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Updated Japanese growth references for infants and preschool children, based on historical, ethnic and environmental characteristics

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Keywords
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ABSTRACT

Aim: To provide updated growth references for Japanese children from birth to 6 years of age, for use in both growth monitoring and child care.

Methods: We analysed data from two national representative surveys that provided cross-sectional data on 3000 areas in the 2005 national census and longitudinal data from 136 hospitals. Growth references for length/height, weight, head circumference and chest circumference were constructed using the lambda-mu-sigma (LMS) method, with estimates of the *L*, *M* and *S* parameters. These updated values were then compared with growth references published by the World Health Organization.

Results: The 3rd, 50th and 97th smoothed percentile values of length/height, weight, head circumference and chest circumference for boys and girls from birth to 6 years are presented. The comparisons show some large differences in median measurements between the charts.

Conclusion: Our growth references are based on a current, nationally representative sample of Japanese children. The results provide deep insight into child growth from a historical, ethnic and environmental point of view.

INTRODUCTION

Comparing a child's body measurements with growth references, representative of the corresponding population is one of the most useful ways of assessing their growth. National growth surveys provide useful references for assessing individual children and monitoring the overall growth of children from a public health point of view (1).

Japanese national growth references for infants and preschool children, based on a representative national sample consisting of an almost homogeneous population, have been monitored at 10-year intervals for more than half a century. The first growth reference for Japanese infants and preschool children was published as the Kuriyama/Yoshinaga reference (University of Tokyo, Department of Pediatrics Values) in 1929 and was based on an investigation of healthy children in the suburbs of Tokyo (2). Subsequent growth references were primarily compiled by the National Institute of Public Health, on the basis of surveys funded by the Ministry of Education. The Saito/Shimizu reference was conducted in 1940, and the Saito/Funakawa reference was conducted in 1950 (3,4). Governmental surveys have been carried out every 10 years since 1960 by the Ministry of Health and Welfare, with the latest carried out in 2010 by the Ministry of Health, Labour and Welfare (5–9). Our study is based on the updated references from the 2010 survey.

Normal neonates experience weight loss during the first few days of life (10). Therefore, growth references for weight during the first few months of life are more useful if the

Abbreviations
CDC, Centers for Disease Control and Prevention; WHO, World Health Organization.

Key notes

- This paper presents updated growth references for Japanese children from birth to 6 years of age.
- It shows that Japanese preschool children are smaller than children raised in Western countries and some Asian countries and are smaller than children of Japanese origin raised in America.
- The findings reflect changes in Japan's socioeconomic status, infant feeding practices and birthweight and provide a useful weight reference for infants in the first few months of life.

references are constructed taking neonatal weight loss into account. Therefore, hospital data, including daily weight measurements during the first 5 days, were included in the analysis.

In this paper, we present the length/height, weight, head circumference and chest circumference references for infants and children in Japan using data from a current sample of Japanese children from birth to 6 years of age and compare the resulting selected centiles with chosen growth references. We also took advantage of the large sample, representative of the population, to provide updated growth references for Japanese children, including body weight changes during the neonatal period.

METHODS

The 2010 growth survey of infants and children was conducted by the Equal Employment, Children and Families Bureau of the Ministry of Health, Labour and Welfare in Japan. The study design and evaluation of the results were discussed by a committee of academic experts, and the growth references were created by the working group funded by the Ministry.

Subjects

The survey consisted of two components: a cross-sectional general survey and a longitudinal hospital survey. Subjects included in the community-based, cross-sectional general survey were all infants and preschool children aged from 14 days to 2 years on the day of measurement, who were living in the 3000 areas randomly sampled by stratification from the 2005 census areas (11). Preschool children aged from two to 6 years in 900 areas, selected randomly from the 3000 areas mentioned above, were also recruited. The municipalities were asked to look at the resident files that were used in the 2005 census, and in August 2010, a letter was mailed to all residents in the 2005 census, asking them general questions about the number of infants and preschool children they would have in September 2010. As a result of the letter, we identified 10 880 infants and preschool children who were eligible for the current study. The 1-month survey was performed between 1 and 30 September 2010. Municipality health centres gathered infants and preschool children on the appointed day and health personnel measured them and carried out health examinations. Home visits were made to those who failed to attend the examination on that day. These two initiatives resulted in data from 7652 infants and preschool children, with a response rate of 70.3%.

The hospital survey collected longitudinal growth data over a 1-month period Hospitals throughout Japan (n = 150) with an obstetrics department, and inpatient beds were sampled randomly from the basic file of medical facilities from the national survey of medical facilities (12). Data were obtained on all infants who were born in the hospitals and underwent their 1-month health check during the 1-month study period in September 2010. This yielded data on 4774 infants from 146 hospitals.

Survey items

During the community survey, the length/height, weight, head circumference and chest circumference of infants and preschool children were measured and their general health status was assessed by a physician. The parents provided the following information interviewed by health personnel: the medical history of the children, including past and present diseases, medication used, date of birth, birth weight and social status.

During the hospital survey, all recorded measurements of the four items of length/height, weight, head circumference and chest circumference during the baby's hospital stay and at their 1-month health check-up after birth were collected. The study team also checked their medical records for items such as gestational age, multiple birth and birth order, mode of delivery and any disorders during delivery and the neonatal period that can affect the growth of neonates. The longitudinal hospital data were collected in addition to cross-sectional community data so that body weight changes were clear from birth to around 1 month of age. Although the data were collected longitudinally, they were analysed cross-sectionally.

Ethical issues

The two surveys were conducted as official Government surveys approved by the Ministry of General Affairs. The present research was approved by the Institutional Review Board of the National Institute of Public Health. The procedures followed were in accordance with the Helsinki Declaration of 1975, as revised in 1983.

Measurements

All the children and infants were measured by trained staff. The nurses and public health personnel used standardised instruments and methods that conformed with the guidelines outlined in the study manual. A neonatometer was used to measure the length of infants and children under the age of 2, to the nearest 0.1 cm. The infants were naked, in the supine position, head in the Frankfurt plane, knees loosely fixed and plantars perpendicular to both the vertical axis and horizontal plane. A stadiometer was used to measure the height of children aged 2 and over, to the nearest 0.1 cm. The children were standing upright, with their heels, hips and back straight against the pillar and their head in the Frankfurt plane. The body weight of the infants was measured before feeding and after they passed stools and urine, to the nearest 10 g. If they wore diapers or cloths, the weight of them was subtracted.

The head circumference was measured along the line passing the glabella and external occipital protuberance, and the chest circumference was measured in the plane passing the bilateral nipples and perpendicular to the body axis. The measurement was to the nearest 0.1 cm using a plastic measure.

Data processing

The data were processed centrally, with data entry performed by trained staff, according to the study's data entry manual.

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The data were initially checked to see whether there were values of <0.3 kg or over 50 kg for weight, under 25 cm of over 80 cm for height/length and under 15 cm or over 80 cm for head circumference and chest circumference. If the values were over or under these figures, the original sheets were checked and the data entry errors were corrected. Data on the individual cards that were confirmed to be abnormal were excluded. Outliers were excluded. They were defined as values larger or smaller than 0.01% among the distribution of the data and which appeared to be artificial errata during data recording and/or transfer. A total of 0.46% of the data were excluded from the analysis.

Centile curves

The distribution of the data was somewhat skewed, especially the data for weight and chest circumference. Therefore, the *Z*-scores and centiles could not be calculated from the mean and standard deviation, which assume a normal distribution. Therefore, the LMS method was used to create the growth reference (13) except for the age group from 8 to 22 days. We performed weighed calculations by sample size for smoothing. The assumption underlying the LMS method is that after the Box–Cox power transformation, the data at each age are normally distributed.

The LMS method uses three quantities: the power (*L*), median (*M*) and coefficient of variation (*S*) calculated for each group. It then uses these values to determine the value that best approximates the median (50th centile of the distribution). The parameter *L* shows the skewness of the distribution. The distribution is symmetrical when $L = 1$, trails long to smaller values when $L > 1$, and trails long to larger values when $L < 1$.

From the values of *L*, *S* and *M*, smoothed by the cubic equation, a given percentile value can be calculated using the following equation: $M(1 + \mathrm{ZLS})^{1/L}$, where *Z* is the *Z*-score of the normalised distribution. To calculate the third, 50th and 97th percentile values, *Z* was substituted as −1.88079, 0 or 1.88079, respectively.

The three corresponding values, *L*, *M* and *S*, were calculated for each age interval which were set at 5-day intervals until 2 months after birth, 1-month intervals until 2 years after birth and 6-month intervals after the age of 2 years, because growth is more rapid in the earlier ages of life. The sample size for each age group is shown in Table 1 for both boys and girls. Each sample size was above the sample size for LMS smoothing recommended by Cole (13), except for the age group from 8 to 22 days.

All of the data in all age groups were used for LMS smoothing for length/height, head circumference and chest circumference, but only the data after 5 days of life were used for weight, because of neonatal weight loss (10). Neonates show abrupt body weight changes in the first few days of life. The daily values for body weight for the first 5 days of life, which is the age at which most neonates are discharged from hospitals in Japan, were calculated from the hospital records.

The values of *L*, *M* and *S*, calculated for each age level, were smoothed using a cubic spline function, which smoothly connects several cubic equations at knots and is one of the most frequently used methods of smoothing. At each knot, the linear and quadratic differential coefficients are equal. The calculation of spline smoothing was carried out by proc transreg in SAS statistical software version 9.2 (SAS Institute, Cary, NC, USA) with weights according to the number of samples in each age group. Several combinations of knots were examined for the corresponding age values of knots, and the most appropriate for creating the reference was chosen. We chose the positions of the knots where the smoothed curves were in good agreement with the percentile values that had been directly calculated from the data set of each age group, showing no unnatural ups and downs nor unnatural widening and narrowing of the intervals. The age in months for the corresponding knots for each item is shown in Table 2.

Difference between supine length and standing height

Stature is shorter when measured in the standing than the supine position. When the World Health Organization (WHO) 2006 reference was created, it was estimated that the length in the supine position was 0.7 cm more than the height measured in the standing position (14). To fit a single model for the whole age range, 0.7 cm was therefore added to the measured height values. After the model was fitted, the final curves were shifted downwards by 0.7 cm for children aged 2 years and above to create the height for age standards. The Centers for Disease Control and Prevention (CDC) 2000 reference estimated that length measurements were 0.8 cm higher than height measurements (15).

In the present study, the difference was estimated from our data set. Data were divided into children under 2 years of age and children 2 years of age and over and two partial regressions coefficients were calculated for the constants. The difference between two partial regression coefficients was 1.319 cm for boys and 1.366 cm for girls, which correspond to the difference between the two types of measurement.

Comparison with chosen growth references

Based on ethnic differences and historical usage, the medians were compared with growth references for Japanese children in 1970 (6) and 2000 (9) and the WHO 2006 reference (16). The standard deviation scores of the 1970, 2000 and 2010 Japanese references were then compared with the WHO 2006 reference.

RESULTS

The three quantities used in the LMS method were calculated for length/height, weight, head circumference and chest circumference in both boys and girls from birth to 6 years of age. The third and 97th centiles were calculated from the parameters *L*, *M* and *S*.

References for length/height, weight, head circumference and chest circumference

L, *M* and *S* values along with the 3rd and the 97th percentile values are presented for length/height, weight,

Table 1 Age distribution of the reference sample

Age	Boys: Longitudinal hospital data	Boys: Cross-sectional community data	Girls: Longitudinal hospital data	Girls: Cross-sectional community data
Birth	2414		2284	
1 day	2135		2026	
2 days	2160		2050	
3 days	2187		2084	
4 days	2188		2093	
5 days	2078		1936	
8–22 days	10	4	17	6
23–27 days	141	4	154	3
28–32 days	1087	3	1004	4
33–37 days	931	6	884	4
38–42 days	190	9	177	8
43 days–1.99 months	41	42	38	43
2–2.99 months		103	2	89
3–3.99 months	1	90		98
4–4.99 months		118		112
5–5.99 months		103		119
6–6.99 months		116		119
7–7.99 months		110		113
8–8.99 months		103		99
9–9.99 months		121		114
10–10.99 months		101		92
11–11.99 months		112		106
12–12.99 months		113		111
13–13.99 months		111		98
14–14.99 months		95		86
15–15.99 months		80		91
16–16.99 months		105		106
17–17.99 months		106		87
18–18.99 months		105		106
19–19.99 months		101		84
20–20.99 months		93		89
21–21.99 months		101		82
22–22.99 months		107		93
23–23.99 months		105		96
24–29.99 months		198		195
30–35.99 months		163		166
36–41.99 months		182		130
42–47.99 months		155		159
48–53.99 months		198		164
54–59.99 months		147		149
60–65.99 months		159		149
66–71.99 months		156		148
72–77.99 months		145		159

head circumference and chest circumference in Tables 3–6, respectively. For height/length, head circumference and chest circumference, smoothed *L*, *M* and *S* values are presented from birth to the age of 75 months. For weight, percentile values were directly calculated from the data set of each day from birth to 4 days of age, and LMS smoothed values are presented from the fifth day to the age of 75 months. There was a decrease in the median values of body weight from birth to 2 days of life by 162 g for boys and 174 g for girls.

Comparison of length/height with chosen references

Figure 1 shows the median values for length/height for the Japanese 1970, 2000 and 2010 references, in relation to the WHO 2006 reference. This shows that the standard deviation scores of the Japanese references, compared with the

WHO 2006 reference, decreased between three and 33 months of age, after which they became stable for each month of age. The 2000 and 2010 Japanese references were smaller, or equal to, the 1970 reference from three to 33 months of age. After that, they were larger than the 1970 reference.

Table 2 The location of knots (months of age) for cubic spline smoothing

Items	*L*	*M*	*S*
Boys length/height	24	6, 12, 24, 48	12
Girls length/height	24	6, 12, 24, 48	12
Boys weight	12, 48	6, 10.8, 25.2, 42	12
Girls weight	24	6, 10.8, 25.2, 42	12
Boys head circumference	24	6, 12, 24, 48	12
Girls head circumference	24	6, 12, 24, 48	12
Boys chest circumference	24	6, 12, 24, 48	12
Girls chest circumference	24	6, 12, 24, 48	12

Comparison of weight with chosen references

Figure 2 shows the median weight values for the Japanese 1970, 2000 and 2010 references in relation to the WHO 2006 reference. The gap between the Japanese reference and the WHO 2006 reference got larger as the children's age increased. Among the Japanese references, the weight from 3 to 39 months of age decreased from 1970 to 2010.

Body weight in the early infantile period

Figure 3 compares the third, 50th and 97th percentile curves between the WHO 2006 reference and the present study. The WHO 2006 curves are based on the values

Table 3 Length and height (cm) from birth to 75 months of age in boys and girls

	Boys					Girls				
	LMS			Centiles		LMS			Centiles	
Age	*L*	*M*	*S*	Third	97th	*L*	*M*	*S*	Third	97th
Length										
Birth	4.03648	48.8269	0.048931	43.5	52.8	3.33677	48.3616	0.043758	43.9	52.0
30 days	3.45039	53.5057	0.042617	48.7	57.4	3.56997	52.6627	0.041261	48.1	56.4
1.5 months	3.16789	55.6113	0.041182	50.9	59.6	3.67013	54.6229	0.040132	50.0	58.4
2.5 months	2.66263	59.1256	0.038788	54.5	63.2	3.82464	57.9383	0.038254	53.3	61.7
3.5 months	2.21290	61.9813	0.036874	57.5	66.1	3.92880	60.6839	0.036761	56.0	64.5
4.5 months	1.81573	64.3058	0.035389	59.9	68.5	3.98586	62.9599	0.035610	58.2	66.8
5.5 months	1.46812	66.2263	0.034283	61.9	70.4	3.99911	64.8667	0.034763	60.1	68.7
6.5 months	1.16706	67.8680	0.033506	63.6	72.1	3.97181	66.5035	0.034177	61.7	70.4
7.5 months	0.90957	69.3121	0.033006	65.0	73.6	3.90724	67.9385	0.033812	63.1	71.9
8.5 months	0.69265	70.5954	0.032733	66.3	75.0	3.80866	69.2097	0.033627	64.4	73.2
9.5 months	0.51331	71.7527	0.032637	67.4	76.2	3.67936	70.3536	0.033583	65.5	74.5
10.5 months	0.36856	72.8190	0.032668	68.4	77.4	3.52260	71.4067	0.033636	66.5	75.6
11.5 months	0.25539	73.8292	0.032774	69.4	78.5	3.34166	72.4055	0.033748	67.4	76.7
12.5 months	0.17081	74.8173	0.032906	70.3	79.6	3.13980	73.3857	0.033878	68.3	77.8
13.5 months	0.11184	75.8003	0.033040	71.2	80.6	2.92030	74.3648	0.034006	69.3	78.9
14.5 months	0.07547	76.7775	0.033173	72.1	81.7	2.68644	75.3417	0.034131	70.2	79.9
15.5 months	0.05871	77.7477	0.033307	73.0	82.8	2.44147	76.3147	0.034253	71.1	81.0
16.5 months	0.05857	78.7095	0.033440	73.9	83.8	2.18869	77.2821	0.034372	72.1	82.1
17.5 months	0.07205	79.6618	0.033574	74.8	84.8	1.93135	78.2422	0.034488	73.0	83.2
18.5 months	0.09616	80.6031	0.033707	75.6	85.9	1.67272	79.1931	0.034602	73.9	84.2
19.5 months	0.12791	81.5322	0.033840	76.5	86.9	1.41610	80.1333	0.034714	74.8	85.3
20.5 months	0.16429	82.4478	0.033974	77.3	87.9	1.16473	81.0608	0.034823	75.7	86.3
21.5 months	0.20232	83.3486	0.034106	78.1	88.8	0.92190	81.9741	0.034930	76.6	87.4
22.5 months	0.23899	84.2333	0.034239	78.9	89.8	0.69088	82.8713	0.035034	77.5	88.4
23.5 months	0.27133	85.1007	0.034372	79.7	90.7	0.47494	83.7507	0.035137	78.3	89.4
Height										
27 months	0.32279	86.6700	0.034833	81.1	92.5	−0.13210	85.3081	0.035481	79.8	91.2
33 months	0.21404	91.1293	0.035615	85.2	97.4	−0.66426	89.8120	0.036027	84.1	96.3
39 months	−0.05050	95.0672	0.036379	88.8	101.8	−0.65790	93.8000	0.036537	87.7	100.6
45 months	−0.36265	98.5999	0.037121	92.0	105.8	−0.23372	97.4178	0.037032	90.9	104.5
51 months	−0.61423	101.8445	0.037835	95.0	109.5	0.48759	100.8098	0.037532	93.8	108.1
57 months	−0.69705	104.9390	0.038516	97.8	113.0	1.38533	104.0856	0.038061	96.5	111.4
63 months	−0.50293	108.0426	0.039158	100.5	116.5	2.33879	107.3198	0.038639	99.1	114.8
69 months	0.07632	111.3150	0.039756	103.3	119.9	3.22729	110.5859	0.039288	101.6	118.2
75 months	1.14888	114.9162	0.040305	106.2	123.6	3.93011	113.9571	0.040030	104.2	121.7

Table 4 Weight (g) from birth to 75 months of age in boys and girls

	Boys						Girls					
	LMS				Centiles		LMS				Centiles	
Age	*L*	*M*	*S*	Median	Third	97th	*L*	*M*	*S*	Median	Third	97th
Birth				3000	2104	3760				2935	2126	3666
1 day				2894	2060	3634				2814	2074	3534
2 days				2838	2010	3560				2761	2038	3458
3 days				2840	2000	3590				2761	2028	3470
4 days				2880	2034	3618				2788	2046	3500
5 days	1.321.51	2891.19	0.14831		2040	3650	1.28793	2804.23	0.13858		2026	3544
30 days	1.32907	4132.99	0.13907		2997	5173	1.14659	3889.05	0.13189		2905	4838
15 months	1.32342	4791.78	0.13390		3527	5955	1.06356	4472.27	0.12814		3385	5543
2.5 months	1.29158	5842.38	0.12512		4413	7175	0.91379	5418.33	0.12178		4190	6671
3.5 months	1.23507	6634.32	0.11788		5120	8071	0.77874	6150.71	0.11653		4837	7530
4.5 months	1.15734	7221.66	0.11203		5672	8720	0.65765	6710.37	0.11228		5346	8178
5.5 months	1.06184	7658.47	0.10742		6101	9197	0.54974	7138.26	0.10893		5744	8668
6.5 months	0.95199	7998.00	0.10388		6443	9568	0.45425	7474.79	0.10636		6061	9052
7.5 months	0.83124	8274.75	0.10126		6725	9875	0.37041	7747.89	0.10446		6318	9366
8.5 months	0.70304	8504.47	0.09940		6960	10137	0.29745	7973.04	0.10311		6529	9627
9.5 months	0.57082	8702.09	0.09815		7160	10372	0.23460	8165.13	0.10222		6707	9854
10.5 months	0.43802	8882.56	0.09735		7339	10593	0.18108	8339.10	0.10167		6864	10064
11.5 months	0.30809	9059.94	0.09685		7511	10817	0.13614	8509.86	0.10133		7015	10272
12.5 months	0.18447	9239.34	0.09649		7682	11045	0.09901	8680.09	0.10112		7164	10480
13.5 months	0.06849	9420.58	0.09619		7853	11276	0.06890	8852.42	0.10097		7312	10691
14.5 months	−0.03981	9603.43	0.09595		8023	11510	0.04506	9025.97	0.10087		7460	10903
15.5 months	−0.14081	9787.63	0.09576		8193	11746	0.02671	9200.75	0.10083		7608	11117
16.5 months	−0.23479	9972.95	0.09563		8362	11985	0.01309	9376.72	0.10084		7755	11332
17.5 months	−0.32205	10159.15	0.09556		8531	12225	0.00342	9553.89	0.10091		7902	11550
18.5 months	−0.40287	10345.97	0.09553		8698	12467	−0.00306	9732.23	0.10102		8049	11769
19.5 months	−0.47755	10533.18	0.09556		8865	12711	−0.00712	9911.75	0.10118		8195	11991
20.5 months	−0.54637	10720.53	0.09563		9030	12955	−0.00954	10092.41	0.10138		8342	12215
21.5 months	−0.60962	10907.78	0.09575		9194	13200	−0.01108	10274.22	0.10163		8488	12441
22.5 months	−0.66759	11094.69	0.09592		9357	13446	−0.01251	10457.15	0.10191		8635	12669
23.5 months	−0.72058	11281.01	0.09613		9518	13692	−0.01460	10641.21	0.10224		8782	12901
27 months	−0.87092	11925.16	0.09719		10065	14552	−0.03451	11293.78	0.10367		9299	13734
33 months	−1.03047	12988.37	0.10003		10936	16010	−0.11446	12425.37	0.10696		10184	15230
39 months	−1.11983	13985.05	0.10387		11720	17434	−0.24237	13529.86	0.11095		11038	16761
45 months	−1.20152	14900.16	0.10836		12417	18824	−0.40668	14558.38	0.11524		11828	18266
51 months	−1.33280	15758.03	0.11316		13066	20240	−0.59582	15506.40	0.11941		12559	19734
57 months	−1.44983	16622.35	0.11795		13714	21724	−0.79822	16413.82	0.12306		13273	21200
63 months	−1.36768	17558.50	0.12237		14374	23149	−1.00232	17322.46	0.12578		14009	22692
69 months	−0.89616	18631.88	0.12611		15027	24325	−1.19656	18274.13	0.12715		14808	24221
75 months	0.15491	19907.88	0.12880		15552	25253	−1.36938	19310.65	0.12677		15710	25773

appearing in the tables of weight for age in weeks. At birth, the Japanese reference was 0.4 kg lower in both boys and girls. At 1 week of age, the Japanese reference was 0.6 kg lower in boys and 0.7 kg lower in girls. The Japanese reference was 0.3 kg lower at 4 weeks of age and 0.2 kg lower at 8 weeks of age in both boys and girls.

DISCUSSION

This paper provides updated growth references for Japanese infants and preschool children. The length/height, weight, head circumference and chest circumference references were constructed using data from a contemporary and nationally representative sample. The sampling scheme resulted in an accurate social and geographical representation of the population.

The present study included children up to 6 years of age because the growth survey was carried out by the Ministry of Health, Labour and Welfare, which is mainly incharge of observing the welfare of children up to that age. Another survey on children over 6 years of age was carried out by the Ministry of Education, Culture, Sports, Science and Technology, but that used different methods to the present study. The response rate in this current study was 70.3% and it is

Table 5 Head circumference (cm) from birth to 75 months of age in boys and girls

	Boys					Girls				
	LMS			Centiles		LMS			Centiles	
Age	*L*	*M*	*S*	Third	97th	*L*	*M*	*S*	Third	97th
Birth	3.57516	33.5340	0.041033	30.6	35.9	3.16302	33.0616	0.039349	30.4	35.3
30 days	3.51357	36.6508	0.038015	33.8	39.1	3.31746	35.8649	0.036895	33.1	38.2
1.5 months	3.47738	37.9537	0.036657	35.1	40.4	3.38432	37.0473	0.035782	34.3	39.4
2.5 months	3.39959	39.9479	0.034410	37.1	42.4	3.48864	38.8785	0.033925	36.2	41.2
3.5 months	3.31270	41.3592	0.032639	38.6	43.7	3.56084	40.2025	0.032438	37.5	42.5
4.5 months	3.21754	42.3408	0.031291	39.7	44.7	3.60300	41.1507	0.031282	38.5	43.4
5.5 months	3.11495	43.0462	0.030314	40.4	45.4	3.61724	41.8547	0.030417	39.3	44.1
6.5 months	3.00576	43.6255	0.029657	41.0	45.9	3.60563	42.4433	0.029803	39.9	44.7
7.5 months	2.89081	44.1563	0.029267	41.6	46.5	3.57027	42.9833	0.029401	40.4	45.2
8.5 months	2.77094	44.6439	0.029092	42.1	47.0	3.51326	43.4792	0.029171	40.9	45.7
9.5 months	2.64698	45.0903	0.029081	42.5	47.5	3.43670	43.9330	0.029074	41.4	46.2
10.5 months	2.51976	45.4977	0.029181	42.9	47.9	3.34267	44.3466	0.029069	41.7	46.6
11.5 months	2.39013	45.8680	0.029340	43.2	48.3	3.23327	44.7219	0.029118	42.1	47.0
12.5 months	2.25893	46.2032	0.029508	43.5	48.7	3.11059	45.0609	0.029182	42.4	47.4
13.5 months	2.12698	46.5059	0.029658	43.8	49.0	2.97674	45.3658	0.029240	42.7	47.7
14.5 months	1.99512	46.7783	0.029791	44.1	49.3	2.83380	45.6395	0.029293	43.0	48.0
15.5 months	1.86419	47.0232	0.029906	44.3	49.6	2.68386	45.8847	0.029340	43.2	48.3
16.5 months	1.73503	47.2431	0.030005	44.5	49.9	2.52903	46.1042	0.029381	43.4	48.6
17.5 months	1.60847	47.4406	0.030088	44.7	50.1	2.37140	46.3008	0.029418	43.6	48.8
18.5 months	1.48535	47.6181	0.030156	44.9	50.3	2.21305	46.4772	0.029448	43.8	49.0
19.5 months	1.36650	47.7783	0.030210	45.0	50.5	2.05609	46.6363	0.029474	44.0	49.1
20.5 months	1.25277	47.9238	0.030249	45.2	50.6	1.90261	46.7807	0.029496	44.1	49.3
21.5 months	1.14498	48.0570	0.030276	45.3	50.8	1.75470	46.9134	0.029512	44.3	49.5
22.5 months	1.04397	48.1806	0.030290	45.4	50.9	1.61446	47.0370	0.029524	44.4	49.6
23.5 months	0.95058	48.2970	0.030292	45.5	51.1	1.48399	47.1543	0.029531	44.5	49.7
27 months	0.69015	48.6746	0.030216	45.9	51.5	1.12237	47.5434	0.029525	44.9	50.2
33 months	0.45065	49.2382	0.029846	46.5	52.0	0.80613	48.1547	0.029414	45.5	50.8
39 months	0.39445	49.7113	0.029298	47.0	52.5	0.76467	48.7035	0.029206	46.0	51.4
45 months	0.43079	50.1119	0.028712	47.4	52.9	0.87148	49.1982	0.028934	46.5	51.9
51 months	0.46891	50.4577	0.028230	47.8	53.2	1.00006	49.6471	0.028633	47.0	52.3
57 months	0.41804	50.7642	0.027995	48.1	53.5	1.02390	50.0499	0.028337	47.4	52.7
63 months	0.18741	51.0444	0.028148	48.4	53.8	0.81650	50.3975	0.028081	47.7	53.1
69 months	−0.31374	51.3113	0.028831	48.6	54.2	0.25137	50.6807	0.027898	48.1	53.4
75 months	−1.17618	51.5780	0.030185	48.8	54.7	−0.79801	50.8899	0.027824	48.3	53.7

possible that the nonresponders may have included higher percentages of children who had been poorly raised or had an illness or disability.

Smoothing

Using the LMS method, smooth curves for *L*, *M* and *S* can be fitted by a statistical method such as cubic spline or polynomial equations or can be drawn by eye (13). In the reference charts for height and weight of schoolchildren in Malaysia, *L*, *M* and *S* parameters were smoothed by the LOWESS method (17). The penalised likelihood method was introduced for smoothing *L*, *M* and *S* curves, which led to natural cubic splines with knots at the age of observation (18). Although many recent studies have smoothed *L*, *M* and *S* by the maximum penalised likelihood (19,20), the present study aimed to show the mathematical functions for smoothing more simply. This means that municipal health personnel can calculate the percentile level of the measured values using ordinary business software on a personal computer in their public health practice.

Comparison between references

In this paper, the Japanese growth references were compared with the 2006 WHO reference (16), which is currently one of the most popular international references. The present analysis showed that recent Japanese growth references are smaller than the WHO 2006 and CDC 2000 references.

Western growth references (15,19) were similar to the CDC 2000 and WHO 2006 references and are larger than the Japanese reference. Chinese growth references for preschool children have been calculated, and their values are larger than the respective values in the CDC 2000 reference (21). In a Taiwanese reference from birth to 5

Table 6 Chest circumference (cm) from birth to 75 months of age in boys and girls

	Boys					Girls				
	LMS			Centiles		LMS			Centiles	
Age	*L*	*M*	*S*	Third	97th	*L*	*M*	*S*	Third	97th
Birth	3.16516	31.7371	0.057430	27.8	34.8	3.10503	31.5588	0.053836	27.9	34.5
30 days	2.58105	35.8494	0.054964	31.8	39.3	2.50596	35.1340	0.052168	31.4	38.4
1.5 months	2.29569	37.5436	0.053802	33.5	41.1	2.21644	36.6310	0.051376	32.9	40.0
2.5 months	1.77769	40.0833	0.051770	36.0	43.8	1.69714	38.9212	0.049978	35.1	42.5
3.5 months	1.30631	41.8029	0.050017	37.8	45.7	1.23293	40.5301	0.048757	36.8	44.2
4.5 months	0.87925	42.9125	0.048517	39.0	46.8	0.82090	41.6220	0.047698	37.9	45.4
5.5 months	0.49421	43.6223	0.047244	39.8	47.6	0.45814	42.3611	0.046785	38.7	46.2
6.5 months	0.14889	44.1382	0.046173	40.4	48.1	0.14177	42.9087	0.046004	39.3	46.8
7.5 months	−0.15902	44.5721	0.045278	41.0	48.6	−0.13114	43.3559	0.045339	39.8	47.2
8.5 months	−0.43182	44.9418	0.044532	41.4	48.9	−0.36347	43.7238	0.044776	40.2	47.6
9.5 months	−0.67181	45.2610	0.043909	41.8	49.3	−0.55814	44.0305	0.044299	40.6	48.0
10.5 months	−0.88130	45.5433	0.043385	42.1	49.6	−0.71805	44.2941	0.043894	40.9	48.2
11.5 months	−1.06259	45.8023	0.042932	42.4	49.8	−0.84610	44.5326	0.043546	41.1	48.5
12.5 months	−1.21799	46.0516	0.042527	42.7	50.1	−0.94519	44.7636	0.043239	41.4	48.7
13.5 months	−1.34979	46.2977	0.042154	42.9	50.3	−1.01823	44.9958	0.042966	41.6	49.0
14.5 months	−1.46030	46.5408	0.041814	43.2	50.6	−1.06813	45.2289	0.042725	41.9	49.2
15.5 months	−1.55182	46.7806	0.041505	43.5	50.8	−1.09778	45.4621	0.042516	42.1	49.4
16.5 months	−1.62666	47.0169	0.041227	43.7	51.1	−1.11008	45.6948	0.042339	42.3	49.7
17.5 months	−1.68713	47.2494	0.040979	43.9	51.3	−1.10795	45.9261	0.042191	42.6	49.9
18.5 months	−1.73551	47.4778	0.040761	44.2	51.5	−1.09428	46.1554	0.042072	42.8	50.1
19.5 months	−1.77412	47.7020	0.040572	44.4	51.8	−1.07199	46.3818	0.041982	43.0	50.4
20.5 months	−1.80527	47.9216	0.040411	44.6	52.0	−1.04396	46.6048	0.041919	43.2	50.6
21.5 months	−1.83124	48.1365	0.040277	44.8	52.2	−1.01311	46.8234	0.041883	43.4	50.8
22.5 months	−1.85436	48.3464	0.040171	45.0	52.4	−0.98234	47.0371	0.041872	43.6	51.1
23.5 months	−1.87691	48.5510	0.040090	45.2	52.7	−0.95455	47.2450	0.041886	43.8	51.3
27 months	−1.97327	49.2247	0.040006	45.9	53.4	−0.90845	47.9222	0.042119	44.4	52.0
33 months	−2.19528	50.2508	0.040511	46.8	54.6	−1.00984	48.9335	0.043096	45.3	53.3
39 months	−2.44558	51.1673	0.041712	47.6	55.8	−1.29056	49.8324	0.044640	46.0	54.5
45 months	−2.67353	52.0357	0.043468	48.3	57.1	−1.69409	50.7083	0.046566	46.7	55.8
51 months	−2.82852	52.9161	0.045638	49.0	58.4	−2.16389	51.6463	0.048686	47.5	57.2
57 months	−2.85991	53.8332	0.048079	49.7	59.8	−2.64342	52.6453	0.050815	48.3	58.8
63 months	−2.71708	54.7763	0.050649	50.3	61.2	−3.07614	53.6171	0.052764	49.2	60.4
69 months	−2.34941	55.7332	0.053206	50.9	62.5	−3.40551	54.4697	0.054349	49.9	61.8
75 months	−1.70625	56.6917	0.055610	51.5	63.6	−3.57500	55.1114	0.055382	50.4	62.8

years of age (22), the length/height was 0.1 cm shorter than the respective value in the WHO 2006 reference and the weight was 0.3 kg heavier in boys and 0.2 kg heavier in girls. These are much larger than the respective values in the present Japanese reference.

Research suggests that child growth differs among ethnic groups due to genetic factors and environmental factors (23). Child growth differs among Asian countries. Chinese and Taiwanese children are not smaller than children in Western countries, but Japanese children do tend to be smaller than their Asian and Western counterparts. In 1976, Greulich (24) pointed out that children of Japanese origin raised in America were larger than those raised in Japan. The difference was several times larger than the secular increase in the growth of native Japanese children from 1970 to 2010 in the present study. Therefore, recent American-born Japanese children might also be larger than recent native Japanese-born children. With the same genetic background and potentiality, American-born Japanese children are large because of socio-economic factors such as the American lifestyle (24). Japanese children are generally well nourished, so their growth potential is fully realised. The reason why Japanese children are smaller than children in both Western countries and other Asian countries, such as China and Taiwan, is uncertain.

Secular trends in child growth

When we examined the Japanese growth references trends over the decades, we could see that the median values for both length/height and weight decreased slightly from birth to 3 years of age. It is suggested that this trend is due to the consistent decline in birth weight after 1975 in Japan (25), as child growth during the early years of life is affected by birth weight (26). The feeding practice of infants changed after 1975. In 1970, the proportion of 1-month-old infants who were exclusively breastfed was 32%, by 1980 it had increased to 45% and by 2010 it had reached 52%. In addition, the concentrations of proteins and carbohydrates in formula became lower after 1975 (9).

Since Japanese growth references before 1960 are provided as means and standard deviations, not as medians or percentiles, they cannot be compared with median values after 1970. Despite this, the mean weight and length/height increased clearly and consistently from 1940 to 1970 (3–6), showing similar characteristics after 1970 (Table 7). In Japan, consistent improvements in the physique of schoolchildren and adults are clearly observed (27). There are a number of factors that can affect the growth rates of children, including economic conditions. For example, in Poland, gross domestic product rose from a very low level to half the EU average in the 1990s, and this could explain why children born in the early 1990s were smaller than those born around 2000 (20). In addition, when Komlos and Breitfelder (28) analysed the growth trend of African American children from 1940 until 2000, they found that African American children were taller than Caucasian children in 1940 and that a cumulative improvement occurred thereafter. They suggested that this could be explained by improvements in the incomes of African American citizens compared to the incomes of Caucasians (28). In Japan, rapid economic growth was observed from 1950 to 1970 (29), and this might be one of the factors that has contributed to the rapid improvement in the physique of children.

Updated reference

Data for the Japanese 2010 reference were collected by a single survey over a period of 1 month. There were a number of limitations, including the small data size and seasonal bias due to the fact that the study period was in September, towards the end of the hot summer weather, which could reduce the appetites, and therefore weight, of infants and preschool children. However, the growth references have been updated every 10 years for more than half a century, which could be a strength in spite of the limitations of sample size and seasonal bias.

Karlberg et al. (30) discussed the optimal interval for updating growth references. For a population with large secular changes in body size, updates should be carried out every 5–10 years, and for populations with little change, updates should preferably be carried out every 15–20 years.

Neonatal weight loss

Newborn infants experience physiological body loss in the first few days of life and then rapid weight gain occurs. Growth assessment can be more effective if it is compared with a reference that takes neonatal weight loss into account. For example, when the Belgian reference was created, extra data were collected during the neonatal period and added to the data in the later age groups (19). If the body weight of babies up to a few months of age is

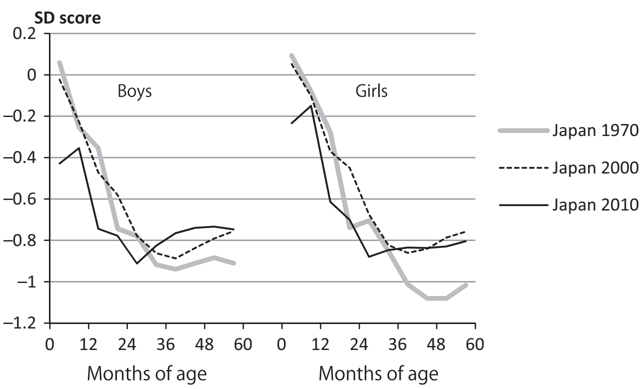

Figure 1 Comparison of the median length/height of boys and girls in three Japanese references as standard deviation scores compared with the WHO 2006 reference. The Japan 2010 reference in the present study, Japan 2000 reference (9), Japan 1970 reference (6), WHO 2006 reference (16).

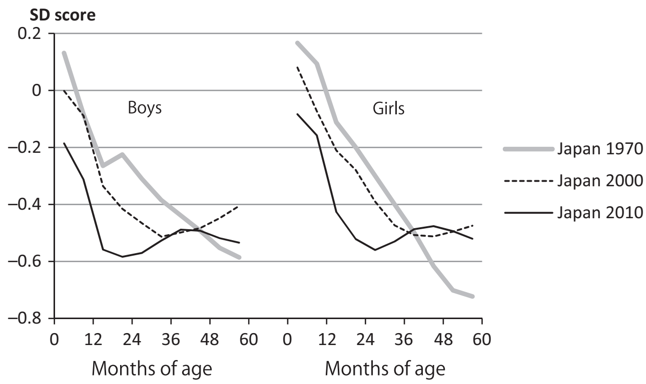

Figure 2 Comparison of the median weight of boys and girls in three Japanese references as standard deviation scores compared with the WHO 2006 reference. The Japan 2010 reference in the present study, Japan 2000 reference (9), Japan 1970 reference (6), WHO 2006 reference (16).

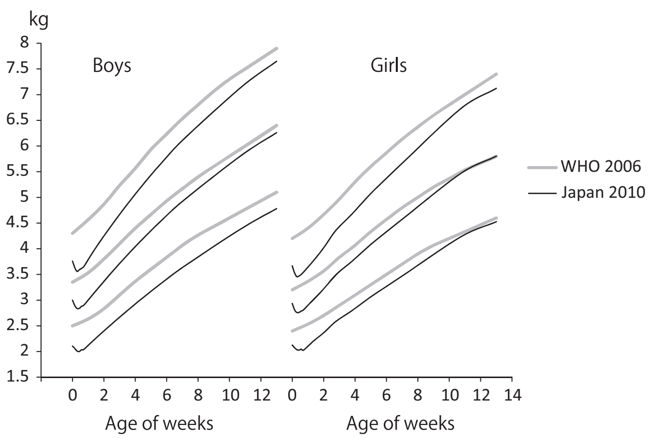

Figure 3 Comparison of selected percentiles for weight references Japan 2010 reference in the present study, WHO 2006 reference (16). The three lines correspond to the 3rd, 50th and 97th percentile values from the lower to the upper lines.

Table 7 Secular trend of length/height and weight of Japanese infants and preschool children

		1940			1950			1960			1970			2010		
		n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
Length/Height (cm)																
Boys	1–1.99 months	150	54.8	3.4	213	55.7	4.2	101	55.4	2.8	169	56.6	2.7	66	56.7	2.3
	11–11.99 months	268	70.9	3.2	269	72.2	3.4	94	73.1	2.8	227	74.3	2.5	111	73.9	2.6
	2–2.99 years	1183	84.5	4.4	1358	84.0	4.3	1148	86.7	3.7	777	88.8	3.5	363	88.8	3.4
	3–3.99 years	1225	91.3	4.1	1016	90.6	4.1	1349	93.3	4.2	749	96.1	3.5	343	96.7	4.0
	4–4.99 years	1403	97.5	4.6	942	96.5	4.4	1436	99.7	3.4	663	103.0	4.1	342	103.3	4.0
	5–5.99 years	1357	103.1	4.7	1107	102.0	4.4	1523	105.8	4.4	731	108.4	4.4	317	109.5	4.4
Girls	1–1.99 months	85	54.6	3.3	185	54.2	2.9	91	54.2	2.3	186	55.4	2.6	57	54.6	2.4
	11–11.99 months	193	69.7	2.9	255	70.0	3.1	98	71.6	2.4	233	72.9	2.7	105	72.5	2.4
	2–2.99 years	1123	83.3	4.5	1339	83.0	4.1	1229	85.3	3.5	715	87.6	3.3	362	87.6	3.7
	3–3.99 years	1207	90.2	4.4	1003	89.1	4.1	1265	92.2	3.9	714	94.8	3.6	289	95.7	3.7
	4–4.99 years	1281	96.3	4.8	904	95.9	4.5	1356	98.8	4.3	557	101.6	3.9	309	102.9	4.2
	5–5.99 years	1287	102.2	4.9	1065	101.2	4.2	1461	104.4	4.3	661	107.7	4.4	299	108.3	5.1
Weight (kg)																
Boys	1–1.99 months	150	4.4	0.8	213	4.7	0.9	101	4.8	0.8	169	5.1	0.7	66	5.1	0.7
	11–11.99 months	268	8.1	1.2	277	8.5	1.0	94	8.8	1.1	227	9.4	1.0	111	9.1	0.9
	2–2.99 years	1183	11.5	1.5	1258	11.8	1.4	1348	12.0	1.3	777	12.7	1.5	363	12.4	1.6
	3–3.99 years	1225	13.3	1.4	1016	13.4	1.3	1349	13.8	1.4	749	14.7	1.6	340	14.4	2.2
	4–4.99 years	1403	15.0	1.4	942	15.1	1.5	1436	15.3	1.6	663	16.3	2.0	342	16.3	2.0
	5–5.99 years	1357	16.2	1.8	1107	16.5	1.7	1523	17.0	1.7	731	17.8	2.1	317	18.3	2.9
Girls	1–1.99 months	85	1.0	0.7	185	4.7	0.7	91	4.5	0.7	186	4.7	0.6	58	4.5	0.6
	11–11.99 months	193	7.6	1.1	257	8.0	1.0	98	8.4	1.0	233	8.9	1.0	105	8.6	0.9
	2–2.99 years	1123	11.0	1.3	1339	11.3	1.3	1229	11.5	1.2	715	12.1	1.3	366	11.8	1.9
	3–3.99 years	1207	12.8	1.4	1093	12.7	1.3	1205	13.3	1.4	714	13.9	1.6	289	14.0	1.9
	4–4.99 years	1281	14.3	1.6	904	14.6	1.5	1356	15.0	1.5	557	15.6	1.7	310	16.0	2.3
	5–5.99 years	1287	15.8	1.7	1065	15.9	1.6	1461	16.5	1.8	661	17.6	2.1	299	18.1	2.5

The Japan 2010 reference in the present study, Japan 1940 reference (3), Japan 1950 reference (4), Japan 1960 reference (5), Japan 1970 reference (6).

evaluated using a reference where neonatal weight loss is not taken into account, low body weight could be overestimated. Cut-off values for low body weight differed by 0.7 kg between the present study and the WHO 2006 reference.

CONCLUSION

The length/height, weight, head circumference and chest circumference references we present in this paper are based on a current, nationally representative sample of Japanese infants and preschool children. This showed that they were smaller than infants and children raised in Western countries and in Asian countries such as China and Taiwan. They were also smaller than infants and children of Japanese origin raised in America. In addition, the growth of Japanese children under 3 years of age showed a reverse secular trend from 1970 until 2010. The results provide a detailed insight into the growth of Japanese children from a historical, ethnical and environmental point of view.

English language versions of the growth charts are available as pdfs – entitled 201117020A0006.pdf and 201117020A0007.pdf – that can be downloaded from the website: http://mhlw-grants.niph.go.jp/niph/search/NIDD00.do?resrchNum=201117020A.

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