0										
34.5										
35.0										

* Circumference Value = abdomen circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR MEN

Circumference Value*	Height (in) 65.0	65.5	66.0	66.5	67.0	67.5	68.0	68.5	69.0	69.5
13.5										
14.0										
14.5	10	9	9							
15.0	11	11	10	10	10	10	10	9	9	
15.5	12	12	12	11	11	11	11	11	10	10
16.0	13	13	13	13	12	12	12	12	12	11
16.5	14	14	14	14	14	13	13	13	13	12
17.0	16	15	15	15	15	14	14	14	14	14
17.5	17	16	16	16	16	16	15	15	15	15
18.0	18	18	17	17	17	17	16	16	16	16
18.5	19	19	18	18	18	18	17	17	17	17
19.0	20	20	19	19	19	19	18	18	18	18
19.5	21	21	20	20	20	20	19	19	19	19
20.0	22	21	21	21	21	21	20	20	20	20
20.5	23	22	22	22	22	21	21	21	21	21
21.0	24	23	23	23	23	22	22	22	22	21
21.5	24	24	24	24	23	23	23	23	23	22
22.0	25	25	25	25	24	24	24	24	23	23
22.5	26	26	26	25	25	25	25	24	24	24
23.0	27	27	26	26	26	26	26	25	25	25
23.5	28	27	27	27	27	27	26	26	26	26
24.0	28	28	28	28	28	27	27	27	27	26
24.5	29	29	29	29	28	28	28	28	27	27
25.0	30	30	30	29	29	29	29	28	28	28
25.5	31	31	30	30	30	30	29	29	29	29
26.0	31	31	31	31	31	30	30	30	30	29
26.5	32	32	32	32	31	31	31	31	30	30
27.0	33	33	32	32	32	32	32	31	31	31
27.5	34	33	33	33	33	32	32	32	32	32
28.0	34	34	34	34	33	33	33	33	32	32
28.5	35	35	34	34	34	34	34	33	33	33
29.0	36	35	35	35	35	34	34	34	34	34
29.5	36	36	36	36	35	35	35	35	34	34
30.0	37	37	36	36	36	36	35	35	35	35
30.5			37	37	37	36	36	36	36	35
31.0						37	37	36	36	36
31.5									37	37
32.0										
32.5										
33.0										
33.5										
34.0										
34.5										
35.0										

* Circumference Value = abdomen circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR MEN

Circumference Value*	Height (in) 70.0	70.5	71.0	71.5	72.0	72.5	73.0	73.5	74.0	74.5
13.5										
14.0										
14.5										
15.0										
15.5	10	10	9	9	9					
16.0	11	11	11	10	10	10	10	10	9	9
16.5	12	12	12	12	11	11	11	11	11	10
17.0	13	13	13	13	13	12	12	12	12	11
17.5	14	14	14	14	14	13	13	13	13	13
18.0	15	15	15	15	15	14	14	14	14	14
18.5	17	16	16	16	16	15	15	15	15	15
19.0	18	17	17	17	17	16	16	16	16	16
19.5	18	18	18	18	18	17	17	17	17	17
20.0	19	19	19	19	19	18	18	18	18	18
20.5	20	20	20	20	19	19	19	19	19	18
21.0	21	21	21	21	20	20	20	20	20	19
21.5	22	22	22	21	21	21	21	21	20	20
22.0	23	23	23	22	22	22	22	22	21	21
22.5	24	24	23	23	23	23	23	22	22	22
23.0	25	24	24	24	24	24	23	23	23	23
23.5	25	25	25	25	25	24	24	24	24	24
24.0	26	26	26	26	25	25	25	25	25	24
24.5	27	27	27	26	26	26	26	26	25	25
25.0	28	28	27	27	27	27	26	26	26	26
25.5	29	28	28	28	28	27	27	27	27	27
26.0	29	29	29	29	28	28	28	28	28	27
26.5	30	30	30	29	29	29	29	28	28	28
27.0	31	30	30	30	30	30	29	29	29	29
27.5	31	31	31	31	30	30	30	30	30	29
28.0	32	32	32	31	31	31	31	31	30	30
28.5	33	32	32	32	32	32	31	31	31	31
29.0	33	33	33	33	32	32	32	32	32	31
29.5	34	34	34	33	33	33	33	32	32	32
30.0	35	34	34	34	34	34	33	33	33	33
30.5	35	35	35	35	34	34	34	34	34	33
31.0	36	36	35	35	35	35	35	34	34	34
31.5	36	36	36	36	36	35	35	35	35	35
32.0	37	37	37	36	36	36	36	36	35	35
32.5				37	37	36	36	36	36	36
33.0							37	37	36	36
33.5										37
34.0										
34.5										
35.0										

* Circumference Value = abdomen circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR MEN

Circumference Value*	Height (in) 75.0	75.5	76.0	76.5	77.0	77.5	78.0	78.5	79.0	79.5
13.5										
14.0										
14.5										
15.0										
15.5										
16.0										
16.5	10	10	10	10	9	9				
17.0	11	11	11	11	10	10	10	10	10	9
17.5	12	12	12	12	12	11	11	11	11	11
18.0	13	13	13	13	13	12	12	12	12	12
18.5	14	14	14	14	14	13	13	13	13	13
19.0	15	15	15	15	15	14	14	14	14	14
19.5	16	16	16	16	16	15	15	15	15	15
20.0	17	17	17	17	17	16	16	16	16	16
20.5	18	18	18	18	17	17	17	17	17	16
21.0	19	19	19	19	18	18	18	18	18	17
21.5	20	20	20	19	19	19	19	19	18	18
22.0	21	21	20	20	20	20	20	20	19	19
22.5	22	22	21	21	21	21	21	20	20	20
23.0	23	22	22	22	22	22	21	21	21	21
23.5	23	23	23	23	23	22	22	22	22	22
24.0	24	24	24	24	23	23	23	23	23	22
24.5	25	25	25	24	24	24	24	24	23	23
25.0	26	25	25	25	25	25	24	24	24	24
25.5	26	26	26	26	26	25	25	25	25	25
26.0	27	27	27	27	26	26	26	26	26	25
26.5	28	28	27	27	27	27	27	26	26	26
27.0	29	28	28	28	28	28	27	27	27	27
27.5	29	29	29	29	28	28	28	28	28	27
28.0	30	30	29	29	29	29	29	29	28	28
28.5	31	30	30	30	30	30	29	29	29	29
29.0	31	31	31	31	30	30	30	30	30	29
29.5	32	32	31	31	31	31	31	30	30	30
30.0	32	32	32	32	32	31	31	31	31	31
30.5	33	33	33	32	32	32	32	32	32	31
31.0	34	33	33	33	33	33	33	32	32	32
31.5	34	34	34	34	33	33	33	33	33	33
32.0	35	35	34	34	34	34	34	33	33	33
32.5	35	35	35	35	35	34	34	34	34	34
33.0	36	36	36	35	35	35	35	35	34	34
33.5	37	36	36	36	36	36	35	35	35	35
34.0		37	37	37	36	36	36	36	36	35
34.5					37	37	37	36	36	36
35.0								37	37	36

* Circumference Value = abdomen circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in)									
	58.0	58.5	59.0	59.5	60.0	60.5	61.0	61.5	62.0	62.5
45.0	19									
45.5	20	20	19							
46.0	21	20	20	20	19					
46.5	21	21	21	20	20	20	19	19		
47.0	22	22	22	21	21	20	20	20	19	19
47.5	23	23	22	22	22	21	21	21	20	20
48.0	24	23	23	23	22	22	22	21	21	21
48.5	24	24	24	23	23	23	22	22	22	21
49.0	25	25	24	24	24	23	23	23	22	22
49.5	26	26	25	25	24	24	24	23	23	23
50.0	27	26	26	26	25	25	24	24	24	23
50.5	27	27	27	26	26	26	25	25	25	24
51.0	28	28	27	27	27	26	26	26	25	25
51.5	29	28	28	28	27	27	27	26	26	26
52.0	29	29	29	28	28	28	27	27	27	26
52.5	30	30	29	29	29	28	28	28	27	27
53.0	31	30	30	30	29	29	29	28	28	28
53.5	31	31	31	30	30	30	29	29	29	28
54.0	32	32	31	31	31	30	30	30	29	29
54.5	33	32	32	32	31	31	31	30	30	30
55.0	33	33	33	32	32	32	31	31	31	30
55.5	34	34	33	33	33	32	32	32	31	31
56.0	35	34	34	34	33	33	33	32	32	31
56.5	35	35	35	34	34	34	33	33	32	32
57.0	36	36	35	35	34	34	34	33	33	33
57.5	37	36	36	35	35	35	34	34	34	33
58.0	37	37	36	36	36	35	35	35	34	34
58.5	38	37	37	37	36	36	36	35	35	35
59.0	38	38	38	37	37	37	36	36	36	35
59.5	39	39	38	38	38	37	37	36	36	36
60.0	40	39	39	38	38	38	37	37	37	36
60.5	40	40	39	39	39	38	38	38	37	37
61.0	41	40	40	40	39	39	39	38	38	38
61.5	41	41	41	40	40	40	39	39	38	38
62.0	42	42	41	41	40	40	40	39	39	39

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in) 58.0	58.5	59.0	59.5	60.0	60.5	61.0	61.5	62.0	62.5
62.5	42	42	42	41	41	41	40	40	40	39
63.0	43	43	42	42	42	41	41	41	40	40
63.5	44	43	43	42	42	42	41	41	41	40
64.0	44	44	43	43	43	42	42	42	41	41
64.5	45	44	44	44	43	43	43	42	42	42
65.0	45	45	45	44	44	43	43	43	42	42
65.5	46	45	45	45	44	44	44	43	43	43
66.0	46	46	46	45	45	45	44	44	43	43
66.5	47	46	46	46	45	45	45	44	44	44
67.0			47	46	46	46	45	45	45	44
67.5				47	46	46	46	45	45	45
68.0					47	47	46	46	46	45
68.5							47	46	46	46
69.0								47	47	46
69.5										47
70.0										
70.5										
71.0										
71.5										
72.0										
72.5										
73.0										
73.5										
74.0										
74.5										
75.0										
75.5										
76.0										
76.5										
77.0										
77.5										
78.0										
78.5										
79.0										
79.5										

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference	Height (in)									
Value*	63.0	63.5	64.0	64.5	65.0	65.5	66.0	66.5	67.0	67.5
45.0										
45.5										
46.0										
46.5										
47.0										
47.5	19	19								
48.0	20	20	20	19						
48.5	21	21	20	20	20	19				
49.0	22	21	21	21	20	20	20	19	19	
49.5	22	22	22	21	21	21	20	20	20	19
50.0	23	23	22	22	22	21	21	21	21	20
50.5	24	23	23	23	23	22	22	22	21	21
51.0	25	24	24	24	23	23	23	22	22	22
51.5	25	25	25	24	24	24	23	23	23	22
52.0	26	26	25	25	25	24	24	24	23	23
52.5	27	26	26	26	25	25	25	24	24	24
53.0	27	27	27	26	26	26	25	25	25	24
53.5	28	28	27	27	27	26	26	26	25	25
54.0	29	28	28	28	27	27	27	26	26	26
54.5	29	29	29	28	28	28	27	27	27	26
55.0	30	30	29	29	29	28	28	28	27	27
55.5	31	30	30	30	29	29	29	28	28	28
56.0	31	31	30	30	30	30	29	29	29	28
56.5	32	31	31	31	30	30	30	29	29	29
57.0	32	32	32	31	31	31	30	30	30	29
57.5	33	33	32	32	32	31	31	31	30	30
58.0	34	33	33	33	32	32	32	31	31	31
58.5	34	34	34	33	33	33	32	32	32	31
59.0	35	35	34	34	34	33	33	33	32	32
59.5	35	35	35	34	34	34	33	33	33	33
60.0	36	36	35	35	35	34	34	34	33	33
60.5	37	36	36	36	35	35	35	34	34	34
61.0	37	37	37	36	36	36	35	35	35	34
61.5	38	37	37	37	36	36	36	36	35	35
62.0	38	38	38	37	37	37	36	36	36	35

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in)									
	63.0	63.5	64.0	64.5	65.0	65.5	66.0	66.5	67.0	67.5
62.5	39	39	38	38	38	37	37	37	36	36
63.0	40	39	39	39	38	38	38	37	37	37
63.5	40	40	39	39	39	38	38	38	37	37
64.0	41	40	40	40	39	39	39	38	38	38
64.5	41	41	41	40	40	40	39	39	39	38
65.0	42	41	41	41	40	40	40	39	39	39
65.5	42	42	42	41	41	41	40	40	40	39
66.0	43	42	42	42	41	41	41	41	40	40
66.5	43	43	43	42	42	42	41	41	41	40
67.0	44	44	43	43	43	42	42	42	41	41
67.5	44	44	44	43	43	43	42	42	42	41
68.0	45	45	44	44	44	43	43	43	42	42
68.5	45	45	45	44	44	44	43	43	43	43
69.0	46	46	45	45	45	44	44	44	43	43
69.5	46	46	46	45	45	45	44	44	44	44
70.0	47	47	46	46	46	45	45	45	44	44
70.5			47	46	46	46	46	45	45	45
71.0				47	47	46	46	46	45	45
71.5						47	47	46	46	46
72.0							47	47	46	46
72.5									47	47
73.0										
73.5										
74.0										
74.5										
75.0										
75.5										
76.0										
76.5										
77.0										
77.5										
78.0										
78.5										
79.0										
79.5										

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in) 68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5
45.0										
45.5										
46.0										
46.5										
47.0										
47.5										
48.0										
48.5										
49.0										
49.5	19									
50.0	20	20	19							
50.5	21	20	20	20	19	19				
51.0	21	21	21	20	20	20	19	19		
51.5	22	22	21	21	21	20	20	20	20	19
52.0	23	22	22	22	21	21	21	21	20	20
52.5	23	23	23	22	22	22	22	21	21	21
53.0	24	24	23	23	23	22	22	22	22	21
53.5	25	24	24	24	23	23	23	23	22	22
54.0	25	25	25	24	24	24	24	23	23	23
54.5	26	26	25	25	25	24	24	24	24	23
55.0	27	26	26	26	25	25	25	25	24	24
55.5	27	27	27	26	26	26	25	25	25	25
56.0	28	28	27	27	27	26	26	26	25	25
56.5	29	28	28	28	27	27	27	26	26	26
57.0	29	29	29	28	28	28	27	27	27	26
57.5	30	29	29	29	29	28	28	28	27	27
58.0	30	30	30	29	29	29	29	28	28	28
58.5	31	31	30	30	30	29	29	29	29	28
59.0	32	31	31	31	30	30	30	29	29	29
59.5	32	32	32	31	31	31	30	30	30	29
60.0	33	32	32	32	32	31	31	31	30	30
60.5	33	33	33	32	32	32	32	31	31	31
61.0	34	34	33	33	33	32	32	32	32	31
61.5	35	34	34	34	33	33	33	32	32	32
62.0	35	35	35	34	34	34	33	33	33	32

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in) 68.0	68.5	69.0	69.5	70.0	70.5	71.0	71.5	72.0	72.5
62.5	36	35	35	35	34	34	34	34	33	33
63.0	36	36	36	35	35	35	34	34	34	34
63.5	37	37	36	36	36	35	35	35	34	34
64.0	37	37	37	36	36	36	36	35	35	35
64.5	38	38	37	37	37	36	36	36	36	35
65.0	38	38	38	38	37	37	37	36	36	36
65.5	39	39	38	38	38	37	37	37	37	36
66.0	40	39	39	39	38	38	38	37	37	37
66.5	40	40	39	39	39	39	38	38	38	37
67.0	41	40	40	40	39	39	39	39	38	38
67.5	41	41	41	40	40	40	39	39	39	38
68.0	42	41	41	41	40	40	40	40	39	39
68.5	42	42	42	41	41	41	40	40	40	39
69.0	43	42	42	42	41	41	41	41	40	40
69.5	43	43	43	42	42	42	41	41	41	41
70.0	44	43	43	43	43	42	42	42	41	41
70.5	44	44	44	43	43	43	42	42	42	42
71.0	45	44	44	44	44	43	43	43	42	42
71.5	45	45	45	44	44	44	43	43	43	43
72.0	46	45	45	45	45	44	44	44	43	43
72.5	46	46	46	45	45	45	44	44	44	44
73.0	47	46	46	46	45	45	45	45	44	44
73.5		47	47	46	46	46	45	45	45	44
74.0				47	46	46	46	46	45	45
74.5					47	47	46	46	46	45
75.0							47	46	46	46
75.5								47	47	46
76.0										47
76.5										
77.0										
77.5										
78.0										
78.5										
79.0										
79.5										

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in) 73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5
45.0										
45.5										
46.0										
46.5										
47.0										
47.5										
48.0										
48.5										
49.0										
49.5										
50.0										
50.5										
51.0										
51.5										
52.0	20	19	19							
52.5	20	20	20	19	19					
53.0	21	21	20	20	20	20	19	19		
53.5	22	21	21	21	21	20	20	20	19	19
54.0	22	22	22	21	21	21	21	20	20	20
54.5	23	23	22	22	22	22	21	21	21	20
55.0	24	23	23	23	22	22	22	22	21	21
55.5	24	24	24	23	23	23	23	22	22	22
56.0	25	25	24	24	24	23	23	23	23	22
56.5	26	25	25	25	24	24	24	24	23	23
57.0	26	26	26	25	25	25	24	24	24	24
57.5	27	26	26	26	26	25	25	25	25	24
58.0	27	27	27	27	26	26	26	25	25	25
58.5	28	28	27	27	27	27	26	26	26	25
59.0	29	28	28	28	27	27	27	27	26	26
59.5	29	29	29	28	28	28	27	27	27	27
60.0	30	30	29	29	29	28	28	28	28	27
60.5	30	30	30	30	29	29	29	28	28	28
61.0	31	31	30	30	30	30	29	29	29	28
61.5	32	31	31	31	30	30	30	30	29	29
62.0	32	32	32	31	31	31	30	30	30	30

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

PERCENT FAT ESTIMATION FOR WOMEN

Circumference Value*	Height (in) 73.0	73.5	74.0	74.5	75.0	75.5	76.0	76.5	77.0	77.5
62.5	33	32	32	32	32	31	31	31	30	30
63.0	33	33	33	32	32	32	32	31	31	31
63.5	34	34	33	33	33	32	32	32	32	31
64.0	34	34	34	34	33	33	33	32	32	32
64.5	35	35	34	34	34	33	33	33	33	32
65.0	35	35	35	35	34	34	34	33	33	33
65.5	36	36	35	35	35	35	34	34	34	33
66.0	37	36	36	36	35	35	35	35	34	34
66.5	37	37	37	36	36	36	35	35	35	35
67.0	38	37	37	37	36	36	36	36	35	35
67.5	38	38	38	37	37	37	36	36	36	36
68.0	39	38	38	38	38	37	37	37	36	36
68.5	39	39	39	38	38	38	37	37	37	37
69.0	40	39	39	39	39	38	38	38	37	37
69.5	40	40	40	39	39	39	39	38	38	38
70.0	41	40	40	40	40	39	39	39	38	38
70.5	41	41	41	40	40	40	40	39	39	39
71.0	42	41	41	41	41	40	40	40	39	39
71.5	42	42	42	41	41	41	41	40	40	40
72.0	43	42	42	42	42	41	41	41	40	40
72.5	43	43	43	42	42	42	42	41	41	41
73.0	44	43	43	43	43	42	42	42	41	41
73.5	44	44	44	43	43	43	42	42	42	42
74.0	45	44	44	44	44	43	43	43	42	42
74.5	45	45	45	44	44	44	43	43	43	43
75.0	46	45	45	45	44	44	44	44	43	43
75.5	46	46	46	45	45	45	44	44	44	44
76.0	47	46	46	46	45	45	45	45	44	44
76.5		47	46	46	46	46	45	45	45	44
77.0			47	47	46	46	46	45	45	45
77.5					47	47	46	46	46	45
78.0						47	47	46	46	46
78.5								47	47	46
79.0										47
79.5										

* Circumference Value = waist circumference + hip circumference – neck circumference (in inches)

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This report summarizes the research findings that led to the policy decisions for development of the body fat content screening procedures and equations that are currently under consideration for inclusion in the Department of Defense (DoD) Instruction (DoDI) 1308.3, Physical Fitness and Body Fat Programs. After reviewing research results, a DoD *ad* hoc working group recommended that a tiered body fat content standard be adopted. A weight-for-height screen would be adopted based on the recommendations of the Healthy People 2000 Committee: Healthy weights are represented by body mass index (BMI) values between 19 and 25, irrespective of gender. Service members exceeding the weight-for-height standards would have their body fat content determined using equations currently in use by the Navy and Air Force.

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