10 Body Weight

10.1 Introduction

Body weight is an important variate in risk assessment that is used in calculating dose (mg/kg body wt). Many of the point estimates and distributions of exposure variates are based on studies that collected body weight data on individual subjects. For example, the food consumption rate data for each subject collected in the Continuing Survey of Food Intake Among Individuals (USDA, 2000) was divided by the body weight of that subject, and distributions of consumption per unit body weight per day were generated. However, a few variates (i.e., fish consumption and soil ingestion) are based on studies that did not collect body weight information on the individual subjects. Therefore a review of the body weight literature was conducted and appropriate body weight defaults were selected to use to calculate the dose in mg/kg body weight in risk assessments for exposure via fish consumption and soil ingestion. Note that the fish consumption pathway has been very rarely invoked in the Hot Spots program.

10.2 Recommended Point Estimates for Body Weights

Recommended body weight point estimates in Table 10.1 for specific age groupings are based on raw data for age-specific body weights of U.S. residents collected in the National Health and Nutrition Examination Surveys (NHANES) discussed below in Section 10.3. The measured NHANES-derived body weight data likely represent accurate estimates of body weight for Californians and U.S. citizens.

In the interest of simplicity males and females are averaged. Little gender-based data is available for the two variates in which this body weight information is used, namely soil ingestion and angler-caught fish consumption. OEHHA concluded that the additional level of refinement by gender for body weight to use in these two exposure pathways does not add enough useful information to a risk assessment to warrant the increased complexity of the assessment. If a toxicant affects only one or predominantly one gender, the assessor may want to adjust point estimates and distributions of intake parameters to reflect body weight of the gender in question. However, such an adjustment will not result in a significant change in the results of the risk assessment.

Table 10.1. Mean Point Estimates for Body Weight (Kg)

Age Range (years)	Mean
0<2	9.7
2<9	21.9
2<16	37.0
16<30	75.9
16-70	80.0

Although body weight data of Californians are available, the data are self-reported (See Section 10.4, The California Health Interview Survey). Comparison of the NHANES and California Health Interview Survey datasets presented in Tables 10.4 and 10.7, respectively, shows that California body weight values are similar to the NHANES body weights, but consistently lower in most age groups by <1 to 12%. These generally small differences could mean that self-reported body weights are often underestimated by the CHIS participants. Another possibility is that Californians have body weights that are lower compared to the rest of the U.S. Obesity trends in the U.S. show a lower prevalence for obesity in California compared to many other states (CDC, 2009). However, because the California body weight data was self-reported and NHANES body weight data was not, we chose to utilize the NHANES data.

OEHHA is not recommending body weight distributions for a stochastic approach because most of the consumption rate distributions that we derive from raw data, or recommend from the literature already incorporate subject body weight. It may be appropriate to use body weight distributions when the correlation between body weight and the consumption rate of interest is known. For the fish consumption distribution we have chosen to divide the consumption distribution by a point estimate of body weight because the correlation is not known. If body weight distributions are used without the appropriate correlation, broad distributions are generated that may overestimate the variability in the parameter of interest. We do not have enough information to derive appropriate soil ingestion distributions; thus, use of a point estimate for body weight is appropriate.

10.3 Body Weights Derived from the National Health and Nutrition Examination Surveys (NHANES)

The data collected by NHANES includes detailed anthropometric measurements such as body weight for assessments on the health and nutrition status of U.S. residents (CDC, 2006). The most comprehensive surveys (NHANES II, and III) for body weight were conducted periodically by the National Center for Health Statistics (NCHS) since the 1970s. However, NHANES became a continuous survey in 1999. As anthropometric reference data collection for children and adults is ongoing, 2-year data sets are released as more data become available. The survey samples are nationally representative, from birth to 80+ years of age, from the civilian, non-institutionalized population of the United States. Body weights were recorded for individuals wearing disposable gowns and socks to the nearest 0.1 kg. Some subpopulation subgroups (low income, preschool children, elderly) were oversampled to ensure that sufficient numbers of subjects are available to support estimation to the specified level of precision.

NHANES body weight data represent the most current information on body weight of the U.S. population. NHANES has a large sample size and provides raw data from which interindividual variability can be assessed and categorized by specific age groupings. The body weights recorded for the NHANES reports also have the advantage of being directly measured rather than self-reported.

The most current information on body weights is preferred and summarized in this document because of the rapid increase in obesity incidence in U.S. residents over the last 30 years (Portier et al., 2007). Thus, earlier studies of body weight distributions derived from the NHANES II, including Brainard and Burmaster (1992), Burmaster and Hull (1997), Burmaster and Crouch (1997), and Finley et al. (1994), are not summarized here but can be found in the first edition of this document (OEHHA, 2000).

10.3.1 NCHS Analysis of NHANES 2003-2006 body weight data

The most recently published study by the NCHS that presented NHANES-generated body weight distributions used a combined 4-year dataset based on 2003-2004 and 2005-2006 data (McDowell et al., 2008). A 4-year dataset improves the stability and reliability of the statistical estimates for subgroup analysis. Adolescents 12-19 years of age, persons 60 years of age or older, Mexican Americans, black persons, and low-income persons were oversampled to improve the precision of the statistical estimates for these groups. The 2003-2006 analytic sample was based on 19,593 persons and excluded pregnant females from body weight tabulations. Mean, standard error, and selected percentiles by age group and sex are shown in Table 10.2.

In Table 10.2, estimation of some of the higher percentiles (90^{th} and 95^{th}) did not meet standards of reliability or precision. The reliability of the estimates was evaluated using the relative standard error (RSE), which is calculated by dividing the standard error by the estimate, and the minimum sample size criterion. NCHS recommends that an estimate with an RSE greater than 30 percent be considered unreliable.

Table 10.2. Body Weight in Kg for Children and Adults Derived by NCHS From NHANES 2003-2006

Age Category	Body Weight Means and Percentiles in Kg									
	Males [a]					Females [b]				
	Mean	SE	50th	90th	95th	Mean	SE	50th	90th	95th
0-2 mo	5.2	0.12	5.2	[c]	[c]	4.9	0.10	4.9	[c]	[c]
3-5 mo	7.3	0.08	7.2	8.2	[c]	6.8	0.10	6.6	[c]	[c]
6-8 mo	8.4	0.13	8.4	9.9	[c]	8.1	0.13	8.0	[c]	[c]
9-11 mo	9.7	0.15	9.7	[c]	[c]	9.2	0.11	9.0	[c]	[c]
1 yr	11.6	0.12	11.5	13.8	14.4	10.9	0.11	10.9	13.0	13.4
2 yr	14.1	0.14	13.9	16.4	16.9	13.4	0.13	13.1	16.1	16.8
3 yr	15.8	0.16	15.3	18.7	[c]	15.8	0.20	15.5	18.5	[c]
4 yr	18.6	0.31	18.1	22.7	[c]	17.9	0.21	17.5	20.8	[c]
5 yr	22.1	0.49	21.0	26.9	[c]	20.5	0.37	19.6	25.5	[c]
6 yr	24.2	0.33	23.7	29.5	[c]	23.4	0.49	22.1	29.7	[c]
7 yr	26.6	0.58	25.6	33.9	[c]	27.3	0.62	25.7	35.5	[c]
8 yr	31.4	0.90	29.0	41.9	[c]	30.7	0.94	28.2	42.1	[c]
9 yr	34.6	0.71	32.3	44.1	[c]	36.7	0.99	34.0	50.7	[c]
10 yr	40.1	0.86	37.3	56.8	[c]	42.4	1.07	40.5	58.5	[c]
11 yr	46.8	1.62	44.2	67.0	[c]	49.2	1.31	47.3	68.2	[c]
12 yr	50.8	1.23	46.9	72.8	82.9	52.9	1.31	49.5	76.2	[c]
13 yr	57.8	1.37	55.6	81.0	90.9	57.4	0.98	54.4	76.0	88.5
14 yr	63.1	1.73	59.8	84.3	99.1	58.8	1.75	54.4	81.0	[c]
15 yr	70.2	1.36	66.3	89.9	100.4	60.9	0.76	57.6	81.0	[c]
16 yr	76.1	1.50	70.7	101.9	116.1	61.5	0.95	58.8	79.6	[c]
17 yr	75.0	1.30	70.6	101.3	111.0	66.0	1.66	60.6	87.3	[c]
18 yr	77.2	1.67	72.7	105.8	110.4	67.6	2.15	63.0	92.1	[c]
19 yr	80.2	1.69	76.5	107.3	117.3	67.4	1.79	63.0	92.7	[c]
20-29 yr	85.4	1.06	81.1	111.5	122.6	70.7	1.03	65.3	98.6	110.7
30-39 yr	88.1	0.80	85.9	109.6	120.8	74.7	1.06	70.2	101.7	114.2
40-49 yr	91.8	0.83	88.9	114.0	124.7	77.7	1.03	72.9	106.6	116.9
50-59 yr	90.2	0.95	88.7	113.1	124.4	78.0	1.15	73.7	106.3	117.8
60-69 yr	90.0	0.98	88.0	112.9	121.3	77.3	0.91	74.0	102.0	112.9
70-79 yr	85.0	0.92	83.8	104.5	116.7	70.6	1.07	68.3	91.2	98.9
20 yrs and over	88.3	0.46	85.6	111.5	122.6	74.7	0.53	70.7	101.8	113.6

[a] For male children age groups, n ranged from 101 to 360; for male adult 10-year age groups, n ranged from 555 to 811.
[b] For female children age groups, n ranged from 81 to 335; for female adult 10-year age groups, n ranged from 468 to 779.
[c] Figure does not meet standards of reliability or precision.

10.3.2 U.S. EPA Analysis of NHANES 1999-2006 body weight data

The U.S. EPA analyzed data from the 1999-2006 NHANES to generate distributions of body weight for various age ranges of children in their Child-Specific Exposure Factors Handbook (U.S. EPA, 2008). Because four NHANES datasets were utilized in the analysis (NHANES 1999-2000, 2001-2002, 2003-2004, and 2005-2006) containing approximately 20,000 children, sample weights were developed for the combined dataset in accordance with CDC guidance. Mean and selected percentile body weights for specified age groups derived from NHANES are presented in Table 10.3 for males and females combined.

Table 10.3. Body Weight For Children in Kg Derived by U.S. EPA (2008) From NHANES 1999-2006, Males and Females Combined

Age Group	N	Body Weight Means and Percentiles in Kg				
		Mean	50th	75th	90th	95th
Birth to < 1 mo	158	4.8	4.8	5.1	5.8	6.2
1 to <3 mo	284	5.9	5.9	6.6	7.1	7.3
3 to <6 mo	489	7.4	7.3	8.0	8.7	9.1
6 to <12 mo	927	9.2	9.1	10.1	10.8	11.3
1 to <2 yr	1176	11.4	11.3	12.4	13.4	14.0
2 to <3 yr	1144	13.8	13.6	14.9	16.3	17.1
3 to <6 yr	2318	18.6	17.8	20.3	23.6	26.2
6 to <11 yr	3593	31.8	29.3	36.8	45.6	52.5
11 to <16 yr	5297	56.8	54.2	65.0	79.3	88.8
16 to <21 yr	4851	71.6	67.6	80.6	97.7	108.0

For our objectives, the OEHHA stochastic risk assessment approach is focused on chronic exposure and on deriving parameter distributions for use in assessing cancer risk weighted by age-at-exposure. Thus, we need age groupings that represent 0<2, 2<9, 2<16, 16<30, and 16-70 yrs. The U.S. EPA's body weight data for specified age groups would be useful for assessing hazard for acute and subchronic exposures.

10.3.3 OEHHA Analysis of NHANES 1999-2006 body weight data

The body weight estimates derived by OEHHA in this document consist of a combined 8-year NHANES dataset from 1999 to 2006, each one spanning 2 years (1999-2000, 2001-2002, 2003-2004, and 2005-2006) (NCHS, 2005; 2006; 2007). As of this writing, the 2007-2008 NHANES dataset results had not been finalized. The NHANES body weight data represent the most current information on body weight. NHANES has a large sample size and provides raw data from which OEHHA can assess interindividual variability and categorize by specific age groupings for the purposes of the "Hot Spots" program. Since the survey was meant to be representative of the U.S. population, the

raw data were weighted to reflect the age structure, sex and race of the population at the time of the survey.

The NHANES data included the body weight and age for each participant, so participants were placed into the age groupings consistent with OEHHA's "Hot Spots" program. The body weights for each age group were fit to a lognormal distribution using Crystal Ball® (Decisioneering, 2009). Crystal Ball® was also used to determine the best parametric model fit for the distribution of body weights for each age group. The Anderson-Darling goodness-of-fit test was chosen to determine the best fit distribution because this test specifically gives greater weight to the tails than to the center of the distribution. OEHHA is interested in the tails since the right tail represents the high-end (e.g., 95th percentile) body weights.

For each age group, males and females combined, the mean, and percentiles (50th, 75th, 90th, and 95th) of the body weight distributions are presented in Table 10.4.

Table 10.4. OEHHA-Derived Body Weight Distributional Results Based on the NHANES IV 1999-2006 Surveys, Males and Females Combined

Age Range (years)	N	Body Weight Mean and Percentiles (in kg)				
		Mean	50th	75th	90th	95th
0<2	3034	9.7	9.9	11.5	12.7	13.4
2<9	5626	21.9	20.3	25.5	32.7	36.8
2<16	12,352	37.0	32.1	50.1	64.3	74.8
16<30	8083	75.9	72.1	85.9	102.8	114.9
16-70	32,012	80.0	77.4	91.5	106.6	116.8

Directly measured body weights that are representative of the U.S. population and the large sample sizes are clear advantages for using these body weight distributions. The limitation for using NHANES body weight data is that it is not California-specific; the body weights collected from California participants could not be removed from the report and analyzed separately.

10.3.4 Analysis of NHANES data for body weight changes over time

Distributional changes in body weight over a 24-year period were investigated by Portier et al. (2007) based on NHANES data from three different surveys (II, 1976-1980; III, 1988-1994; IV 1999-2002). For each of the three body weight data sets, the weighted mean and standard deviation of natural log-transformed body weights were computed for single-year age groups and population-specific weight patterns further described using piece-wise polynomial spline functions and nonparametric age-smoothed trend lines.

The analysis demonstrated that there were changes in body weight as well as changes in age-specific distributions over the 24-year time period (Table 10.5). However, the

changes were not constant for all ages. For the most part, mean body weights of children (1-6 yrs) did not change for males, and there was only about a 1 kg change in females from NHANES III to IV. Similarly, there was no change for adolescent males (7-16 years), but there was an upward change in female adolescent average body weight of about 4 kg from the NHANES II to IV surveys. The major differences occurred among adults, where mean body weight for males (18-65 yrs) showed an upward trend of about 3.5 to 4 kg between each survey with about a 4 to 5 kg increase for females (18-65 yrs). Percentile distributions by age group were not provided. This study demonstrates the changing nature of body weights in the U.S. population and the value of using more recent data for risk assessment purposes.

Table 10.5. Comparison of Body Weights in Kg for Selected Age Groupings from NHANES II, III AND IV Surveys

Age Range (years)	NHANES	Male		Female		Overall Male and Female	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1-6	II	17.04	4.58	16.34	4.70	16.66	4.47
	III	16.88	4.70	16.52	4.91	16.75	4.98
	IV	17.10	4.86	17.46	5.02	17.27	4.97
7-16	II	45.15	17.64	43.93	15.91	44.75	17.49
	III	49.34	20.94	46.77	18.02	47.76	18.40
	IV	47.86	20.10	47.87	19.19	47.73	19.13
18-65	II	78.65	13.23	65.47	13.77	71.23	11.97
	III	82.19	16.18	69.45	16.55	75.61	18.02
	IV	85.47	19.03	74.55	19.32	79.96	20.73
65+	II	74.45	13.05	66.26	13.25	69.56	12.20
	III	79.42	14.66	66.76	14.52	72.25	15.71
	IV	83.50	16.35	69.59	14.63	75.54	15.88

10.3.5 Child Growth Charts Derived from NHANES data

Child growth charts, including weight-for-age data, were published by the Centers for Disease Control (Kuczmarski et al., 2002) using improved statistical smoothing procedures in conjunction with several national surveys (NHANES II and III, NHANES I, II and III). Growth charts and percentile distributions for weight by sex and age were presented in two sets of data: Birth to 36 months (infants) and 2 to 20 years (children and adolescents). The surveys were pooled because no single survey in the NHANES series had enough observations to construct growth charts. Sample sizes from 400 to 500 were required to achieve precision of the empirical percentiles at the specific ages for the curve fitting. The weight-for-age curves were smoothed using a 3-parameter linear model and locally weighted regression.

The evaluation of the growth charts found no large or systematic differences between the smoothed percentiles and the empirical data. Very low birth weight (VLBW) infants

were excluded from the infant percentiles, but included in the older child percentile where the effect of VLBW is diminished. The observed mean, standard deviation, and selected percentiles were presented in one month age intervals for infants (birth to 36 months), and 0.5-year intervals for children and adolescents ages 2-20 years.

More recent children body weight results derived from NHANES data have been published and presented above (McDowell et al., 2008; U.S. EPA, 2008), so the CDC growth charts are not reprinted here in this document. However, the growth charts can be downloaded from the website in the listed citation by Kuczmarski et al. (2002) below. The report did not address the upward trend in weight of female children over time noted by Portier et al. (2007), possibly because the later release of NHANES IV survey data (1999-2002) strengthened the observed trend that was not yet firmly established by the earlier surveys used in the CDC report.

10.4 California Health Interview Survey

The California Health Interview Survey (CHIS) is conducted by the California Department of Health Services every two years, with the most recent published survey data collected in 2005 (CHIS, 2006). CHIS is the largest population-based state health survey including individual health information such as health conditions and limitations, health behaviors, and health care access and health insurance coverage information. The report used the same method to adjust for non-response as that used by NHANES, correcting for several factors (e.g., race, ethnicity, household income, etc.) in order to make the body weights more representative of the California population. The individual self-reported body weight information is available to researchers in a statistical program format.

Because body weight and age information was collected for each participant, OEHHA combined the data into the specified age groups and fit a lognormal distribution to their body weights using Crystal Ball® (Decisioneering, 2009), as similarly performed for the NHANES body weight data. The best parametric model fit for the distribution of body weights was determined for each age group and the Anderson-Darling test was used for goodness-of-fit. For each age group, males and females combined, minimum and maximum values, mean, standard error of the mean, and percentiles of the body weight distributions are presented in Table 10.6.

Table 10.6. Body Weight Distributional Data from the California Health Interview Survey, Males and Females Combined

Age Group (years)	N	Body Weight Mean and Percentiles (in kg)						
		Min	Max	Mean	SEM	50th	90th	95th
0<2	1,927	3	32	9.4	0.07	10	13	14
2<9	6,022	9	79	21.4	0.095	20	31	36
2<16	11,719	9	145	36.6	0.176	32	62	71
16<30	6,367	41	150	72.1	0.22	68	95	107
16<70	37,108	41	150	76.0	0.095	73	100	109

Although the state-wide body weight database is specific for Californians, it is self-reported. Self-reported body weights are often underestimated by the participants. The survey, which was conducted by phone, reported a relatively low response rate of 29.2%. However, the report noted that this nonresponse rate was similar to the rate for other phone surveys, and the sampling weights used in the analysis would be expected to adjust much of the bias associated with the high nonresponse rate.

10.5 Analysis of CSFII body weight data

The U.S. Department of Agriculture (USDA) conducts a continuing survey of the food intakes by individuals. Self-reported body weight data were collected during the USDA's 1994-1996 and 1998 Continuing Survey of Food Intake by Individuals (CSFII), which was a multistage probability sample survey of individuals within U.S. households. Distributions of body weights by different age categories from this survey were calculated by Kahn and Stralka (2009) and are shown in Table 10.7.

Table 10.7. Body Weight Distributions from the CSFII, Males and Females Combined

Age Group	N	Body Weight Mean and Percentiles (in kg)				
		Mean	50th	75th	90th	95th
<1 mo	88	4	3	4	4[a]	5[a]
1 to <3 mo	245	5	5	6	6	7[a]
3 to <6 mo	411	7	7	8	9	10
6 to <12 mo	678	9	9	10	11	12
1 to <2 yr	1002	12	11	13	14	15
2 to <3 yr	994	14	14	16	18	19
3 to <6 yr	4112	18	18	20	23	25
6 to <11 yr	1553	30	27	35	41	45
11 to <16 yr	975	54	52	61	72	82
16 to <18 yr	360	67	63	73	86	100[a]
18 to <21 yr	383	69	66	77	89	100[a]
≥21 yr	9049	76	74	86	99	107
≥65 yr	2139	72	71	81	93	100

[a] The sample size did not meet minimum reporting requirements

The CSFII body weight results have the same limitation as the CHIS body weight data, in that self-reported body weights are often underestimated by the participants. Also, more recent and comprehensive national body weight data are available from NHANES.

10.6 International Commission on Radiological Protection

The International Commission on Radiological Protection (ICRP) reviewed and compiled extensive data on anatomical measurements, elemental composition, and physiological values for the human body (ICRP, 2003). Weight (W), length (L), and surface area (SA) during prenatal life are presented as means +/- standard deviation (SD) as a function of gestational age. From the data, a number of allometric relations were derived which relate gestational age to average length, and length to surface area and weight. Postnatal life data from a number of sources were reviewed. Charts presented in the report show mean body weight $\pm$ one SD from 0 to 15 years and adults by sex. However, the bulk of the body weight information is based on Western European data, and it was noted that in some age groupings, differences exist in body weight between North Americans and Europeans.

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