5. Acrylamide Hemoglobin Adducts

- Acrylamide
- Glycidamide
- Glycidamide-to-acrylamide ratio

Acrylamide Hemoglobin Adducts

Background Information

Sources. Acrylamide is a chemical naturally found in starchy foods that are cooked at high temperatures (above 120°C) and low-moisture conditions, such as those used for baking or frying. There are also several foods in which acrylamide appears to form in high-moisture conditions at lower temperatures, such as prune juice and canned ripe black olives (Robin 2007). Acrylamide is formed in food mainly due to a reaction between the amino acid asparagine and reducing sugars, such as glucose and fructose (Stadler 2002, Mottram 2002). The formation of acrylamide is part of the Maillard reaction, which leads to browning and flavor changes in cooked foods. Foods that contain high acrylamide levels include potato chips, crackers, snacks, and coffee (U.S. Food and Drug Administration 2006, Dybing 2005). Most people consume foods containing acrylamide on a daily basis. Acrylamide is present in tobacco smoke (Smith 2000), and it is an industrial chemical used in products for water purification, grouts, packaging, cosmetics, and scientific research (U.S. Environmental Protection Agency 1994).

Health Effects. High levels of acrylamide can be neurotoxic in both humans and animals and carcinogenic in animals. Acrylamide has been categorized by the International Agency for Research on Cancer as a suspected human carcinogen (IARC 1995). In the most recent edition of the National Toxicology Program Report on Carcinogens, acrylamide has been categorized as "*reasonably anticipated to be a human carcinogen* based on sufficient evidence of carcinogenicity from studies in experimental animals" (U.S. National Toxicology Program 2011). The U.S. Environmental Protection Agency has characterized acrylamide as "likely to be carcinogenic to humans" (U.S. Environmental Protection Agency 2010). In the body, some acrylamide is metabolized to glycidamide, an epoxide of acrylamide, through action of cytochrome P450 2E1. In contrast to acrylamide, glycidamide reacts with DNA in the body and is therefore considered the genotoxic agent. Acrylamide and glycidamide are cleared through the body mainly by formation of glutathione adducts and excretion in urine. Neither compound accumulates in the body.

Intake. The estimated intake of acrylamide from food in the general U.S. population (ages 2 and older) is on average 0.44 microgram per kilogram bodyweight per day (µg/kg bw/day), with a 90th percentile of 0.95 µg/kg bw/day. Children 2–5 years of age consume about twice the amount that adults consume (U.S. Food and Drug Administration 2006, Tran 2010). These levels are about 100 times below those known to cause neurotoxic effects or cancer in animals. The lifelong exposure of most of the population to acrylamide through food and smoking has, however, raised concerns about its potential health effects at these low levels of intake. Initial studies using food intake questionnaires to investigate possible associations between acrylamide intake and various cancers mostly did not find any associations (Hogervorst 2010). To obtain more information about the actual acrylamide exposure in the body, further investigations using biomarkers of acrylamide exposure were recommended.

Biochemical Indicators and Methods. Hemoglobin adducts of acrylamide and glycidamide reliably reflect the internal dose of acrylamide during the preceding two to four months (Bergmark 1991, Törnqvist 2002). The measured hemoglobin adduct levels reflect a time-weighted average of exposure over the lifetime of the erythrocyte (Fennell 1992). Hemoglobin adducts show a high within-person correlation over time, suggesting that a single blood measurement is a relatively good indicator of long-term acrylamide intake (Wilson 2009). Hemoglobin adducts, however, are not specific with regard to the source of acrylamide intake or

exposure. Therefore, studies using these biomarkers to investigate acrylamide intake from foods need to control for exposures from other sources, such as smoking. Persons who smoke tobacco products have higher acrylamide exposure than those not smoking (Vesper 2007). Exposure to second hand smoke seems to have a small but significant effect on hemoglobin adduct levels in non-smokers (Vesper 2010).

Analytical methods measuring hemoglobin adducts of acrylamide determine the adducts at the N-terminal valine of the hemoglobin protein chains. Initial methods employed gas chromatography coupled with mass spectrometry; these methods were based on a modified Edman reaction, which was first described for measuring N-terminal hemoglobin adducts of ethylene oxide, propylene oxide, and styrene oxide (Mowrer 1986). These initial methods were further developed and optimized to measure hemoglobin adducts of acrylamide and glycidamide (Törnqvist 1986, Vesper 2006).

Data in NHANES. No data exist on acrylamide hemoglobin adduct concentrations in NHANES prior to 2003. This report shows first-time NHANES data for hemoglobin adducts of acrylamide and glycidamide. Data presented in this report were generated by use of high-performance liquid chromatography coupled to tandem mass spectrometry (LC-MS/MS); this method uses stable isotope labeled peptide adducts (same amino acid sequence as hemoglobin) of acrylamide and glycidamide as internal standards (Vesper 2008).

Highlights

The first-time acrylamide hemoglobin adduct concentrations in the U.S. population showed the following demographic patterns and characteristics:

- Hemoglobin adduct concentrations were detectable in 98% of all blood samples measured.
- We found demographic differences for the glycidamide-to-acrylamide hemoglobin adduct ratios, but no consistent age, gender, or race/ethnicity patterns for the hemoglobin adduct concentrations.

New data from NHANES 2003–2004 allow us for the first time to assess the exposure of the U.S. population to acrylamide. Measurement of hemoglobin adducts provides information both about acrylamide exposure and metabolism. The glycidamide-to-acrylamide hemoglobin adduct ratio can be used as an indicator of the extent of acrylamide metabolism and thus as an indicator of formation of the genotoxic metabolite glycidamide in the body and its detoxification. Children had higher glycidamide-to-acrylamide hemoglobin adduct ratios compared to adolescents and adults (Figure H.5.a), suggesting differences in acrylamide metabolism or metabolic rate among age groups (Vesper 2010). Non-Hispanic blacks (NHB) had lower hemoglobin adduct ratios compared to non-Hispanic whites (NHW) and Mexican Americans (MA), which may indicate differences in polymorphisms of the genes involved in phase II detoxification of acrylamide and glycidamide (Vesper 2010). More research is needed to better understand factors influencing acrylamide metabolism and the relationship between acrylamide exposure and health risks.
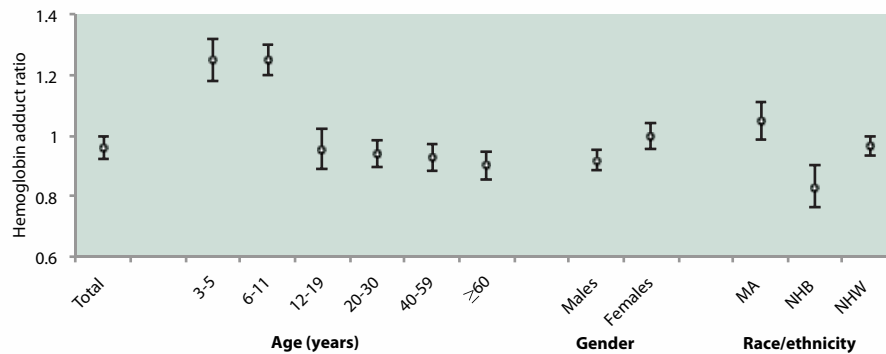
Figure H.5.a. *Geometric mean of glycidamide-to-acrylamide hemoglobin adduct ratio in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.*

Error bars represent 95 percent confidence intervals.

Detailed Observations

The selected observations mentioned below are derived from the tables and figures presented next. Statements about categorical differences between demographic groups noted below are based on non-overlapping confidence limits from univariate analysis without adjusting for demographic variables (e.g., age, sex, race/ethnicity) or other blood concentration determinants (e.g., dietary intake, supplement usage, smoking, BMI). A multivariate analysis may alter the size and statistical significance of these categorical differences. Furthermore, additional significant differences of smaller magnitude may be present despite their lack of mention here (e.g., if confidence limits slightly overlap or if differences are not statistically significant before covariate adjustment has occurred). For a selection of citations of descriptive NHANES papers related to these biochemical indicators of diet and nutrition, see **Appendix G**.

Geometric mean concentrations (NHANES 2003–2004):

- Acrylamide and glycidamide hemoglobin adduct concentrations were comparable across age groups except for older persons, who had lower concentrations (Tables 5.1.a.1 and 5.2.a.1; Figures 5.1.a and 5.2.a).

- Acrylamide (Table 5.1.a.1) and glycidamide hemoglobin adduct concentrations (Table 5.2.a.1) were comparable for males and females.

- Acrylamide hemoglobin adduct concentrations were comparable across the three race/ethnic groups (Table 5.1.a). Non-Hispanic blacks had lower glycidamide hemoglobin adduct concentrations than both non-Hispanic whites and Mexican Americans (Table 5.2.a.1).

- Glycidamide-to-acrylamide hemoglobin adduct ratios were higher in children (3-5 and 6-11 years of age) compared to adolescents and adults, higher in females compared to males, and lower in non-Hispanic blacks compared to both non-Hispanic whites and Mexican Americans (Table 5.3.a.1 and Figure 5.3.a).

Table 5.1.a.1. Acrylamide hemoglobin adduct: Concentrations

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)						Sample size
		2.5th	5th	50th	95th	97.5th		
Total, 3 years and older	61.2 (58.1 – 64.4)	25.7 (23.7 – 26.8)	29.2 (27.6 – 30.5)	54.7 (52.8 – 57.6)	192 (170 – 219)	236 (219 – 277)		7,101
Age group								
3–5 years	59.4 (53.6 – 65.7)	30.9† (28.9 – 34.0)	35.9 (29.7 – 38.0)	58.2 (52.5 – 64.7)	108 (90.3 – 229)	115† (107 – 238)		350
6–11 years	58.6 (56.1 – 61.2)	31.5 (27.2 – 35.1)	36.1 (32.2 – 38.7)	57.3 (55.1 – 59.6)	98.7 (91.3 – 103)	106 (101 – 137)		769
12–19 years	57.4 (54.4 – 60.5)	28.4 (25.7 – 29.8)	31.4 (30.0 – 32.6)	54.4 (52.1 – 57.3)	132 (118 – 156)	173 (147 – 214)		1,889
20–39 years	68.5 (64.1 – 73.3)	26.5 (23.9 – 28.4)	30.3 (28.0 – 31.7)	59.8 (57.0 – 63.9)	225 (200 – 254)	270 (237 – 341)		1,406
40–59 years	64.0 (59.9 – 68.4)	24.1 (22.2 – 27.0)	29.1 (26.1 – 31.2)	55.1 (52.1 – 59.1)	219 (189 – 250)	256 (227 – 328)		1,164
60 years and older	50.1 (47.9 – 52.3)	21.6 (19.1 – 23.3)	26.0 (23.2 – 27.2)	46.5 (44.1 – 49.1)	140 (126 – 153)	175 (151 – 211)		1,523
Gender								
Males	63.9 (60.2 – 67.9)	26.0 (23.0 – 28.0)	29.0 (27.2 – 31.1)	56.9 (53.6 – 60.0)	219 (195 – 237)	257 (236 – 305)		3,509
Females	58.7 (55.9 – 61.5)	25.0 (23.3 – 26.2)	29.4 (27.9 – 30.3)	53.3 (51.8 – 55.8)	164 (149 – 196)	213 (179 – 253)		3,592
Race/ethnicity								
Mexican Americans	61.7 (58.7 – 64.9)	33.4 (29.4 – 35.5)	36.5 (34.5 – 38.3)	57.4 (54.4 – 60.3)	149 (127 – 186)	211 (186 – 244)		1,792
Non-Hispanic Blacks	63.8 (57.1 – 71.2)	23.9 (23.1 – 24.7)	27.3 (26.0 – 29.1)	57.0 (51.9 – 64.0)	217 (181 – 285)	285 (233 – 357)		1,818
Non-Hispanic Whites	62.3 (58.9 – 65.9)	26.5 (24.1 – 27.7)	29.6 (28.2 – 31.3)	55.2 (52.9 – 58.5)	196 (175 – 223)	235 (222 – 276)		2,958

† Estimate is subject to greater uncertainty due to small cell size.

Figure 5.1.a. Acrylamide hemoglobin adduct: Concentrations by age group

Geometric mean (95% confidence interval), National Health and Nutrition Examination Survey, 2003–2004

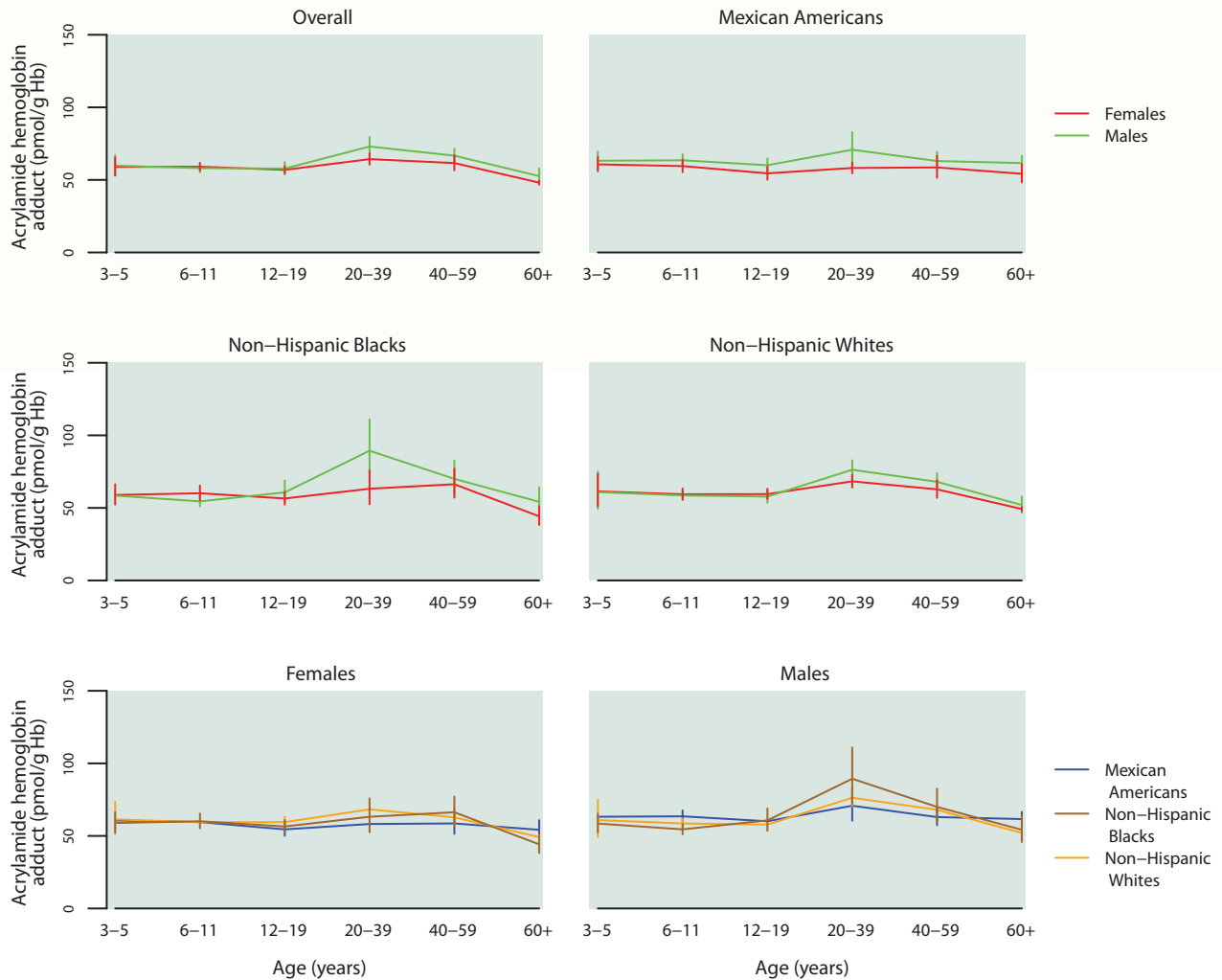## Table 5.1.a.2. Acrylamide hemoglobin adduct: Total population

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)						Sample size
		10th		50th		90th		
Males and Females								
Total, 3 years and older	61.2 (58.1 – 64.4)	33.7	(32.4 – 35.1)	54.7	(52.8 – 57.6)	140	(125 – 155)	7,101
3–5 years	59.4 (53.6 – 65.7)	38.5	(33.3 – 42.9)	58.2	(52.5 – 64.7)	90.2	(83.2 – 108)	350
6–11 years	58.6 (56.1 – 61.2)	39.6	(37.9 – 42.7)	57.3	(55.1 – 59.6)	86.7	(81.9 – 93.0)	769
12–19 years	57.4 (54.4 – 60.5)	35.6	(33.8 – 37.1)	54.4	(52.1 – 57.3)	99.9	(91.0 – 115)	1,889
20–39 years	68.5 (64.1 – 73.3)	35.1	(32.5 – 37.7)	59.8	(57.0 – 63.9)	164	(153 – 195)	1,406
40–59 years	64.0 (59.9 – 68.4)	33.5	(31.9 – 35.3)	55.1	(52.1 – 59.1)	160	(142 – 190)	1,164
60 years and older	50.1 (47.9 – 52.3)	29.6	(27.7 – 31.2)	46.5	(44.1 – 49.1)	96.1	(90.2 – 107)	1,523
Males								
Total, 3 years and older	63.9 (60.2 – 67.9)	33.6	(31.3 – 35.6)	56.9	(53.6 – 60.0)	152	(140 – 177)	3,509
3–5 years	59.8 (53.2 – 67.2)	38.8	(30.3 – 43.5)	57.8	(49.4 – 65.8)	91.4	(82.7 – 115)	189
6–11 years	58.1 (55.2 – 61.1)	39.6	(35.4 – 41.9)	56.6	(54.7 – 59.3)	86.5	(81.2 – 91.3)	370
12–19 years	57.8 (53.7 – 62.3)	35.0	(32.0 – 37.2)	53.9	(51.1 – 57.7)	107	(94.6 – 127)	976
20–39 years	73.0 (66.9 – 79.7)	35.0	(30.8 – 38.7)	63.8	(59.3 – 68.6)	209	(168 – 228)	655
40–59 years	66.7 (62.2 – 71.6)	33.4	(29.3 – 36.0)	57.3	(51.0 – 64.1)	177	(150 – 205)	572
60 years and older	52.6 (47.8 – 57.9)	29.1	(27.4 – 31.3)	48.0	(42.9 – 52.8)	117	(96.9 – 143)	747
Females								
Total, 3 years and older	58.7 (55.9 – 61.5)	33.9	(32.7 – 35.1)	53.3	(51.8 – 55.8)	125	(112 – 143)	3,592
3–5 years	58.9 (52.9 – 65.5)	37.6	(22.3 – 43.7)	59.5	(53.1 – 63.3)	86.1	(79.4 – 134)	161
6–11 years	59.1 (56.5 – 61.8)	40.4	(36.7 – 44.2)	57.4	(55.2 – 60.2)	86.9	(81.0 – 97.5)	399
12–19 years	56.9 (54.5 – 59.5)	36.9	(33.7 – 37.9)	55.3	(53.0 – 57.7)	97.5	(87.4 – 109)	913
20–39 years	64.3 (60.5 – 68.3)	35.2	(33.0 – 37.5)	56.8	(54.4 – 59.0)	152	(131 – 163)	751
40–59 years	61.6 (56.6 – 67.0)	33.4	(32.1 – 35.4)	53.8	(50.2 – 58.9)	151	(125 – 186)	592
60 years and older	48.1 (46.7 – 49.6)	29.8	(27.2 – 31.7)	45.4	(44.3 – 46.9)	84.0	(77.5 – 93.6)	776

Table 5.1.a.3. Acrylamide hemoglobin adduct: Mexican Americans

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for Mexican Americans in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)						Sample size
		10th		50th		90th		
Males and Females								
Total, 3 years and older	61.7 (58.7 – 64.9)	40.0	(38.2 – 42.1)	57.4	(54.4 – 60.3)	101	(95.4 – 115)	1,792
3–5 years	62.0 (57.8 – 66.6)	45.6†	(39.5 – 48.1)	59.6	(56.9 – 65.0)	87.4†	(78.8 – 104)	90
6–11 years	61.6 (58.2 – 65.3)	44.3	(40.9 – 45.6)	61.4	(55.9 – 67.0)	88.3	(84.0 – 96.4)	250
12–19 years	57.3 (53.8 – 61.0)	38.7	(37.4 – 40.1)	55.2	(51.4 – 59.8)	86.9	(79.6 – 96.5)	590
20–39 years	64.5 (59.9 – 69.5)	40.7	(38.6 – 42.6)	57.5	(54.6 – 60.4)	118	(96.2 – 191)	321
40–59 years	60.9 (55.2 – 67.1)	38.7	(33.8 – 42.2)	56.1	(48.4 – 63.9)	117	(91.6 – 153)	208
60 years and older	57.5 (53.9 – 61.4)	36.5	(31.9 – 38.3)	53.9	(50.0 – 57.9)	108	(91.3 – 120)	333
Males								
Total, 3 years and older	65.7 (60.9 – 70.9)	41.4	(38.6 – 43.4)	58.2	(55.0 – 62.6)	122	(103 – 185)	882
3–5 years	63.2 (57.5 – 69.5)	47.3†	(40.5 – 48.8)	59.8	(57.1 – 65.5)	88.0†	(74.1 – 122)	47
6–11 years	63.5 (59.7 – 67.6)	44.5	(40.8 – 48.3)	62.5	(59.6 – 68.1)	92.0	(84.2 – 102)	117
12–19 years	60.1 (55.8 – 64.8)	39.4	(36.8 – 41.5)	56.8	(53.7 – 61.0)	96.3	(85.5 – 124)	301
20–39 years	70.8 (60.5 – 82.9)	42.1	(37.6 – 44.7)	59.4	(53.2 – 66.6)	176	(111 – 353)	146
40–59 years	63.0 (57.3 – 69.3)	39.2†	(25.0 – 44.2)	54.8	(50.1 – 59.7)	124†	(92.9 – 193)	109
60 years and older	61.6 (57.0 – 66.5)	36.7	(32.5 – 38.2)	58.0	(51.6 – 64.0)	118	(101 – 151)	162
Females								
Total, 3 years and older	57.6 (54.8 – 60.6)	39.0	(36.5 – 40.8)	55.4	(52.0 – 59.4)	89.0	(82.5 – 96.2)	910
3–5 years	60.7 (55.9 – 65.8)	43.4†	(36.4 – 48.5)	59.5	(49.3 – 68.0)	82.5†	(77.2 – 102)	43
6–11 years	59.5 (55.3 – 64.1)	44.0	(39.6 – 45.0)	58.4	(52.3 – 65.7)	82.2	(79.6 – 96.2)	133
12–19 years	54.5 (50.1 – 59.3)	38.1	(35.0 – 39.7)	53.1	(47.3 – 60.0)	79.4	(72.0 – 93.5)	289
20–39 years	58.2 (54.6 – 62.0)	39.1	(34.9 – 41.9)	55.1	(50.8 – 60.9)	94.5	(81.1 – 108)	175
40–59 years	58.6 (51.4 – 66.7)	38.7†	(35.6 – 39.6)	57.8	(45.5 – 66.9)	94.9†	(82.2 – 138)	99
60 years and older	54.2 (48.2 – 60.9)	35.7	(19.3 – 40.4)	50.5	(46.3 – 57.3)	85.6	(79.3 – 110)	171

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.1.a.4. Acrylamide hemoglobin adduct: Non-Hispanic blacks

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for non-Hispanic blacks in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)			Sample size
		10th	50th	90th	
Males and Females					
Total, 3 years and older	63.8 (57.1 – 71.2)	32.3 (30.6 – 33.9)	57.0 (51.9 – 64.0)	156 (123 – 210)	1,818
3–5 years	58.7 (53.4 – 64.5)	39.9 (34.1 – 44.1)	56.0 (53.0 – 62.9)	87.1 (74.3 – 156)	126
6–11 years	57.1 (53.6 – 60.8)	38.6 (33.8 – 41.1)	56.7 (52.3 – 60.4)	85.6 (77.4 – 97.8)	277
12–19 years	58.6 (53.3 – 64.3)	34.4 (31.6 – 36.7)	55.2 (52.3 – 58.9)	110 (97.5 – 138)	667
20–39 years	73.8 (60.9 – 89.4)	33.2 (29.8 – 37.8)	64.4 (53.5 – 80.8)	209 (155 – 293)	290
40–59 years	67.9 (59.3 – 77.8)	32.3 (28.5 – 34.5)	59.4 (49.7 – 69.9)	182 (152 – 250)	259
60 years and older	48.1 (42.3 – 54.6)	24.5 (21.4 – 26.1)	43.1 (39.3 – 50.7)	106 (94.7 – 133)	199
Males					
Total, 3 years and older	68.7 (60.8 – 77.6)	32.1 (29.1 – 34.8)	61.7 (55.2 – 68.2)	194 (140 – 241)	918
3–5 years	58.5 (52.4 – 65.4)	37.0† (25.8 – 45.7)	55.7 (52.2 – 65.1)	88.3† (74.7 – 158)	70
6–11 years	54.5 (51.1 – 58.1)	37.7 (31.8 – 40.3)	55.5 (48.5 – 59.4)	75.3 (70.6 – 97.3)	133
12–19 years	60.7 (53.5 – 68.9)	35.2 (30.8 – 37.2)	55.8 (50.8 – 63.8)	121 (102 – 161)	356
20–39 years	89.4 (72.1 – 111)	34.0 (29.9 – 40.4)	86.5 (66.6 – 110)	240 (202 – 361)	142
40–59 years	70.0 (59.3 – 82.6)	29.0 (20.9 – 33.2)	63.9 (51.4 – 72.9)	207 (158 – 290)	123
60 years and older	54.2 (45.8 – 64.2)	25.4† (21.5 – 28.9)	46.2 (40.9 – 61.0)	116† (98.5 – 230)	94
Females					
Total, 3 years and older	59.8 (53.4 – 66.8)	32.4 (30.2 – 34.4)	54.5 (48.3 – 60.5)	133 (106 – 171)	900
3–5 years	58.9 (52.3 – 66.3)	43.6† (32.2 – 45.3)	56.2 (48.4 – 67.3)	82.9† (67.1 – 129)	56
6–11 years	60.1 (55.2 – 65.4)	39.4 (35.3 – 43.2)	58.1 (52.1 – 68.0)	95.1 (85.5 – 106)	144
12–19 years	56.5 (52.2 – 61.0)	33.5 (30.4 – 36.7)	53.7 (51.3 – 57.4)	106 (86.0 – 136)	311
20–39 years	63.2 (52.5 – 75.9)	32.8 (27.1 – 37.6)	56.4 (45.3 – 69.7)	153 (106 – 290)	148
40–59 years	66.3 (57.0 – 77.1)	35.1 (24.1 – 39.3)	56.5 (47.1 – 71.0)	173 (147 – 228)	136
60 years and older	44.2 (38.2 – 51.2)	23.7† (19.4 – 26.0)	41.1 (37.8 – 46.9)	92.1† (69.4 – 143)	105

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.1.a.5. Acrylamide hemoglobin adduct: Non-Hispanic whites

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for non-Hispanic whites in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)			Sample size
		10th	50th	90th	
Males and Females					
Total, 3 years and older	62.3 (58.9 – 65.9)	34.0 (32.5 – 35.7)	55.2 (52.9 – 58.5)	145 (130 – 165)	2,958
3–5 years	61.1 (51.7 – 72.2)	39.0† (20.8 – 44.7)	58.5 (47.7 – 78.2)	98.7† (82.6 – 118)	93
6–11 years	59.0 (56.2 – 62.0)	39.9 (35.1 – 44.6)	58.0 (55.2 – 60.3)	85.9 (80.4 – 91.5)	178
12–19 years	58.6 (55.3 – 62.2)	36.3 (33.3 – 38.5)	54.9 (52.7 – 57.9)	105 (95.0 – 120)	505
20–39 years	72.2 (67.6 – 77.0)	35.7 (31.4 – 39.4)	63.5 (59.2 – 68.5)	174 (157 – 198)	663
40–59 years	65.3 (60.6 – 70.4)	33.7 (32.1 – 36.1)	56.2 (52.1 – 61.1)	167 (143 – 206)	606
60 years and older	50.4 (47.9 – 53.0)	30.6 (28.5 – 31.9)	46.8 (43.9 – 49.7)	92.3 (84.1 – 113)	913
Males					
Total, 3 years and older	64.7 (60.6 – 69.0)	33.9 (31.4 – 36.3)	57.4 (53.1 – 60.9)	155 (141 – 187)	1,441
3–5 years	60.9 (49.4 – 75.0)	41.3† (31.0 – 45.6)	57.3 (44.2 – 82.0)	103† (81.4 – 118)	50
6–11 years	58.6 (55.5 – 61.9)	40.0† (30.1 – 46.5)	56.6 (54.7 – 59.1)	85.9† (77.4 – 94.8)	84
12–19 years	57.8 (53.5 – 62.5)	34.4 (31.7 – 37.0)	52.9 (50.2 – 57.0)	109 (94.7 – 134)	257
20–39 years	76.3 (70.4 – 82.8)	36.1 (30.0 – 41.0)	67.0 (60.9 – 73.8)	213 (166 – 228)	293
40–59 years	68.0 (62.5 – 74.0)	34.6 (29.3 – 38.0)	58.2 (50.8 – 66.1)	183 (150 – 213)	302
60 years and older	52.0 (46.7 – 57.8)	29.8 (27.5 – 31.5)	47.8 (42.4 – 52.5)	110 (87.5 – 136)	455
Females					
Total, 3 years and older	60.2 (57.0 – 63.5)	34.3 (32.8 – 35.5)	54.0 (52.1 – 57.1)	135 (119 – 154)	1,517
3–5 years	61.4 (51.2 – 73.6)	37.6† (20.8 – 44.2)	62.2 (47.4 – 75.7)	91.2† (79.5 – 238)	43
6–11 years	59.4 (55.7 – 63.4)	39.7† (28.6 – 44.8)	58.5 (55.3 – 61.2)	84.6† (78.2 – 141)	94
12–19 years	59.5 (56.1 – 63.2)	38.1 (34.4 – 40.4)	57.4 (54.1 – 59.9)	100 (92.2 – 117)	248
20–39 years	68.3 (64.0 – 72.9)	35.4 (30.6 – 39.3)	59.6 (54.7 – 65.8)	160 (147 – 182)	370
40–59 years	62.8 (56.9 – 69.2)	33.3 (32.2 – 35.2)	54.5 (50.3 – 60.7)	155 (129 – 217)	304
60 years and older	49.2 (47.8 – 50.6)	31.3 (29.5 – 33.2)	45.7 (45.0 – 47.4)	84.3 (74.6 – 103)	458

† Estimate is subject to greater uncertainty due to small cell size.

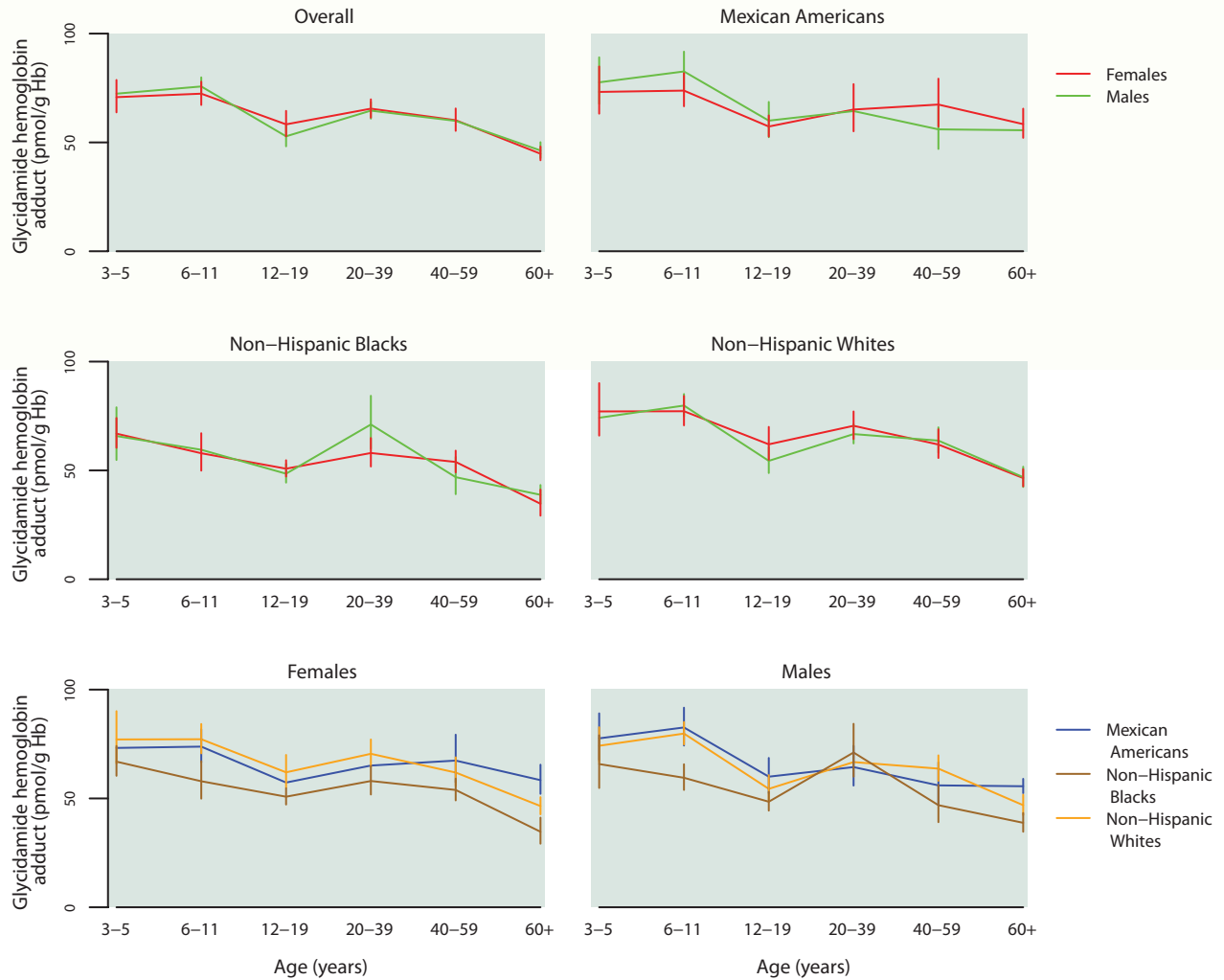## Table 5.2.a.1. Glycidamide hemoglobin adduct: Concentrations

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)					Sample size
		2.5th	5th	50th	95th	97.5th	
Total, 3 years and older	59.3 (56.7 – 62.1)	17.5 (<LOD – 20.9)	24.1 (21.4 – 25.8)	59.9 (57.5 – 62.4)	167 (155 – 183)	205 (193 – 235)	7,278
Age group							
3–5 years	71.6 (66.9 – 76.7)	35.3† (27.7 – 37.8)	38.9 (33.4 – 46.3)	71.1 (67.0 – 79.1)	126 (121 – 136)	135† (128 – 166)	411
6–11 years	74.1 (70.3 – 78.2)	36.8 (33.0 – 38.6)	41.2 (36.8 – 44.6)	75.0 (70.9 – 77.9)	140 (128 – 158)	157 (144 – 201)	784
12–19 years	55.4 (51.1 – 60.1)	<LOD	23.3 (<LOD – 27.0)	59.2 (56.1 – 62.0)	145 (126 – 171)	173 (152 – 230)	1,931
20–39 years	65.0 (61.4 – 68.9)	20.6 (<LOD – 23.8)	26.9 (23.8 – 28.9)	64.0 (60.1 – 68.8)	195 (175 – 220)	244 (221 – 282)	1,446
40–59 years	60.1 (56.8 – 63.5)	17.8 (<LOD – 22.8)	24.1 (18.8 – 27.2)	58.8 (55.1 – 61.1)	179 (158 – 201)	210 (194 – 265)	1,177
60 years and older	45.5 (42.8 – 48.3)	<LOD	18.6 (12.1 – 21.1)	46.8 (44.8 – 49.2)	129 (115 – 145)	163 (141 – 199)	1,529
Gender							
Males	59.5 (56.9 – 62.3)	17.8 (11.3 – 20.7)	24.0 (21.5 – 25.7)	59.3 (56.9 – 61.7)	174 (158 – 199)	219 (193 – 292)	3,604
Females	59.1 (56.0 – 62.5)	14.3 (<LOD – 21.4)	24.5 (19.2 – 27.3)	60.4 (57.5 – 63.9)	158 (146 – 175)	197 (183 – 212)	3,674
Race/ethnicity							
Mexican Americans	64.7 (61.2 – 68.4)	22.5 (<LOD – 30.5)	32.8 (25.7 – 36.1)	65.4 (61.1 – 69.8)	152 (138 – 171)	199 (167 – 246)	1,841
Non-Hispanic Blacks	53.6 (50.6 – 56.7)	<LOD	17.4 (9.74 – 20.9)	55.5 (51.9 – 59.2)	159 (134 – 216)	206 (162 – 315)	1,900
Non-Hispanic Whites	61.1 (57.6 – 64.9)	19.6 (8.65 – 23.2)	25.5 (23.3 – 26.9)	60.6 (57.8 – 64.2)	172 (158 – 195)	213 (196 – 249)	3,008

< LOD means less than the limit of detection, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

Figure 5.2.a. Glycidamide hemoglobin adduct: Concentrations by age group

Geometric mean (95% confidence interval), National Health and Nutrition Examination Survey, 2003–2004

Table 5.2.a.2. Glycidamide hemoglobin adduct: Total population

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval) 10th	50th	90th	Sample size
Males and Females					
Total, 3 years and older	59.3 (56.7 – 62.1)	30.6 (28.7 – 32.4)	59.9 (57.5 – 62.4)	130 (120 – 140)	7,278
3–5 years	71.6 (66.9 – 76.7)	47.8 (39.0 – 51.4)	71.1 (67.0 – 79.1)	118 (107 – 126)	411
6–11 years	74.1 (70.3 – 78.2)	47.5 (43.8 – 49.4)	75.0 (70.9 – 77.9)	121 (113 – 135)	784
12–19 years	55.4 (51.1 – 60.1)	31.5 (27.3 – 33.8)	59.2 (56.1 – 62.0)	113 (96.8 – 141)	1,931
20–39 years	65.0 (61.4 – 68.9)	33.0 (29.9 – 35.4)	64.0 (60.1 – 68.8)	149 (136 – 167)	1,446
40–59 years	60.1 (56.8 – 63.5)	30.6 (27.7 – 32.8)	58.8 (55.1 – 61.1)	139 (124 – 158)	1,177
60 years and older	45.5 (42.8 – 48.3)	24.4 (22.6 – 25.6)	46.8 (44.8 – 49.2)	96.2 (90.6 – 103)	1,529
Males					
Total, 3 years and older	59.5 (56.9 – 62.3)	29.8 (27.6 – 32.0)	59.3 (56.9 – 61.7)	136 (124 – 148)	3,604
3–5 years	72.4 (67.5 – 77.7)	47.9 (38.4 – 52.2)	70.7 (66.8 – 76.6)	117 (99.9 – 145)	215
6–11 years	75.7 (71.8 – 79.9)	48.2 (45.6 – 50.3)	75.7 (69.9 – 79.6)	118 (112 – 140)	381
12–19 years	52.8 (48.2 – 57.8)	29.3 (24.5 – 32.7)	57.0 (53.2 – 61.0)	111 (97.5 – 134)	1,000
20–39 years	64.6 (60.9 – 68.6)	32.0 (28.6 – 33.8)	60.6 (57.6 – 65.9)	163 (149 – 174)	681
40–59 years	59.9 (56.3 – 63.8)	29.6 (26.1 – 32.8)	58.9 (54.3 – 62.2)	140 (128 – 164)	577
60 years and older	46.3 (42.8 – 50.1)	24.4 (22.2 – 25.7)	45.8 (41.6 – 48.6)	106 (95.4 – 129)	750
Females					
Total, 3 years and older	59.1 (56.0 – 62.5)	31.3 (29.1 – 33.4)	60.4 (57.5 – 63.9)	125 (116 – 135)	3,674
3–5 years	70.8 (63.8 – 78.7)	45.8 (34.1 – 53.1)	72.1 (65.7 – 82.0)	118 (104 – 130)	196
6–11 years	72.4 (67.2 – 77.9)	46.3 (43.6 – 48.3)	73.7 (69.6 – 77.9)	122 (106 – 142)	403
12–19 years	58.3 (52.8 – 64.5)	33.7 (28.7 – 35.7)	60.9 (56.5 – 65.8)	114 (95.9 – 160)	931
20–39 years	65.5 (61.4 – 69.8)	35.2 (31.0 – 38.2)	67.7 (61.4 – 73.7)	136 (123 – 160)	765
40–59 years	60.2 (55.3 – 65.6)	30.7 (27.8 – 34.3)	58.6 (53.1 – 64.8)	137 (115 – 160)	600
60 years and older	44.8 (41.8 – 48.1)	24.4 (21.3 – 26.3)	47.7 (45.2 – 50.8)	87.0 (81.1 – 93.8)	779

Table 5.2.a.3. Glycidamide hemoglobin adduct: Mexican Americans

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for Mexican Americans in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval) 10th	50th	90th	Sample size
Males and Females					
Total, 3 years and older	64.7 (61.2 – 68.4)	39.4 (38.4 – 40.5)	65.4 (61.1 – 69.8)	118 (111 – 130)	1,841
3–5 years	75.5 (67.6 – 84.3)	49.6 (40.2 – 55.0)	74.4 (65.9 – 87.3)	114 (103 – 164)	117
6–11 years	78.5 (72.8 – 84.6)	52.1 (46.5 – 55.3)	78.5 (76.0 – 81.4)	126 (116 – 140)	256
12–19 years	58.7 (53.3 – 64.5)	37.0 (32.2 – 40.3)	62.3 (55.8 – 67.0)	99.7 (93.8 – 115)	601
20–39 years	64.7 (58.2 – 72.0)	39.0 (35.1 – 42.2)	63.9 (59.4 – 70.5)	128 (108 – 168)	324
40–59 years	61.2 (52.8 – 71.0)	38.4 (17.5 – 41.0)	60.5 (52.9 – 73.0)	115 (103 – 144)	212
60 years and older	57.1 (53.8 – 60.5)	33.1 (29.3 – 36.1)	55.8 (50.6 – 61.9)	107 (97.6 – 117)	331
Males					
Total, 3 years and older	64.2 (60.0 – 68.7)	38.3 (33.3 – 39.7)	63.6 (59.3 – 68.4)	129 (114 – 160)	909
3–5 years	77.6 (67.7 – 89.1)	52.5† (35.6 – 58.5)	75.7 (68.5 – 87.5)	124† (101 – 187)	58
6–11 years	82.6 (74.3 – 91.7)	55.2 (48.0 – 60.9)	79.7 (77.4 – 88.6)	128 (115 – 161)	125
12–19 years	60.0 (52.4 – 68.6)	36.4 (28.3 – 40.4)	63.4 (56.3 – 68.4)	115 (91.4 – 159)	306
20–39 years	64.4 (55.9 – 74.2)	38.2 (29.2 – 40.6)	60.1 (54.5 – 67.4)	161 (107 – 279)	146
40–59 years	56.0 (47.0 – 66.6)	32.8† (4.98 – 39.7)	56.5 (49.9 – 62.8)	111† (94.7 – 157)	111
60 years and older	55.6 (52.4 – 59.0)	30.3 (17.5 – 35.1)	54.6 (51.7 – 58.5)	110 (97.4 – 141)	163
Females					
Total, 3 years and older	65.2 (60.7 – 70.0)	41.9 (39.3 – 44.1)	67.7 (61.8 – 73.7)	111 (106 – 120)	932
3–5 years	73.2 (63.2 – 84.9)	46.6† (42.6 – 49.5)	72.9 (58.1 – 88.9)	108† (91.8 – 155)	59
6–11 years	73.8 (66.6 – 81.8)	47.4 (43.0 – 52.2)	74.0 (66.4 – 81.5)	119 (108 – 144)	131
12–19 years	57.3 (52.7 – 62.4)	37.1 (33.5 – 40.9)	61.2 (54.4 – 67.2)	94.5 (88.0 – 102)	295
20–39 years	65.1 (55.1 – 76.8)	42.4 (28.4 – 46.4)	68.9 (63.2 – 77.5)	114 (104 – 131)	178
40–59 years	67.4 (57.3 – 79.3)	39.8† (34.4 – 43.6)	67.4 (54.8 – 81.6)	118† (105 – 156)	101
60 years and older	58.4 (52.1 – 65.5)	36.0 (27.3 – 39.4)	56.8 (46.6 – 65.2)	104 (87.4 – 124)	168

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.2.a.4. Glycidamide hemoglobin adduct: Non-Hispanic blacks

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for non-Hispanic blacks in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)						Sample size
		10th		50th		90th		
Males and Females								
Total, 3 years and older	53.6	(50.6 – 56.7)	27.1	(24.4 – 29.8)	55.5	(51.9 – 59.2)	121	(110 – 142)	1,900
3–5 years	66.3	(58.9 – 74.6)	41.3	(26.9 – 48.6)	70.0	(58.0 – 79.8)	101	(96.2 – 112)	141
6–11 years	58.7	(54.5 – 63.2)	35.8	(27.2 – 41.1)	63.0	(57.3 – 69.2)	108	(96.7 – 126)	282
12–19 years	49.7	(47.0 – 52.5)	27.0	(24.8 – 29.3)	52.6	(49.5 – 56.1)	106	(87.7 – 124)	690
20–39 years	63.5	(56.8 – 71.1)	33.4	(26.9 – 35.7)	63.7	(55.8 – 73.8)	144	(120 – 228)	311
40–59 years	50.6	(45.2 – 56.7)	23.5	(17.5 – 29.4)	50.9	(46.2 – 56.4)	133	(95.3 – 186)	265
60 years and older	36.3	(32.9 – 40.1)	15.4	(10.4 – 19.4)	39.7	(36.6 – 42.9)	84.6	(79.9 – 98.7)	211
Males								
Total, 3 years and older	54.8	(49.8 – 60.4)	26.5	(23.5 – 28.6)	56.4	(52.2 – 61.8)	134	(114 – 162)	956
3–5 years	65.8	(54.8 – 79.0)	40.1†	(< LOD – 49.0)	70.8	(54.1 – 84.2)	100†	(95.0 – 130)	77
6–11 years	59.5	(53.9 – 65.7)	35.7	(4.48 – 43.5)	62.9	(54.4 – 68.5)	108	(92.6 – 141)	133
12–19 years	48.5	(44.4 – 53.0)	25.3	(21.2 – 27.8)	51.0	(46.6 – 56.0)	113	(90.4 – 141)	369
20–39 years	71.1	(60.0 – 84.3)	33.3	(27.7 – 36.6)	70.1	(57.1 – 83.5)	152	(121 – 309)	154
40–59 years	46.9	(39.1 – 56.2)	17.5	(4.35 – 20.9)	50.3	(43.7 – 56.6)	156	(101 – 207)	124
60 years and older	38.8	(34.7 – 43.3)	19.9†	(9.71 – 22.2)	41.2	(33.6 – 47.1)	81.8†	(74.1 – 120)	99
Females								
Total, 3 years and older	52.5	(49.6 – 55.5)	28.0	(22.2 – 32.1)	55.0	(50.3 – 60.1)	114	(101 – 132)	944
3–5 years	66.9	(60.4 – 74.1)	40.4†	(30.2 – 55.7)	68.3	(58.2 – 79.8)	100†	(89.7 – 109)	64
6–11 years	57.9	(49.9 – 67.1)	35.7	(< LOD – 41.3)	63.5	(54.0 – 74.1)	106	(96.3 – 120)	149
12–19 years	50.8	(47.2 – 54.7)	30.7	(24.9 – 33.1)	54.1	(50.7 – 57.8)	98.7	(83.2 – 122)	321
20–39 years	58.0	(51.8 – 64.9)	33.3	(< LOD – 35.7)	60.3	(52.6 – 69.8)	130	(111 – 183)	157
40–59 years	53.9	(49.1 – 59.1)	29.8	(22.5 – 33.3)	50.9	(46.1 – 57.8)	115	(90.7 – 169)	141
60 years and older	34.7	(29.2 – 41.2)	14.1	(< LOD – 19.4)	38.7	(34.4 – 42.9)	87.3	(74.8 – 103)	112

< LOD means less than the limit of detection, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.2.a.5. Glycidamide hemoglobin adduct: Non-Hispanic whites

Geometric mean and selected percentiles of whole blood concentrations (in pmol/g Hb) for non-Hispanic whites in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)	Selected percentiles (95% conf. interval)						Sample size
		10th		50th		90th		
Males and Females								
Total, 3 years and older	61.1	(57.6 – 64.9)	31.1	(28.9 – 32.8)	60.6	(57.8 – 64.2)	135	(124 – 149)	3,008
3–5 years	75.5	(67.8 – 84.1)	50.7†	(37.9 – 53.7)	72.3	(65.8 – 88.4)	121†	(114 – 133)	110
6–11 years	78.5	(73.8 – 83.6)	51.3	(43.2 – 55.7)	76.0	(74.1 – 79.5)	123	(109 – 150)	183
12–19 years	57.9	(52.8 – 63.5)	33.4	(27.6 – 34.9)	60.4	(57.1 – 62.9)	115	(97.9 – 148)	512
20–39 years	68.5	(63.9 – 73.5)	32.9	(29.7 – 37.3)	67.5	(61.1 – 72.9)	160	(142 – 176)	682
40–59 years	62.8	(58.4 – 67.5)	31.9	(29.1 – 34.2)	60.4	(56.8 – 64.4)	143	(129 – 164)	610
60 years and older	46.6	(43.1 – 50.5)	25.0	(23.3 – 26.6)	47.7	(45.1 – 50.9)	96.7	(89.9 – 106)	911
Males								
Total, 3 years and older	61.0	(57.6 – 64.6)	30.2	(28.2 – 32.5)	60.1	(57.3 – 62.8)	140	(125 – 155)	1,473
3–5 years	74.2	(66.5 – 82.7)	48.0†	(37.9 – 55.0)	68.7	(60.3 – 88.3)	118†	(98.8 – 195)	58
6–11 years	79.8	(74.8 – 85.1)	55.5†	(47.5 – 57.9)	75.8	(70.9 – 84.9)	116†	(108 – 156)	87
12–19 years	54.4	(48.8 – 60.7)	30.4	(24.0 – 34.3)	57.3	(53.2 – 60.5)	102	(93.6 – 143)	264
20–39 years	66.7	(62.4 – 71.3)	31.9	(28.5 – 35.3)	62.9	(58.3 – 67.8)	170	(154 – 182)	308
40–59 years	63.7	(58.1 – 69.8)	32.3	(26.5 – 35.6)	60.6	(56.6 – 64.6)	141	(129 – 168)	303
60 years and older	46.9	(42.4 – 51.7)	24.5	(21.1 – 26.4)	45.9	(41.5 – 49.1)	106	(95.5 – 128)	453
Females								
Total, 3 years and older	61.2	(57.1 – 65.7)	31.7	(29.1 – 34.3)	61.1	(57.9 – 65.8)	132	(120 – 147)	1,535
3–5 years	77.1	(66.0 – 90.1)	51.9†	(< LOD – 60.9)	78.6	(62.4 – 100)	124†	(101 – 135)	52
6–11 years	77.2	(70.7 – 84.2)	48.7†	(39.3 – 53.1)	76.6	(71.9 – 80.3)	125†	(99.1 – 197)	96
12–19 years	62.0	(54.9 – 70.0)	34.4	(27.2 – 41.5)	63.0	(57.9 – 69.5)	119	(99.0 – 168)	248
20–39 years	70.5	(64.4 – 77.1)	36.5	(28.0 – 42.6)	71.2	(63.9 – 78.3)	142	(130 – 191)	374
40–59 years	61.9	(55.7 – 68.9)	30.9	(27.7 – 35.5)	60.0	(54.1 – 68.0)	144	(116 – 182)	307
60 years and older	46.5	(42.7 – 50.6)	25.7	(23.9 – 26.9)	49.3	(46.3 – 51.5)	87.1	(80.4 – 97.9)	458

< LOD means less than the limit of detection, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

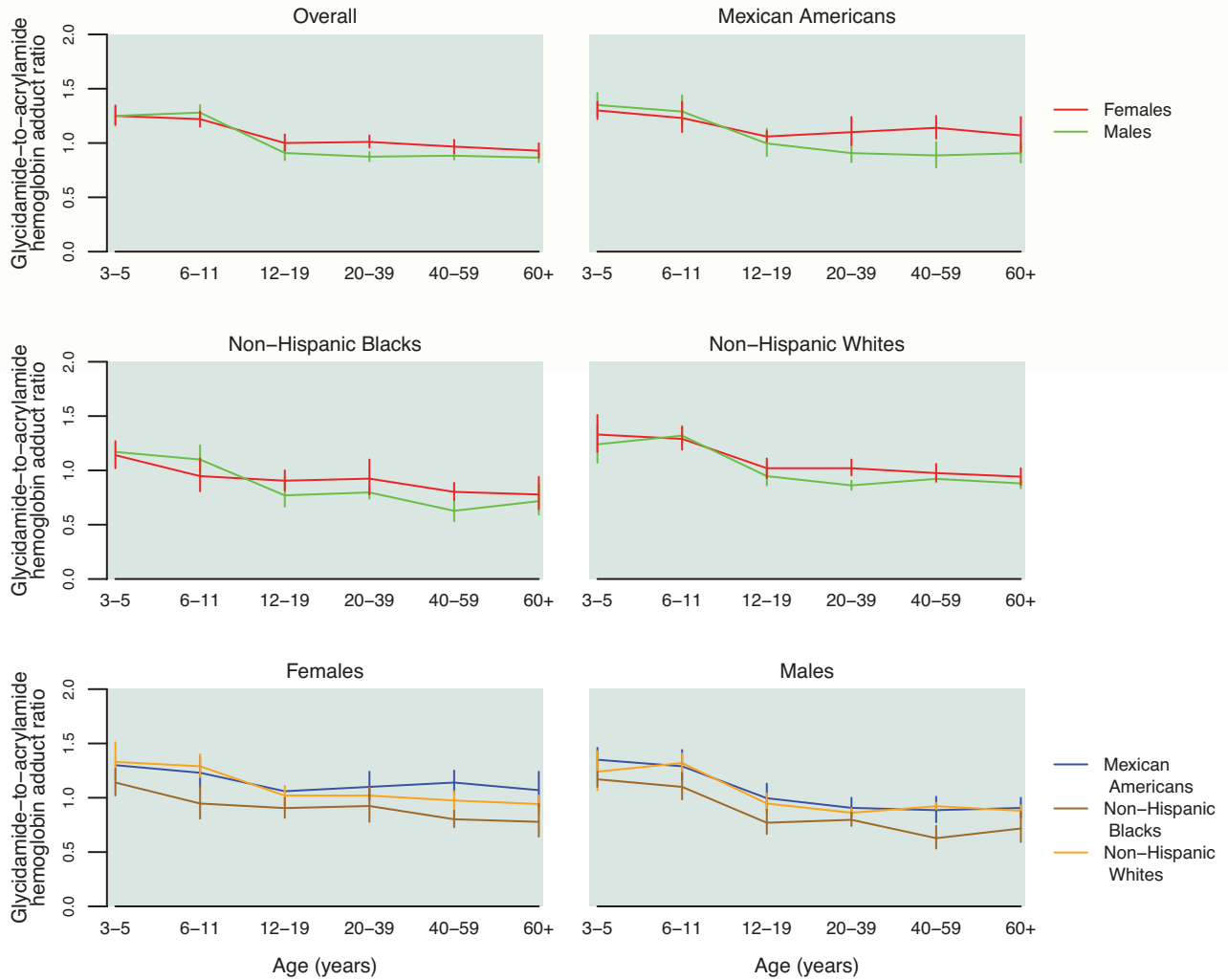# Table 5.3.a.1. Glycidamide-to-acrylamide hemoglobin adduct ratio

Geometric mean and selected percentiles of ratio (no units) of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

| | Geometric mean | Selected percentiles (95% conf. interval) | | | | | | | | | | | | | Sample |
	(95% conf. interval)	2.5th		5th		50th		95th		97.5th		size
Total, 3 years and older	.958 (.923 – .995)	.406 (< LOD – .477)	.529 (.489 – .562)	1.01 (.984 – 1.03)	1.65 (1.57 – 1.81)	1.88 (1.75 – 2.21)	6,844
Age group							
3–5 years	1.25 (1.18 – 1.32)	.715† (.097 – .835)	.836 (.435 – .881)	1.28 (1.23 – 1.38)	1.77 (1.64 – 2.02)	2.00† (1.73 – 2.30)	336
6–11 years	1.25 (1.20 – 1.30)	.691 (.555 – .772)	.807 (.700 – .852)	1.28 (1.23 – 1.33)	2.02 (1.88 – 2.47)	2.51 (2.02 – 4.24)	742
12–19 years	.952 (.889 – 1.02)	< LOD	.560 (< LOD – .625)	1.01 (.987 – 1.04)	1.72 (1.52 – 2.47)	2.14 (1.72 – 3.88)	1,817
20–39 years	.939 (.896 – .985)	.419 (< LOD – .492)	.537 (.474 – .585)	.988 (.939 – 1.03)	1.62 (1.53 – 1.77)	1.84 (1.66 – 2.19)	1,364
40–59 years	.926 (.883 – .970)	.400 (< LOD – .469)	.507 (.466 – .540)	.974 (.935 – 1.01)	1.58 (1.49 – 1.76)	1.75 (1.63 – 2.42)	1,124
60 years and older	.900 (.855 – .948)	< LOD	.475 (.359 – .528)	.961 (.928 – .984)	1.57 (1.48 – 1.73)	1.78 (1.63 – 2.34)	1,461
Gender							
Males	.918 (.886 – .951)	.410 (.313 – .470)	.514 (.487 – .537)	.955 (.926 – .990)	1.58 (1.52 – 1.69)	1.79 (1.66 – 2.09)	3,389
Females	.999 (.956 – 1.04)	.402 (< LOD – .493)	.566 (.464 – .622)	1.06 (1.02 – 1.09)	1.72 (1.62 – 1.93)	1.97 (1.79 – 2.59)	3,455
Race/ethnicity							
Mexican Americans	1.05 (.987 – 1.11)	.513 (< LOD – .603)	.616 (.554 – .684)	1.09 (1.03 – 1.16)	1.73 (1.60 – 2.17)	1.99 (1.77 – 2.57)	1,739
Non-Hispanic Blacks	.830 (.762 – .904)	.098 (.042 – .343)	.397 (.141 – .447)	.893 (.845 – .949)	1.62 (1.46 – 1.96)	1.82 (1.64 – 2.94)	1,736
Non-Hispanic Whites	.967 (.932 – 1.00)	< LOD	.548 (.507 – .591)	1.01 (.984 – 1.03)	1.63 (1.54 – 1.80)	1.85 (1.71 – 2.18)	2,859

< LOD means less than the limit of detection for either the whole blood acrylamide adduct or the glycidamide adduct, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

Figure 5.3.a. Glycidamide–to–acrylamide hemoglobin adduct ratio: By age group

Geometric mean (95% confidence interval), National Health and Nutrition Examination Survey, 2003–2004

Table 5.3.a.2. Glycidamide-to-acrylamide hemoglobin adduct ratio: Total population

Geometric mean and selected percentiles of ratio (no units) of whole blood concentrations (in pmol/g Hb) for the total U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)		Selected percentiles (95% conf. interval)						Sample size
			10th		50th		90th		
Males and Females									
Total, 3 years and older	.958	(.923 – .995)	.642	(.620 – .661)	1.01	(.984 – 1.03)	1.48	(1.42 – 1.54)	6,844
3–5 years	1.25	(1.18 – 1.32)	.944	(.647 – 1.05)	1.28	(1.23 – 1.38)	1.61	(1.57 – 1.78)	336
6–11 years	1.25	(1.20 – 1.30)	.899	(.853 – .923)	1.28	(1.23 – 1.33)	1.72	(1.61 – 1.96)	742
12–19 years	.952	(.889 – 1.02)	.670	(.609 – .719)	1.01	(.987 – 1.04)	1.45	(1.37 – 1.62)	1,817
20–39 years	.939	(.896 – .985)	.643	(.606 – .668)	.988	(.939 – 1.03)	1.43	(1.38 – 1.51)	1,364
40–59 years	.926	(.883 – .970)	.618	(.561 – .643)	.974	(.935 – 1.01)	1.41	(1.36 – 1.51)	1,124
60 years and older	.900	(.855 – .948)	.607	(.550 – .649)	.961	(.928 – .984)	1.39	(1.32 – 1.49)	1,461
Males									
Total, 3 years and older	.918	(.886 – .951)	.610	(.585 – .632)	.955	(.926 – .990)	1.41	(1.35 – 1.49)	3,389
3–5 years	1.25	(1.16 – 1.35)	.863	(.621 – 1.06)	1.26	(1.22 – 1.38)	1.60	(1.54 – 1.86)	181
6–11 years	1.28	(1.22 – 1.35)	.899	(.846 – .983)	1.31	(1.22 – 1.39)	1.72	(1.66 – 1.97)	359
12–19 years	.908	(.842 – .980)	.651	(.599 – .677)	.984	(.952 – 1.01)	1.38	(1.34 – 1.47)	944
20–39 years	.874	(.832 – .918)	.607	(.562 – .641)	.895	(.862 – .939)	1.25	(1.20 – 1.34)	638
40–59 years	.883	(.848 – .920)	.573	(.537 – .618)	.933	(.895 – .979)	1.34	(1.23 – 1.49)	549
60 years and older	.865	(.823 – .908)	.558	(.508 – .629)	.905	(.860 – .943)	1.35	(1.26 – 1.47)	718
Females									
Total, 3 years and older	.999	(.956 – 1.04)	.679	(.641 – .711)	1.06	(1.02 – 1.09)	1.52	(1.47 – 1.61)	3,455
3–5 years	1.25	(1.17 – 1.34)	.971	(.811 – 1.04)	1.29	(1.22 – 1.45)	1.64	(1.51 – 2.07)	155
6–11 years	1.22	(1.15 – 1.29)	.898	(.833 – .923)	1.27	(1.20 – 1.29)	1.71	(1.58 – 2.00)	383
12–19 years	1.00	(.928 – 1.08)	.730	(.635 – .776)	1.04	(1.00 – 1.10)	1.57	(1.41 – 1.84)	873
20–39 years	1.01	(.958 – 1.07)	.690	(.651 – .701)	1.08	(1.02 – 1.13)	1.55	(1.47 – 1.70)	726
40–59 years	.967	(.904 – 1.03)	.639	(.563 – .706)	1.01	(.957 – 1.07)	1.47	(1.39 – 1.59)	575
60 years and older	.929	(.865 – .998)	.647	(.534 – .710)	.998	(.969 – 1.04)	1.41	(1.35 – 1.52)	743

Table 5.3.a.3. Glycidamide-to-acrylamide hemoglobin adduct ratio: Mexican Americans

Geometric mean and selected percentiles of ratio (no units) of whole blood concentrations (in pmol/g Hb) for Mexican Americans in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)		Selected percentiles (95% conf. interval)						Sample size
			10th		50th		90th		
Males and Females									
Total, 3 years and older	1.05	(.987 – 1.11)	.748	(.697 – .780)	1.09	(1.03 – 1.16)	1.57	(1.46 – 1.75)	1,739
3–5 years	1.32	(1.26 – 1.40)	1.06†	(.957 – 1.11)	1.33	(1.25 – 1.41)	1.59†	(1.54 – 1.88)	89
6–11 years	1.27	(1.17 – 1.37)	.953	(.923 – .989)	1.25	(1.19 – 1.34)	1.76	(1.57 – 2.53)	244
12–19 years	1.03	(.965 – 1.09)	.767	(.717 – .822)	1.05	(.999 – 1.12)	1.50	(1.42 – 1.73)	568
20–39 years	.997	(.904 – 1.10)	.689	(.608 – .755)	1.06	(.972 – 1.14)	1.56	(1.42 – 1.77)	312
40–59 years	.999	(.918 – 1.09)	.718	(.616 – .772)	1.04	(.988 – 1.12)	1.51	(1.36 – 2.60)	202
60 years and older	.989	(.908 – 1.08)	.716	(.561 – .774)	.996	(.936 – 1.05)	1.38	(1.28 – 1.62)	324
Males									
Total, 3 years and older	.977	(.916 – 1.04)	.689	(.616 – .722)	1.01	(.949 – 1.07)	1.52	(1.41 – 1.60)	858
3–5 years	1.35	(1.25 – 1.46)	1.09†	(1.02 – 1.15)	1.33	(1.14 – 1.54)	1.60†	(1.55 – 1.95)	46
6–11 years	1.29	(1.16 – 1.44)	.984	(.102 – 1.06)	1.26	(1.19 – 1.38)	1.85	(1.57 – 4.24)	117
12–19 years	.996	(.880 – 1.13)	.750	(.602 – .813)	1.03	(.948 – 1.12)	1.49	(1.42 – 1.67)	290
20–39 years	.907	(.823 – 1.00)	.660	(.532 – .708)	.930	(.877 – 1.02)	1.39	(1.19 – 1.64)	141
40–59 years	.886	(.775 – 1.01)	.611†	(.197 – .722)	.946	(.872 – 1.01)	1.34†	(1.24 – 1.60)	106
60 years and older	.906	(.820 – 1.00)	.642	(.087 – .750)	.937	(.877 – 1.00)	1.28	(1.23 – 1.36)	158
Females									
Total, 3 years and older	1.12	(1.06 – 1.19)	.847	(.801 – .890)	1.17	(1.10 – 1.25)	1.62	(1.49 – 1.96)	881
3–5 years	1.30	(1.22 – 1.38)	.993†	(.905 – 1.11)	1.32	(1.25 – 1.40)	1.58†	(1.45 – 1.76)	43
6–11 years	1.23	(1.10 – 1.38)	.926	(.860 – .977)	1.25	(1.16 – 1.33)	1.68	(1.57 – 1.95)	127
12–19 years	1.06	(1.01 – 1.11)	.820	(.716 – .870)	1.08	(1.02 – 1.16)	1.54	(1.39 – 2.11)	278
20–39 years	1.10	(.980 – 1.24)	.871	(.658 – .936)	1.17	(1.10 – 1.27)	1.70	(1.50 – 2.10)	171
40–59 years	1.14	(1.04 – 1.25)	.823†	(.754 – .889)	1.16	(1.04 – 1.36)	1.54†	(1.43 – 2.60)	96
60 years and older	1.07	(.919 – 1.24)	.777	(.486 – .881)	1.05	(.881 – 1.28)	1.48	(1.32 – 3.87)	166

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.3.a.4. Glycidamide-to-acrylamide hemoglobin adduct ratio: Non-Hispanic blacks

Geometric mean and selected percentiles of ratio (no units) of whole blood concentrations (in pmol/g Hb) for non-Hispanic blacks in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)		Selected percentiles (95% conf. interval)						Sample size
			10th		50th		90th		
Males and Females									
Total, 3 years and older	.830	(.762 – .904)	.526	(.440 – .588)	.893	(.845 – .949)	1.39	(1.27 – 1.60)	1,736
3–5 years	1.15	(1.08 – 1.23)	.865	(.697 – .961)	1.15	(1.07 – 1.24)	1.53	(1.37 – 1.83)	122
6–11 years	1.02	(.927 – 1.13)	.708	(.563 – .793)	1.10	(1.00 – 1.20)	1.74	(1.58 – 1.92)	265
12–19 years	.834	(.752 – .925)	.582	(.484 – .635)	.893	(.858 – .931)	1.38	(1.26 – 1.66)	637
20–39 years	.865	(.768 – .975)	.547	(.424 – .604)	.900	(.827 – .974)	1.39	(1.24 – 1.64)	277
40–59 years	.720	(.642 – .807)	.427	(.340 – .509)	.805	(.746 – .874)	1.19	(1.11 – 1.35)	248
60 years and older	.752	(.652 – .868)	.458	(.184 – .542)	.822	(.743 – .915)	1.24	(1.15 – 1.62)	187
Males									
Total, 3 years and older	.782	(.721 – .847)	.512	(.429 – .546)	.830	(.784 – .878)	1.31	(1.20 – 1.53)	875
3–5 years	1.17	(1.10 – 1.24)	.940†	(< LOD – .985)	1.14	(1.08 – 1.24)	1.57†	(1.39 – 1.82)	68
6–11 years	1.10	(.985 – 1.23)	.711	(.560 – .831)	1.12	(1.02 – 1.20)	1.78	(1.66 – 2.11)	126
12–19 years	.770	(.666 – .890)	.554	(.420 – .613)	.833	(.808 – .859)	1.30	(1.12 – 1.64)	341
20–39 years	.797	(.739 – .860)	.490	(.431 – .537)	.808	(.741 – .880)	1.18	(1.06 – 1.77)	136
40–59 years	.628	(.532 – .741)	.413	(.073 – .483)	.727	(.643 – .809)	1.11	(1.02 – 1.24)	115
60 years and older	.717	(.592 – .869)	.457†	(.046 – .565)	.766	(.691 – .853)	1.15†	(1.02 – 2.25)	89
Females									
Total, 3 years and older	.875	(.788 – .972)	.581	(.412 – .643)	.951	(.885 – 1.00)	1.42	(1.31 – 1.62)	861
3–5 years	1.14	(1.02 – 1.27)	.792†	(.716 – .967)	1.16	(1.03 – 1.26)	1.48†	(1.32 – 2.00)	54
6–11 years	.947	(.807 – 1.11)	.690	(< LOD – .784)	1.08	(.955 – 1.21)	1.55	(1.32 – 2.11)	139
12–19 years	.905	(.815 – 1.00)	.603	(.447 – .701)	.983	(.921 – 1.05)	1.44	(1.31 – 1.82)	296
20–39 years	.924	(.778 – 1.10)	.602	(< LOD – .726)	.974	(.885 – 1.12)	1.52	(1.36 – 1.89)	141
40–59 years	.802	(.728 – .885)	.463	(.380 – .602)	.870	(.805 – .926)	1.24	(1.15 – 1.48)	133
60 years and older	.778	(.643 – .941)	.425†	(< LOD – .574)	.831	(.766 – 1.00)	1.32†	(1.15 – 3.57)	98

< LOD means less than the limit of detection for either the whole blood acrylamide adduct or the glycidamide adduct, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

Table 5.3.a.5. Glycidamide-to-acrylamide hemoglobin adduct ratio: Non-Hispanic whites

Geometric mean and selected percentiles of ratio (no units) of whole blood concentrations (in pmol/g Hb) for non-Hispanic whites in the U.S. population aged 3 years and older, National Health and Nutrition Examination Survey, 2003–2004.

	Geometric mean (95% conf. interval)		Selected percentiles (95% conf. interval)						Sample size
			10th		50th		90th		
Males and Females									
Total, 3 years and older	.967	(.932 – 1.00)	.651	(.629 – .675)	1.01	(.984 – 1.03)	1.47	(1.41 – 1.53)	2,859
3–5 years	1.28	(1.15 – 1.43)	.863†	(.097 – 1.18)	1.32	(1.23 – 1.47)	1.61†	(1.56 – 2.05)	89
6–11 years	1.31	(1.23 – 1.38)	.939	(.852 – .989)	1.32	(1.27 – 1.38)	1.72	(1.55 – 2.41)	172
12–19 years	.979	(.901 – 1.06)	.699	(.642 – .748)	1.02	(.981 – 1.07)	1.42	(1.36 – 1.61)	490
20–39 years	.939	(.896 – .984)	.645	(.610 – .678)	.984	(.924 – 1.02)	1.42	(1.37 – 1.51)	648
40–59 years	.948	(.910 – .988)	.629	(.591 – .658)	.986	(.954 – 1.02)	1.41	(1.34 – 1.50)	586
60 years and older	.914	(.859 – .972)	.631	(.553 – .669)	.966	(.935 – .989)	1.40	(1.33 – 1.55)	874
Males									
Total, 3 years and older	.927	(.898 – .958)	.627	(.605 – .649)	.955	(.922 – .993)	1.39	(1.33 – 1.48)	1,400
3–5 years	1.24	(1.07 – 1.43)	.842†	(.621 – 1.10)	1.27	(1.10 – 1.46)	1.57†	(1.48 – 2.06)	48
6–11 years	1.32	(1.24 – 1.41)	.944†	(.748 – 1.03)	1.33	(1.27 – 1.42)	1.70†	(1.57 – 2.25)	82
12–19 years	.947	(.862 – 1.04)	.669	(.609 – .722)	1.01	(.940 – 1.04)	1.37	(1.32 – 1.41)	254
20–39 years	.862	(.820 – .905)	.609	(.549 – .644)	.886	(.852 – .930)	1.24	(1.20 – 1.30)	289
40–59 years	.922	(.891 – .954)	.619	(.557 – .649)	.945	(.910 – .987)	1.33	(1.23 – 1.44)	291
60 years and older	.880	(.835 – .929)	.570	(.512 – .636)	.922	(.862 – .953)	1.38	(1.27 – 1.49)	436
Females									
Total, 3 years and older	1.01	(.961 – 1.05)	.681	(.648 – .706)	1.06	(1.02 – 1.09)	1.52	(1.45 – 1.62)	1,459
3–5 years	1.33	(1.17 – 1.51)	1.01†	(< LOD – 1.19)	1.46	(1.26 – 1.48)	1.72†	(1.51 – 2.09)	41
6–11 years	1.29	(1.19 – 1.40)	.923†	(.777 – .995)	1.28	(1.20 – 1.39)	1.79†	(1.54 – 2.97)	90
12–19 years	1.02	(.929 – 1.11)	.743	(.636 – .786)	1.05	(.996 – 1.13)	1.57	(1.37 – 1.87)	236
20–39 years	1.02	(.954 – 1.10)	.691	(.654 – .700)	1.06	(1.00 – 1.14)	1.55	(1.46 – 1.77)	359
40–59 years	.975	(.899 – 1.06)	.639	(.513 – .736)	1.02	(.969 – 1.08)	1.43	(1.38 – 1.63)	295
60 years and older	.942	(.866 – 1.02)	.658	(.528 – .724)	1.00	(.968 – 1.05)	1.43	(1.35 – 1.56)	438

< LOD means less than the limit of detection for either the whole blood acrylamide adduct or the glycidamide adduct, which may vary for some compounds by year. See Appendix D for LOD.

† Estimate is subject to greater uncertainty due to small cell size.

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