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Development of birthweight and length for gestational age and sex references in Yucatan, Mexico

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Abstract

Objective: To develop sex- and gestational age specific reference percentiles and curves for birth weight and length for Yucatec neonates using data from birth registers of infants born during 2015–2019.

Material and methods: Observational, descriptive, epidemiologic study in a 5-year period including every registered birth in the state of Yucatan, Mexico using birth registries. A total of 158 432 live, physically healthy singletons (76 442 females and 81 990 males) between 25 and 42 weeks of gestation were included in the analysis. We used the LMS method to construct smoothed reference centiles (3rd, 10th, 25th, 50th, 75th, 95th, and 97th) and curves for males and females separately.

Results: Mean maternal age was 26 (SD = 6.22) years. Fifty-two percent of births occurred by vaginal delivery, 37% were firstborn and similar proportions were second (33%) and third or more (30%) born. 5.5% of newborns included in the references corresponds to neonates born before 37 weeks of gestation (5.9% boys and 5.1% girls). In both sexes, the percentage of infants with a birthweight less than 2500 g was 6.7%. The birthweight at the 50th percentile for males and females at 40 weeks of gestation in this cohort was 3256 and 3167 g, respectively, and the corresponding values for birth length were 50.23 and 49.84 cm (mean differences between sexes: 89 g and 0.40 cm, respectively).

Conclusion: The reference percentile and curves developed in this study are useful for research purposes and can help health practitioners to assess the biological status of infants born in Yucatán.

1 | INTRODUCTION

From a human biology perspective, size at birth (weight and length) represents a crude indicator of intrauterine growth, resulting from the complex interaction between three main components: (1) parental and offspring's genetic load, (2) the mother's own pre- and postnatal growth and her nutritional status before conception and during pregnancy, and (3) socioenvironmental exposures experienced by the mother during pregnancy. Recent evolutionary models propose that phenotype at birth is also shaped by nutritional histories of recent ancestors, particularly through maternal line (Kuzawa, 2005; Kuzawa, 2008; Wells, 2003; Wells, 2007).

From an epidemiological point of view, impaired fetal growth is linked to higher neonatal mortality (Katz et al., 2013; Lawn, et al., 2005) and may affect cognitive development during childhood (de Bie et al., 2010). The theoretical frame of developmental programming suggests that extreme neonatal birthweight (small or large) is associated with a set of structural and functional anomalies that predispose individuals to cardiovascular and metabolic diseases at different stages of postnatal life (Gluckman et al., 2008; Thornburg, 2015). Moreover, lower birthweight may be correlated with a decreased likelihood of attainment of higher education and a higher risk of lower employment rate and earnings in adulthood (Bilgin et al., 2018; Lambris et al., 2021).

Given the importance of fetal growth, weight and length at birth are assessed at birth to serve as reference when planning appropriate, timely interventions. Neonatal evaluations are usually done by comparing the infants with gestational age and sex-specific reference or standards based on newborns' weight or estimated fetal weights. While standards reflect the ideal or desirable growth pattern, reference charts describe the growth pattern of infants who were selected as the source sample, and their ability to discriminate between normal and abnormal growth is limited. Generally, reference values of size at birth are developed from observations of a single or few human groups, and even if translated to diverse populations, references seldom reflect growth of all populations. Therefore, low- and middle-income countries' (LMICs) populations may be underrepresented and considered as of secondary importance.

In the last decade, several international standards for fetal growth and birthweight have been constructed (e.g. Fenton & Kim, 2013; Kiserud et al., 2017; Mikolajczyk et al., 2011; Villar et al., 2014). These standards assume that, in absence of any physiological or environmental constraint, the pattern of fetal growth is similar across ethnic groups. However, when the pattern of different countries is compared with these global standards, significant differences in fetal growth and birthweight, independently of maternal phenotype and fetal sex, have been shown (Kiserud et al., 2017). Moreover, several studies have shown a wide variation in the birthweight of newborns depending on ethnicity or ancestry (Ratnasiri et al., 2018; Spada et al., 2018; Zhang & Bowes Jr., 1995). Overall, these findings highlight the effect of plasticity, the importance of normal variability during prenatal growth and the significance of developing population-specific references. The recent availability of data on birthweight, length and gestational age collected routinely in hospitals and compiled by the Birth Registration Systems in LMICs, provides the opportunity for researchers to produce population-specific references and growth curves for regions with particular demographic characteristics and epidemiological profiles. The development of references for birth weight and length are particularly important in populations where socioeconomic disparities among individuals, reflected in maternal phenotype, risk behavior and access to quality health services, impact fetal growth.

The present study took place in the Mexican state of Yucatan, one of the poorer states of the country, which is located in southeast Mexico. By 2020, Yucatan had a population of about 2.3 million people distributed among 106 municipalities including Merida, which is the state capital. More than 40% of the total population of Yucatan resides in Merida (INEGI, 2020). Maya people, the largest indigenous group in America, reside in rural communities and cities of Yucatan. The Maya as a human group is represented by underserved people living in adverse socioeconomic conditions in terms of income and access to quality education and health services compared to non-Maya people. Yucatan is also characterized by a high prevalence of cardiometabolic diseases among the adult population (ENSANUT, 2018) and the coexistence of low height-for-age and excess body weight in children (double burden of malnutrition) (Mendez et al., 2015; Varela-Silva et al., 2012). Native population from the Yucatan Peninsula exhibit specific genetic characteristics explained by a long history of geographic and cultural isolation from the rest of the country. The patterns of ancestry are still present in mestizo individuals inhabiting rural and urban sites from Yucatan (Moreno-Estrada et al., 2014). These characteristics could be translated to particular growth patterns in individuals from this population, which underlies the need for population-specific references of weight and length at birth. As has been recently discussed by Thompson (2021), given the selection of samples representative of broad regions (mainly from north and South America, Europe and Africa) and the use of rigid inclusion criteria during the recruitment of participants, international standards likely do not capture the current genetic, social and cultural variability of our species.

In the present study, we present sex specific reference percentiles for weight and length at birth at different gestational ages for Yucatec neonates using birth registries of infants born between 2015 and 2019. Along with this purpose, this study describes how neonates' weight and length from this Mexican region vary according to weeks of gestation and sex.

2 | METHODS

The present manuscript depicts an observational, descriptive, epidemiologic study including every registered birth in the state of Yucatan, Mexico, over a 5-year period to provide a reference of size at birth and characterize Yucatec newborns according to maternal and pregnancy related characteristics of the newborns. The reference percentiles and curves we constructed were based on all births contained in the datasets from the Subsystem of Birth Registration (SINAC) of Mexico. The SINAC includes the compilation, storage, and validation of data collected in every birth within the national territory. In Yucatan, the system compiles information from more than 100 public and private hospitals distributed across the state. For the purposes of the reference construction, we used databases corresponding to all live births occurring in Yucatan between January 1, 2015, and December 31, 2019.

We defined the variables of interest for reference construction and descriptive purposes and transformed data from birth registries into variables regarding (a) newborns, (b) maternal characteristics, and (c) pregnancy. Neonatal sex, gestational age, weight, and length were used to produce reference percentiles and curves. Maternal sociodemographic characteristics, including age, level of education, ethnicity and marital status of the studied population were recorded for descriptive purposes. Birth type and order were also recorded as descriptive variables.

Perinatal and maternal sociodemographic data were obtained by neonatologists and/or gynecologist and trained nursing staff, respectively. Gestational length was calculated according to the last menstrual date and defined as a categorical variable indicating completed weeks of gestation. Birth weight and length were obtained within the first hour after birth and recorded in grams and centimeters, respectively, following the ruling protocols for neonatal assessment. These protocols are mandatory for all health personnel nationwide (NOM-008-SSA2-1993, 1994) and continuous education is provided in this regard by every health institution (NOM-005-SSA3-2010, 2011). Neonates' weight was recorded with the bare infant lying in the weighing tray of an electronic scale (Seca, model 354©, 10 g of precision). Recumbent length was measured using a pediatric infantometer (Seca, model 210©) to the nearest centimeter. The same anthropometric equipment models were used in all hospitals in Yucatan, following the specifications for health infrastructure. According to their type of birth and birth order, infants were grouped in (1) born by vaginal delivery and (2) born through cesarean section, and (1) first, (2) second, (3) third and more, respectively. The age of mothers was used as a numerical variable in years and then grouped into (1) <20, (2) 20–29, (3) 30–39, and (4) ≥40. Maternal education was categorized as: (1) low: none, primary school and junior high school; (2) medium: high school; and (3) high: university. The use of language was used as a proxy for Maya ancestry/ethnicity (Colantonio et al., 2003; Relethford, 1995). According to their marital status, women were grouped in (1) with partner and (2) without partner at infants' birth.

The original datasets include information on 178 588 infants born between 2015 and 2019. We exclude infants from multiple pregnancies ($n = 3004$, 1.7%), infants with syndromic and congenital anomalies affecting in utero growth ($n = 4708$, 2.7%) and infants whose mothers do not reside in Yucatan ($n = 6422$, 3.6%). We used weight/gestational age, length/age and weight/length plots to identify cases with birth weights and lengths falling within an infeasible range for each gestational age and then excluded these data from the analysis ($n = 508$, 0.3%). We restricted our analysis to infants born between weeks 25 and 42 of gestation. The final sample used to construct the centile references and curves consisted of 163 946 singletons (81 973 female and 81 973 male).

2.1 | Centile modeling

We developed reference centiles for birthweight and length using the LMS (skewness, median, and coefficient of variation, respectively) method for smoothing reference centile curves (Cole, 1990; Cole & Green, 1992) and its extension (Generalized Additive Models for Location, Scale and Shape [GAMLSS]) by Rigby and Stasinopoulos (2004, 2006). We used the statistical software R (R Development Core Team, 2011). We used algorithms provided in the R package 'gamlss' to choose optimal degrees of freedoms for the parameters L, M, and S. For details see Stasinopoulos et al. (2017).

2.2 | Ethical concerns

Retrospective, secondary, anonymized datasets were used under permission from the Ministry of Health of the State of Yucatan for the purpose of the present study. The health authorities exempted this research from ethical review because involved non-identifiable data and datasets are in the public domain.

3 | RESULTS

On average, maternal age was 26 (SD = 6.22) years, 18% were younger than 20 years old and 2% of them were aged over 40 (Table 1). Sixty-five percent of women had a

TABLE 1 Sociodemographic and pregnancy characteristics of participant women

Characteristic	Frequency (%)
Mothers	
Age (years), mean (standard deviation)	26.22 (SD = 6.22)
Age categories	
<20	27 857 (18%)
20–29	86 801 (55%)
30–39	40 807 (26%)
≥40	2927 (2%)
Levels of education attained	
Low: None, primary and junior high school	98 182 (65%)
Medium: High school	30 071 (20%)
High: University and more	23 675 (15%)
Use of Maya language	
No	118 261 (82%)
Yes	25 297 (18%)
Marital status	
Without partner	11 572 (8%)
With partner	138 694 (92%)
Receive prenatal attention	
No	1787 (1%)
Yes	152 281 (99%)
Trimester of pregnancy when attended to the first prenatal consultation	
First	120 646 (79%)
Second	29 469 (19%)
Third	3495 (2%)
Number of prenatal consultations	
1–5	37 232 (24%)
≥ 6	115 049 (76%)
Newborns	
Sex	
Females	81 973 (48%)
Males	81 973 (52%)
Birth order (%)	
First	58 820 (37%)
Second	51 345 (33%)
Third or more	47 776 (30%)
Type of birth (%)	
Vaginal delivery	82 103 (52%)
Cesarean section	74 414 (48%)
Apgar	
Low (0–3 points)	613 (0.5%)
Medium (4–6 points)	769 (0.5%)
High (7–10 points)	156 646 (99%)

low educational level (none, primary and junior high school) and 15% finished university or any technical course. Most (92%) mothers had a partner at the time of their offspring's birth and 18% can be considered as Maya based on their use of the Maya language. A very low proportion of mothers (1%) did not receive prenatal attention and around 80% attended the first prenatal consultation during first trimester of pregnancy. Fifty-two percent of infants were born by vaginal delivery, 38% were first-borns and similar proportions were born at least in second (33%) or third order (30%). 5.5% of newborns included in the references were born earlier than 37 weeks of gestation (5.9% boys and 5.1% girls); in both sexes the percentage of infants with a birthweight less than 2500 g was 6.7%.

Smoothed percentiles (3rd, 10th, 25th, 50th, 75th, 90th, and 97th) for birthweight and length of male and female newborns for 25–42 weeks of gestational age are presented in Tables 2–5. The median (50th percentile) weight for males and females at 40 weeks of gestation in this cohort is 3255 and 3167 g, respectively, and the corresponding values for birth length were 50.23 and 49.84 cm (mean intersexual differences: 88 g and 0.40 cm, respectively). Male infants were heavier and longer than females across all gestational ages but the intersexual differences for birthweight were greater for the weeks 30–31 and 38–42 of gestation. For length, differences were greater for weeks 25–31 and 38–42. Figures 1–4 show reference charts for male and female newborns based on the smoothed-percentile values. The number of newborns for each gestational week together with their mean values and standard deviations are included in Supplementary materials.

Complementarily, the LMS parameters of birthweight and length were used to develop a tool to calculate the individual z-score and/or percentile of a newborn based on the presented references. Please see Resource Availability Statement to get access to the tool.

4 | DISCUSSION

We produce sex- and gestational age specific reference percentiles and curves for birthweight and length for newborns from Yucatan, Mexico, using a large and population-based dataset from birth registers of infants born during 2015–2019.

When comparing our cohort with references from other populations, including those residing in high income countries and LMICs, remarkable differences are identified in neonatal weight. Birthweight of Yucatec infants at 40 weeks of gestations is, on average, 470 g (males) and 408 g (females) lower than infants from Norway (Skjaerven et al., 2000), 358 g (males) and 303 g (females) lower than infants from Canada (Kramer et al., 2001), 114 g (males), 81 g (males) lower than Brazilian infants (Pedreira et al., 2011) and 190 g (the same difference for both sexes) higher than newborns from South India (Kumar et al., 2013). Very few studies have analyzed the birthweight for gestational age in Mexican infants (Flores Huerta & Martínez Salgado, 2012; Ríos et al., 2008). Compared to infants included in a study undertaken in 33 hospitals belonging to the Mexican Social Security Institute which included all births occurring from June 2000 to March 2002 (Flores Huerta & Martínez Salgado, 2012), newborns of our cohort are, on average, 150, and 100 g lighter than infants from the north and center of Mexico. The difference with neonates from the north of Mexico is similar to that reported by Ríos et al. (2008) in their study with infants from Chihuahua State. However, mean birthweight of Yucatec infants is comparable with birthweight of infants from the south of the country (see Figures S1 and S2 for comparisons with other Mexican populations from 35 to 42 weeks of gestation).

Differences in weight and length between neonates from our study and those reported elsewhere may be explained by a number of variables that influence prenatal growth trajectories, including genetic characteristics of populations, maternal phenotype and physiology, socioeconomic conditions, stress and physical work during pregnancy, physical environment (temperature and altitude), parental health habits and gestational length (e.g., Kramer, 1987; Mallia et al., 2017; Mélançon et al., 2020; Wells & Cole, 2002). In the case of the population from Yucatan, ethnicity and maternal height may have an important influence on neonates' birthweight. We have previously reported that birthweight of infants from Maya mothers are 63 g lighter than infants from non-Maya mothers (3087 g [SD = 408] vs 3150 g [SD = 404]) (Azcorra et al., 2016) and infants from mothers in the shortest quartile of height (129–147 cm) had a birthweight of −0.43 standard deviations compared with infants from mothers in the highest quartile (156–180 cm) (3076 g [SD = 406] vs 3272 g [SD = 397]) (Azcorra & Méndez, 2018). The height of adult women in the state of Yucatan is comparable to heights found among women in Guatemala and the Philippines, populations with the lowest heights in the world (NCD Risk Factor Collaboration [NCDRisC], 2016). From an evolutionary point of view, and particularly from Life History Theory and Parent-Offspring Conflict Theory perspectives, natural selection has operated through physiological mechanisms that allow mothers to deliver infants with optimal birthweights to maximize their lifetime reproductive success under extant ecological conditions

TABLE 2 Smoothed birthweight percentiles (*P*) for Yucatecan newborns (boys) during 2015–2019

Gestation (weeks)	*P3*	*P10*	*P25*	*P50*	*P75*	*P90*	*P97*	*M*	*L*	*S*
25	503	562	629	712	805	898	1000	712	0.064	0.183
25.5	517	582	654	744	846	947	1058	744	0.101	0.190
26	532	602	681	779	889	1000	1120	779	0.137	0.198
26.5	549	625	711	818	938	1057	1188	818	0.168	0.205
27	567	650	743	859	989	1120	1261	859	0.198	0.212
27.5	587	676	777	903	1044	1185	1338	903	0.222	0.218
28	608	705	814	950	1102	1254	1419	950	0.246	0.224
28.5	633	737	854	1000	1163	1325	1502	1000	0.263	0.228
29	662	773	898	1053	1227	1400	1588	1053	0.279	0.231
29.5	696	814	946	1111	1296	1479	1678	1111	0.290	0.232
30	736	860	1001	1175	1369	1562	1771	1175	0.301	0.232
30.5	783	914	1062	1244	1447	1649	1866	1244	0.306	0.228
31	840	978	1132	1322	1533	1741	1966	1322	0.311	0.225
31.5	908	1051	1212	1408	1626	1841	2071	1408	0.312	0.217
32	988	1136	1302	1505	1728	1948	2183	1505	0.312	0.210
32.5	1078	1232	1403	1611	1839	2063	2301	1611	0.310	0.200
33	1180	1339	1514	1726	1959	2186	2427	1726	0.308	0.191
33.5	1292	1456	1635	1852	2089	2318	2562	1852	0.313	0.181
34	1412	1581	1765	1986	2226	2458	2702	1986	0.318	0.172
34.5	1537	1711	1900	2126	2369	2603	2848	2126	0.345	0.164
35	1664	1845	2041	2273	2521	2758	3005	2273	0.372	0.156
35.5	1792	1982	2185	2425	2680	2923	3174	2425	0.412	0.152
36	1920	2118	2330	2578	2841	3089	3345	2578	0.452	0.147
36.5	2047	2252	2470	2725	2992	3243	3501	2725	0.490	0.141
37	2175	2384	2604	2859	3126	3375	3630	2859	0.528	0.135
37.5	2302	2509	2726	2976	3237	3480	3727	2976	0.539	0.128
38	2410	2612	2825	3069	3323	3559	3799	3069	0.549	0.120
38.5	2484	2683	2893	3134	3384	3616	3852	3134	0.534	0.117
39	2535	2733	2941	3180	3428	3659	3894	3180	0.519	0.114
39.5	2579	2775	2981	3219	3466	3695	3929	3219	0.511	0.112
40	2616	2812	3018	3255	3501	3730	3963	3255	0.503	0.110
40.5	2641	2840	3048	3288	3536	3766	4000	3288	0.539	0.111
41	2651	2856	3071	3317	3570	3806	4044	3317	0.575	0.112
41.5	2642	2858	3082	3340	3605	3849	4097	3340	0.625	0.117
42	2620	2849	3088	3360	3639	3896	4156	3360	0.676	0.122

Note: *L*, *M*, and *S* parameters from the LMS method (Cole, 1990; Cole & Green, 1992) for skewness (*L*), median (*M*), and coefficient of variation (*S*).

(Bereczkei et al., 2000; Blurton Jones, 1978; Thomas et al., 2004; Trivers, 1974). Therefore, lower birth weights are expected in populations exposed to chronic adverse living conditions affecting maternal phenotype intergenerationally.

In the present study, the references we provide can be used for research and assessment purposes. Since the references we produced derive from a population-based dataset over 5-year period, these can be used by researchers to compare their samples and answer a wide range of research questions about variability in growth and phenotype at birth. Few studies have analyzed the birthweight in Yucatec population and its relationship with maternal characteristics, neonatal mortality, and

TABLE 3 Smoothed birthweight percentiles (*P*) for Yucatecan newborns (girls) during 2015–2019

Gestation (weeks)	*P3*	*P10*	*P25*	*P50*	*P75*	*P90*	*P97*	*M*	*L*	*S*
25	493	553	618	693	772	847	923	693	0.552	0.165
25.5	516	580	647	727	811	889	971	727	0.537	0.167
26	539	606	678	762	850	934	1020	762	0.522	0.168
26.5	563	633	709	798	892	981	1073	798	0.508	0.170
27	586	660	740	835	935	1030	1129	835	0.493	0.173
27.5	608	687	772	873	980	1082	1187	873	0.478	0.177
28	631	715	805	912	1027	1136	1250	912	0.463	0.180
28.5	655	744	840	955	1077	1195	1318	955	0.448	0.184
29	681	775	878	1001	1133	1260	1393	1001	0.433	0.189
29.5	710	811	921	1054	1196	1334	1478	1054	0.418	0.193
30	744	852	971	1114	1268	1418	1575	1114	0.403	0.198
30.5	785	901	1028	1183	1350	1513	1685	1183	0.388	0.201
31	833	958	1096	1262	1444	1621	1809	1262	0.373	0.205
31.5	892	1026	1174	1355	1552	1744	1948	1355	0.359	0.205
32	962	1106	1265	1459	1671	1879	2099	1459	0.344	0.206
32.5	1045	1198	1367	1574	1800	2022	2258	1574	0.329	0.203
33	1140	1302	1481	1699	1937	2171	2420	1699	0.314	0.199
33.5	1249	1418	1605	1832	2080	2323	2582	1832	0.299	0.191
34	1370	1544	1737	1970	2226	2475	2740	1970	0.284	0.184
34.5	1498	1677	1873	2111	2370	2623	2891	2111	0.269	0.174
35	1631	1813	2012	2253	2514	2767	3036	2253	0.254	0.165
35.5	1768	1952	2153	2395	2656	2910	3178	2395	0.239	0.156
36	1906	2091	2293	2535	2796	3049	3315	2535	0.224	0.147
36.5	2043	2229	2431	2672	2931	3181	3444	2672	0.210	0.139
37	2176	2361	2561	2799	3055	3300	3558	2799	0.195	0.131
37.5	2297	2479	2676	2909	3159	3399	3650	2909	0.180	0.124
38	2395	2575	2767	2995	3239	3472	3716	2995	0.165	0.117
38.5	2465	2641	2830	3054	3293	3521	3759	3054	0.150	0.113
39	2513	2687	2874	3096	3331	3557	3792	3096	0.135	0.109
39.5	2550	2724	2911	3132	3367	3592	3827	3132	0.120	0.108
40	2583	2758	2945	3167	3403	3629	3865	3167	0.105	0.107
40.5	2614	2790	2978	3201	3439	3666	3905	3201	0.090	0.107
41	2633	2811	3002	3228	3470	3703	3946	3228	0.075	0.108
41.5	2630	2813	3010	3244	3495	3736	3990	3244	0.061	0.112
42	2614	2803	3008	3252	3515	3769	4036	3252	0.046	0.115

Note: *L*, *M*, and *S* parameters from the LMS method (Cole, 1990; Cole & Green, 1992) for skewness (*L*), median (*M*), and coefficient of variation (*S*).

body composition during childhood (Azcorra et al., 2016; Azcorra et al., 2021; Azcorra & Méndez, 2018; Osorno-Covarrubias et al., 2002; Varela-Silva et al., 2009). We hope to stimulate future studies aimed at analyzing the link between size at birth and phenotype, and functional characteristics and illnesses during childhood, adolescence, and adulthood by using these references as a methodological tool that allow situating any sample from Yucatan in the context of the population this belong. This aspect is particularly relevant in the context of the population of Yucatan since some of the chronic-degenerative diseases which have a very high prevalence in the state of Yucatan, including overweight/obesity, type 2 diabetes mellitus, hypertension and other cardio-metabolic

TABLE 4 Smoothed birth length percentiles (*P*) for Yucatecan newborns (boys) during 2015–2019

Gestation (weeks)	*P3*	*P10*	*P25*	*P50*	*P75*	*P90*	*P97*	*M*	*L*	*S*
25	28.10	29.27	30.51	31.95	33.46	34.88	36.34	31.95	−0.014	0.068
25.5	28.30	29.56	30.88	32.41	34.01	35.51	37.04	32.41	0.144	0.071
26	28.51	29.86	31.28	32.90	34.59	36.16	37.75	32.90	0.303	0.075
26.5	28.74	30.19	31.70	33.42	35.20	36.83	38.49	33.42	0.457	0.077
27	29.00	30.55	32.15	33.97	35.82	37.53	39.24	33.97	0.612	0.080
27.5	29.27	30.93	32.62	34.53	36.46	38.23	39.98	34.53	0.761	0.082
28	29.58	31.33	33.12	35.11	37.11	38.93	40.72	35.11	0.911	0.084
28.5	29.92	31.77	33.64	35.71	37.77	39.62	41.45	35.71	1.056	0.085
29	30.31	32.25	34.20	36.33	38.44	40.32	42.15	36.33	1.202	0.087
29.5	30.76	32.79	34.79	36.97	39.11	41.00	42.84	36.97	1.346	0.086
30	31.30	33.38	35.43	37.64	39.79	41.68	43.50	37.64	1.490	0.086
30.5	31.92	34.05	36.13	38.35	40.49	42.35	44.15	38.35	1.635	0.084
31	32.65	34.80	36.88	39.09	41.20	43.04	44.79	39.09	1.781	0.082
31.5	33.48	35.63	37.70	39.88	41.95	43.74	45.44	39.88	1.928	0.079
32	34.41	36.54	38.57	40.71	42.73	44.46	46.10	40.71	2.075	0.075
32.5	35.41	37.51	39.49	41.57	43.52	45.19	46.77	41.57	2.221	0.072
33	36.48	38.52	40.44	42.45	44.32	45.93	47.44	42.45	2.367	0.068
33.5	37.60	39.56	41.41	43.34	45.14	46.67	48.11	43.34	2.507	0.064
34	38.73	40.61	42.38	44.21	45.93	47.39	48.76	44.21	2.648	0.059
34.5	39.85	41.64	43.32	45.06	46.68	48.07	49.37	45.06	2.775	0.055
35	40.94	42.63	44.22	45.87	47.41	48.73	49.96	45.87	2.903	0.051
35.5	41.98	43.59	45.10	46.66	48.13	49.38	50.55	46.66	2.996	0.048
36	42.95	44.48	45.92	47.41	48.82	50.01	51.14	47.41	3.090	0.045
36.5	43.83	45.28	46.66	48.10	49.44	50.59	51.68	48.10	3.121	0.043
37	44.59	45.98	47.30	48.68	49.98	51.10	52.14	48.68	3.152	0.041
37.5	45.22	46.55	47.82	49.15	50.41	51.49	52.52	49.15	3.084	0.039
38	45.70	46.98	48.20	49.50	50.73	51.79	52.79	49.50	3.015	0.038
38.5	46.03	47.27	48.46	49.73	50.94	51.98	52.97	49.73	2.857	0.037
39	46.29	47.49	48.66	49.90	51.09	52.12	53.11	49.90	2.699	0.036
39.5	46.55	47.72	48.85	50.06	51.24	52.26	53.23	50.06	2.538	0.036
40	46.76	47.90	49.02	50.23	51.39	52.41	53.39	50.23	2.377	0.035
40.5	46.86	48.02	49.15	50.38	51.56	52.60	53.61	50.38	2.258	0.036
41	46.89	48.07	49.24	50.51	51.74	52.81	53.85	50.51	2.139	0.037
41.5	46.87	48.10	49.32	50.63	51.91	53.03	54.11	50.63	2.036	0.038
42	46.84	48.12	49.38	50.74	52.08	53.25	54.38	50.74	1.934	0.039

Note: *L*, *M*, and *S* parameters from the LMS method (Cole, 1990; Cole & Green, 1992) for skewness (*L*), median (*M*), and coefficient of variation (*S*).

disorders, have been shown to be related with certain growth trajectories and structural and functional alterations occurring during the intrauterine stage (Gluckman et al., 2008; Thornburg, 2015).

In the clinical context, these reference percentile and curves can help health practitioners, including pediatricians, neonatologists and nurses, to assess the health status of newborns. The current official Mexican regulation for the care of the newborn (NOM-007-SSA2-1993, 1994) recommends the use of any of the references developed by Lubchenco and collaborators (Lubchenco et al., 1963; Lubchenco et al., 1966) or Jurado-García et al. (1970) to evaluate the birthweight and length of Mexican neonates. The reference

TABLE 5 Smoothed birth length percentiles (*P*) for Yucatecan newborns (girls) during 2015–2019

Gestation (weeks)	*P3*	*P10*	*P25*	*P50*	*P75*	*P90*	*P97*	*M*	*L*	*S*
25	27.88	29.01	30.18	31.50	32.85	34.09	35.33	31.50	0.530	0.063
25.5	28.18	29.36	30.58	31.95	33.34	34.61	35.88	31.95	0.649	0.064
26	28.48	29.72	30.99	32.41	33.85	35.16	36.46	32.41	0.768	0.066
26.5	28.78	30.08	31.41	32.90	34.39	35.73	37.07	32.90	0.888	0.067
27	29.09	30.46	31.85	33.40	34.94	36.33	37.71	33.40	1.008	0.069
27.5	29.40	30.85	32.31	33.92	35.53	36.96	38.37	33.92	1.128	0.070
28	29.73	31.26	32.79	34.47	36.13	37.61	39.06	34.47	1.249	0.072
28.5	30.08	31.69	33.30	35.05	36.77	38.30	39.78	35.05	1.369	0.073
29	30.46	32.16	33.85	35.67	37.45	39.02	40.53	35.67	1.490	0.075
29.5	30.88	32.68	34.44	36.33	38.16	39.77	41.32	36.33	1.610	0.076
30	31.37	33.25	35.08	37.04	38.92	40.56	42.13	37.04	1.730	0.077
30.5	31.93	33.89	35.79	37.80	39.72	41.38	42.97	37.80	1.848	0.077
31	32.60	34.62	36.56	38.61	40.56	42.23	43.83	38.61	1.966	0.077
31.5	33.36	35.44	37.41	39.48	41.44	43.12	44.72	39.48	2.078	0.075
32	34.24	36.34	38.33	40.40	42.36	44.03	45.61	40.40	2.191	0.074
32.5	35.22	37.32	39.30	41.35	43.28	44.93	46.49	41.35	2.294	0.071
33	36.29	38.36	40.30	42.31	44.20	45.81	47.33	42.31	2.398	0.068
33.5	37.42	39.42	41.31	43.26	45.10	46.65	48.12	43.26	2.490	0.065
34	38.56	40.48	42.29	44.17	45.93	47.42	48.83	44.17	2.581	0.061
34.5	39.65	41.48	43.20	44.99	46.67	48.10	49.44	44.99	2.661	0.057
35	40.71	42.43	44.05	45.75	47.34	48.69	49.97	45.75	2.741	0.053
35.5	41.72	43.33	44.86	46.46	47.96	49.24	50.45	46.46	2.801	0.049
36	42.69	44.19	45.63	47.13	48.55	49.77	50.91	47.13	2.862	0.046
36.5	43.61	45.02	46.37	47.79	49.13	50.28	51.37	47.79	2.893	0.043
37	44.41	45.75	47.03	48.37	49.65	50.75	51.79	48.37	2.924	0.040
37.5	45.05	46.32	47.55	48.84	50.07	51.13	52.14	48.84	2.911	0.039
38	45.50	46.73	47.92	49.18	50.38	51.41	52.39	49.18	2.898	0.037
38.5	45.80	47.00	48.16	49.39	50.57	51.58	52.55	49.39	2.835	0.036
39	46.03	47.20	48.33	49.54	50.70	51.70	52.66	49.54	2.773	0.035
39.5	46.24	47.39	48.50	49.69	50.84	51.83	52.78	49.69	2.676	0.035
40	46.41	47.55	48.66	49.84	50.98	51.98	52.93	49.84	2.579	0.035
40.5	46.51	47.65	48.77	49.97	51.13	52.14	53.11	49.97	2.476	0.035
41	46.49	47.67	48.82	50.07	51.26	52.31	53.32	50.07	2.372	0.036
41.5	46.37	47.60	48.82	50.13	51.39	52.50	53.56	50.13	2.273	0.038
42	46.17	47.48	48.78	50.17	51.52	52.69	53.83	50.17	2.174	0.040

Note: *L*, *M*, and *S* parameters from the LMS method (Cole, 1990; Cole & Green, 1992) for skewness (*L*), median (*M*), and coefficient of variation (*S*).

percentiles developed by Lubchenco and collaborators are based on the birthweight of 5635 white infants born at Colorado General Hospital in the USA between 1948 and 1961 and those developed by Jurado-García et al. (1970) derived from a study in which the birthweight of 16 807 infants was obtained in hospitals of Mexico City during 1968–1970. We consider that these references are not appropriate for their current use in Yucatec newborns since their data were collected more than 50 years ago and because they came from populations that differ genetically and socioeconomically from the population from Yucatan.

Since the references we produced include both low- and high-risk pregnancies and were not tested against

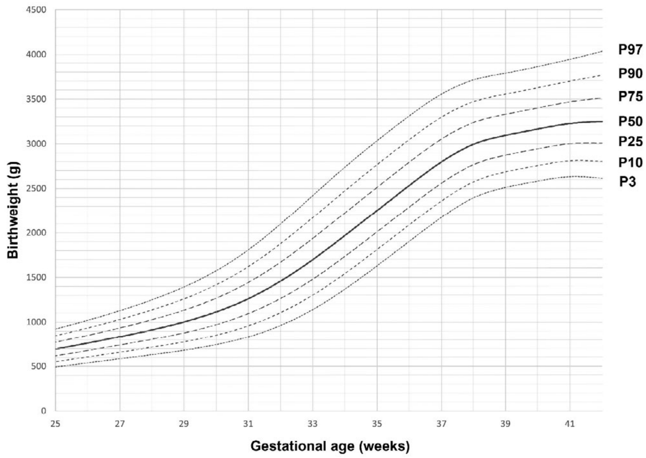

FIGURE 1 Centile curves for birthweight of Yucatecan newborns (girls) during 2015–2019, from week 25 to 42 of gestation

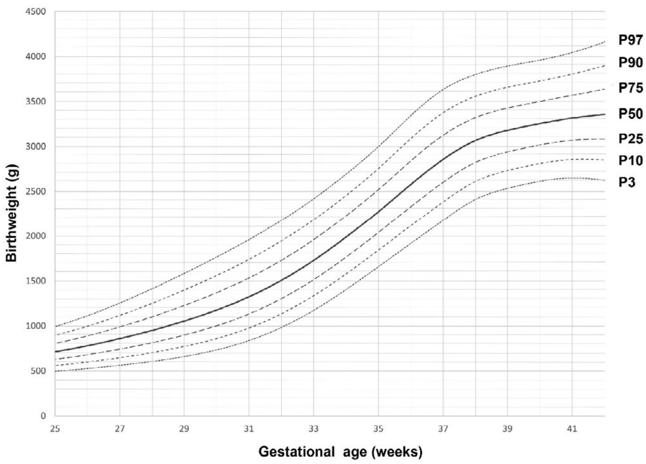

FIGURE 2 Centile curves for birthweight of Yucatecan newborns (boys) during 2015–2019, from week 25 to 42 of gestation

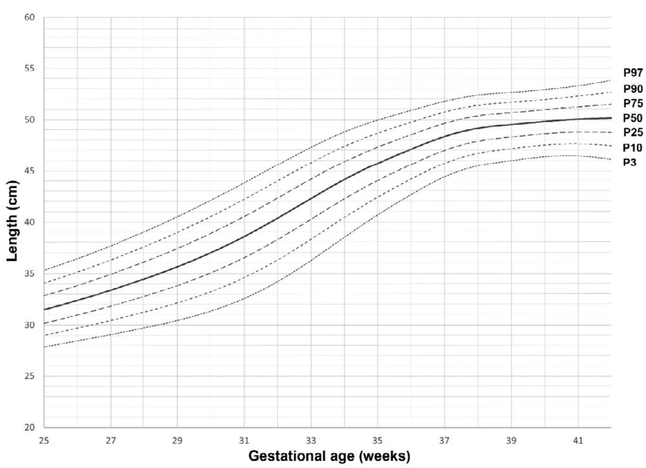

FIGURE 3 Centile curves for birth length of Yucatecan newborns (girls) during 2015–2019, from week 25 to 42 of gestation

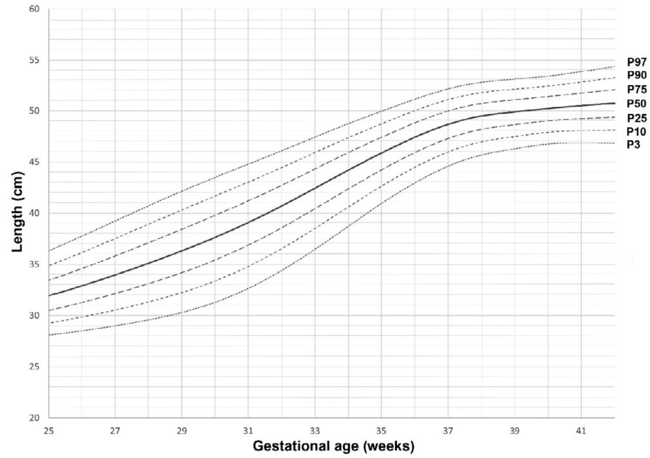

FIGURE 4 Centile curves for birth length of Yucatecan newborns (boys) during 2015–2019, from week 25 to 42 of gestation

morbidity and mortality during neonatal stage, we do not recommend that these references be used to define abnormal/pathological fetal growth. Small for gestational age (SGA) and large for gestational age (LGA) are categories commonly used in the clinical practice and defined by centiles (SGA: <10th percentile, LGA: >90th percentile). We recommend great caution when using the references we developed to define these categories. Our references certainly allow researchers to situate an individual in terms of their birthweight and length in the context of the population she or he belongs to. The integration of other indicators of fetal health, such as heart rate, biophysical profile (estimated fetal weight and abdominal circumference) and amniotic fluid volume, and placental function (all of them routinely assessed during pregnancy), in addition to size at birth, may enhance the assessment of intrauterine growth (Zhang, Merialdi, et al., 2010). The combination of antenatal assessment and birth weight may help to distinguish between normal and abnormal fetal growth. References for Yucatec newborns' weight and length may also in time serve as a baseline comparison for future interventions by public health bodies wishing to evaluate the wellbeing of mothers and their offspring.

The data we present in this article refer to offspring growth under particular environmental conditions at a specific point in time. Intergenerational changes in birthweight have been described in several populations (see for example Chike-Obi et al., 1996; Kramer et al., 2002; Schack-Nielsen et al., 2006). Intergenerational changes in birthweight can be driven by changes in length of gestation and fetal growth (Oken, 2013), which in turn, can be influenced by obstetric practices (Zhang, Joseph, & Kramer, 2010), maternal age and secular changes in maternal phenotype including height, weight and gestational weight gain. Thus, these references must be updated regularly to account for changes in these factors.

The limitations of the present study are inherent to methodological aspects, such as the retrospective nature of the study. As birth length is measured in complete gestational weeks as a discrete variable, the variability of length in full centimeters is limited. The calculation of references always requires smoothing which is more difficult for a discrete variable. By using different algorithms in the R package 'gamlss' e.g. the function lms() to choose the optimal degree of smoothing, we reduced these limitations (Stasinopoulos et al., 2017). We are aware that many health professionals participated in obtain infants' weight and length, however, we believe this situation have a minimal effect on the accuracy of the percentiles.

5 | CONCLUSION

In this article we present reference percentiles and curves for birthweight and length based on a large and population-based dataset from birth registers of infants born in Yucatan during 2015–2019. Percentiles show that birthweight of Yucatec neonates is lower than in populations with different levels of income and also with respect to populations belonging to countries with levels of economic development similar to Mexico. The references for Yucatec newborns regarding weight and length may not only be used for research in inter-population comparisons but may also be used in the clinical context in conjunction with relevant antenatal fetal and maternal indicators to assess newborn's health. These references must be updated in the future to account for secular changes in newborns' size and for socio-economic and political changes in the region.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The developed tool to calculate the individual z-score and/or percentile of a newborn based on the presented references are openly available in Researchgate profiles of the authors of this article.

AUTHOR CONTRIBUTIONS

Hugo Azcorra: Data curation (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal). **FEDERICO DICKINSON:** Conceptualization (equal); methodology (equal); writing – review and editing (equal). **Nina Mendez-Dominguez:** Data curation (equal); methodology (equal); writing – review and editing (equal). **Rebekka Mumm:** Data curation (equal); formal analysis (equal); methodology (equal); writing – review and editing (equal). **Graciela Valentín:** Data curation (equal); writing – review and editing (equal).

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Additional supporting information may be found in the online version of the article at the publisher's website.

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