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MULT: New height references and their efficiency in multi-ethnic populations

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Abstract
Objectives: To develop new height references (MULT) based on longitudinal data of multi-ethnic populations and to compare them to the height references from the Dutch Growth Study, from the Centers for Disease Control and Prevention (CDC) and from the World Health Organization (WHO).
Methods: The MUL height references were developed through the LMS method and the Generalized Additive Models for Location Scale and Shape. They were constructed based on 2611 subjects (15 292 measurements) from the advantaged quintile of the Young Lives (Younger Cohort), Millennium Cohort Study, Adolescent Nutritional Assessment Longitudinal Study, and Epidemiological Health Investigation of Teenagers in Porto studies. The M, S curves were described to compare the growth trajectory of the MULT, DUTCH, CDC and WHO height references. For the population comparative analysis, we used the total sample of the studies (91 063 observations, 17 641 subjects). The Lin's concordance correlation coefficient (CCC) and Cohen's kappa coefficient (K) were used to verify the agreement between MULT, WHO and CDC height references.
Results: The MULT height references showed taller boys for the periods of 61–174 months and 196–240 months and taller girls for 61–147 and 181–240 months, when compared to CDC and WHO height references. There was an almost perfect agreement between WHO and MULT height references (CCC >0.99) for the subjects aged 2 to 5 years.
Conclusions: MULT height references presented a taller population and a high agreement with WHO growth charts, especially for children under 5 years, indicating that it could be useful to assess nutritional status of multi-ethnic populations.

1 | INTRODUCTION

The height-for-age growth chart is the most used tool to assess nutritional status in children and adolescents because it shows the linear growth trajectory, which is the best overall indicator of children's wellbeing and a crucial tool to detect stunting (De Onis & Branca, 2016).

Over the years, some organizations have proposed height references to be used worldwide (Ferreira, 2013). The height-for-age growth charts from the Centers for Disease Control and Prevention (CDC) were developed in the 2000s based only on the United States population and using cross-sectional data from five national surveys conducted between 1963 and 1994 (Kuczmarski et al., 2000, 2002). The World Health Organization (WHO) growth charts were developed in 2006 for children under 5 years old, and in 2007 for 5–19-year-old children and adolescents (De Onis et al., 2007; WHO Multicentre Growth Reference Study Group, 2006). The WHO (2006) growth charts were constructed based on cross-sectional and longitudinal samples of children considered as standard (healthy breastfed children who had better socioeconomic conditions for an adequate growth) and from six countries (Brazil, United States, Ghana, Norway, India and Oman; WHO Multicentre Growth Reference Study Group, 2006). On the other hand, the WHO 2007 growth charts were constructed based only on a cross-sectional sample of subjects born in the 1950s and 1960s in the United States (De Onis et al., 2007).

Beside the differences in the populations included in the CDC and WHO growth references, the methodology for the predictive growth modeling is also different (De Onis et al., 2007; Kuczmarski et al., 2002; WHO Multicentre Growth Reference Study Group, 2006). In the construction of the WHO growth charts, the Box-Cox power exponential approach was applied, which include the possibility of modeling a fourth parameter (kurtosis), while in the CDC growth references the LMS parameters were created by estimating the desired percentiles from the CDC population sample (De Onis et al., 2007; Iftikhar et al., 2018; Kuczmarski et al., 2002; WHO Multicentre Growth Reference Study Group, 2006). Although there was this difference about the methodological approach, the WHO final growth charts were generated without adjusting for kurtosis, fitting only three parameters (median, coefficient of variation and skewness) as in the CDC growth charts, because they identify no need for a kurtosis fitting (De Onis et al., 2007; Iftikhar et al., 2018; Kuczmarski et al., 2002; WHO Multicentre Growth Reference Study Group, 2006).

Additionally, another issue between these two international growth charts is the outline of reference values, which depends on the study design applied. The cross-sectional nature applied in the WHO and CDC height references included only one examination per child, whereas a longitudinal design includes several measurements across time for each subject (De Onis et al., 2007; Iftikhar et al., 2018; Kuczmarski et al., 2002; WHO Multicentre Growth Reference Study Group, 2006). Even though, the use of longitudinal studies can generate autocorrelation bias as an outcome, which could have occurred in the WHO growth standards, a longitudinal design includes several measurements across time for each subject and follow-up measures are important for ascertaining expected growth and checking if the growth is not restricted (Ohuma & Altman, 2019).

Despite the fact that WHO height-for-age growth charts are the most recommended to be used worldwide, several countries have found divergences when comparing their population growth parameters to the WHO population sample (Ferreira, 2013). For this reason, some countries such as China, Bolivia, Denmark, Norway and Belgium have not implemented the WHO growth charts to assess nutritional status of their population and the Netherlands, where the population is considered as the tallest, created its own growth charts (Ferreira, 2013; Schönbeck et al., 2013).

The aims of this study are to develop new height references (0–20 years old) based on longitudinal data from 10 countries and to compare their agreement with the internationally used height-for-age growth charts from the CDC and WHO.

2 | METHODS

2.1 | Study design and population

Anthropometric, demographic and socioeconomic data from multi-ethnic children and adolescents born between 1990 and 2002 were selected from four cohort studies: Young Lives (YL), Millennium Cohort Study (MCS), Adolescent Nutritional Assessment Longitudinal Study (ELANA), and Epidemiological Health Investigation of Teenagers in Porto (EPITeen; Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Moreira et al., 2015).

YL provides data about 12 000 children from Ethiopia, India, Peru and Vietnam (Barnett et al., 2013). This study is divided between two cohorts, the younger cohort (YLYC) with children born in the 2000 s and the older cohort (YLOC) with children born in the 1990s (Barnett et al., 2013). MCS is a study of 18 827 infants born between the years 2000 and 2002 in the United Kingdom (England, Scotland, Wales and Northern Ireland; Connelly & Platt, 2014). However, only data from the MCS second sweep ($n = 15\,588$) was included because there were no infant height data in the baseline, and harmonized height and socioeconomic data were used when available in its surveys (Connelly & Platt, 2014). ELANA describes 1848 adolescents born between the 1990s and 2000s who lived in Rio de Janeiro, Brazil and it is divided between the middle school cohort (MS) and the high school cohort (HS; Moreira et al., 2015). Lastly, EPITeen is a study of 2942 adolescents born in the 1990s who were enrolled in schools from the city of Porto in Portugal (Fraga et al., 2020).

ELANA and EPITeen datasets were obtained through an authorization of the responsible institutions, while the YL and MCS datasets were obtained through the UK Data Service online platform (Boyden, 2018a, 2018b; Cohort and Longitudinal Studies Enhancement Resources, 2019; Jones & Huttly, 2018; Kelly, 2018; Sanchez et al., 2018; University of London, Institute of Education, & Centre for Longitudinal Studies, 2020a, 2020b; Woldehanna et al., 2018). These surveys provided data about 32 162 subjects. As shown in Figure 1, we excluded 14 521 children who had missing data (age, weight, height or socioeconomic indicator), follow-up losses, implausible values (WHO z-score of height-for-age <-6 or $>+6$ or WHO z-score of body mass index (BMI) for age <-5 or $>+5$), measurement errors (children who had decreased their height over the years), and who did not meet the following eligibility criteria: children who were assessed in all waves for the ELANA HS (three waves) and who were assessed at least in four waves for the other surveys; and children who had ethnicity classification into one of the five categories: White, Indian, Black, Asian or Native Peruvians. Therefore, our final analysis included 91 063 observations from 17 641 children.

In all the surveys children under 2 years old were measured in the supine position while children from 2 years old were measured upright (Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Moreira et al., 2015). These anthropometric measurements were collected by trained professionals that followed a

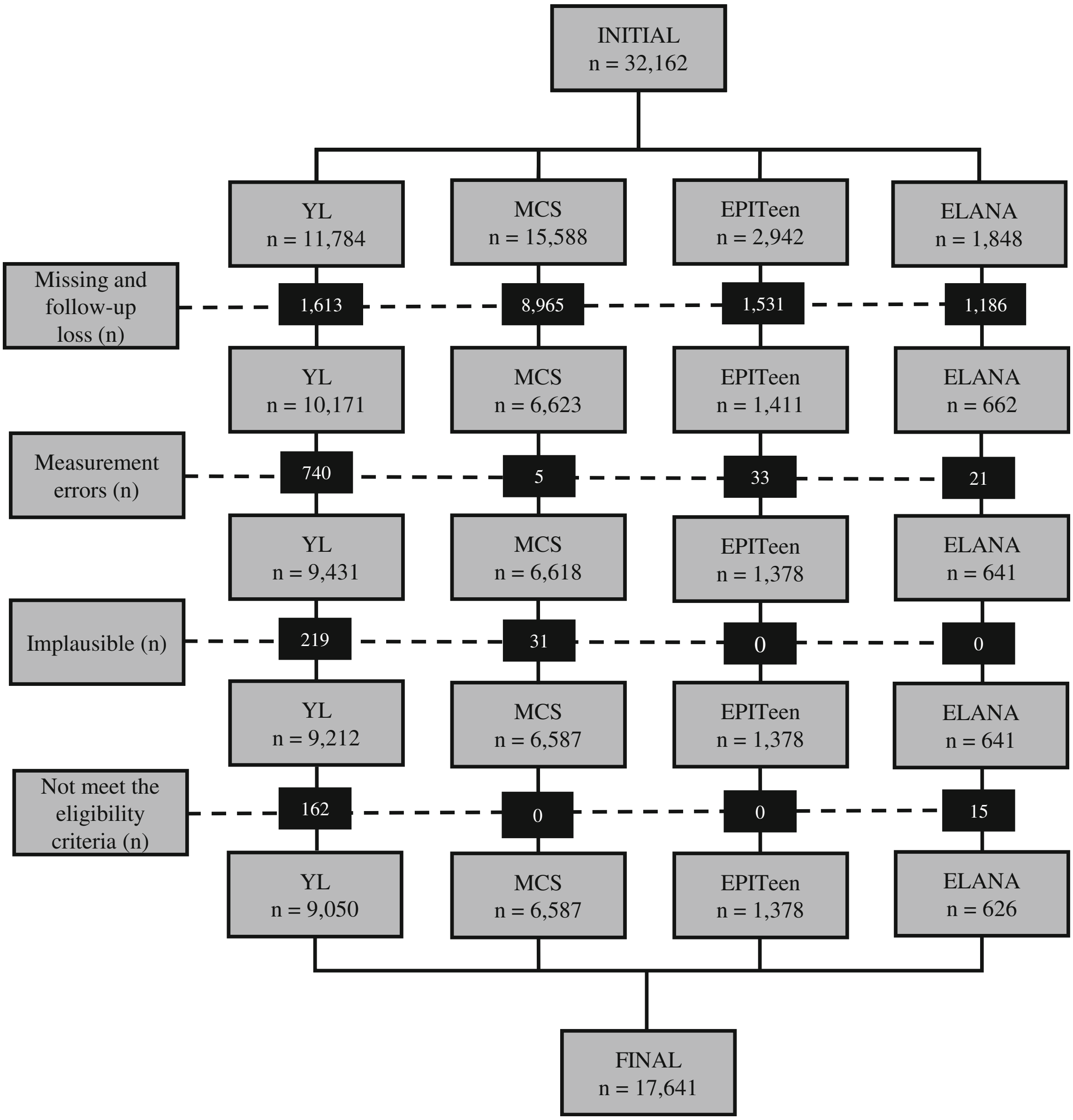

FIGURE 1 Flowchart of the subject selection

standardized examination protocol to ensure data quality of the measurements (Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Moreira et al., 2015).

Additionally, MCS, YL, ELANA and EPITeen studies were conducted according to the guidelines laid down in the Declaration of Helsinki (Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Moreira et al., 2015). Written informed consent was obtained from all participants and/or their parents or guardians (Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Moreira et al., 2015). Data from ELANA was obtained through the authorization of the UERJ and approved by the Ethics Committee of the Institute of Social Medicine of the UERJ (Moreira et al., 2015). Similarly, data from EPITeen was retrieved through the authorization of the Institute of Public Health of the University of Porto (ISPUP), and approved by the Ethics Committees of the Hospital S. João and of the ISPUP (Fraga et al., 2020). Moreover, data from MCS and YL were obtained through the UK Data Service online platform and approved, respectively, by the UK National Health Service Research Ethics Committee, and by the Central University Research Ethics Committee (Barnett et al., 2013; Connelly & Platt, 2014). The details of each study as well their approval from the Research Ethics Committees have been described in their study protocols or in previous studies (Barnett et al., 2013; Connelly & Platt, 2014; Fraga et al., 2020; Joshi & Fitzsimons, 2016; Moreira et al., 2015).

2.2 | Data processing and analysis

For the construction of the height-for-age reference values of our multi-ethnic population, denominated as MULT growth references, subjects aged 0–23 years from the advantaged quintile of the YLYC, MCS, ELANA and EPITeen datasets were selected. Only the younger cohort of the YL was selected, because this study was conducted in developing countries with high poverty rates and children from the younger cohort were born in the 2000s, having better economic and health conditions for growing properly, when compared to the children from the older cohort (born in the 1990s; Barnett et al., 2013). The advantaged quintile was selected using different socioeconomic variables in the four studies: for the EPITeen it was based on the adolescent's mother educational level (Fraga et al., 2020); for MCS it was based on the income quintile variable (based on the household income and consumption/expenditure; Connelly & Platt, 2014); for ELANA it was based on the family social strata, calculated through the *Critério Brasil* (based on the educational level and the number of assets owned by the household; Moreira et al., 2015); and for the YL it was assessed based on the Wealth Index variable, which is an average of the Housing Quality, Consumer Durables and the Services Indexes (Barnett et al., 2013).

Height reference values of our pooled data were calculated separated by sex (determined at birth by the presence or absence of a Y chromosome) and using the LMS method described by Cole and Green in 1992 (Cole & Green, 1992). This method summarizes the distribution by three smooth curves called L, M and S. They represent skewness, median and coefficient of variation, respectively (Cole & Green, 1992). The smoothing parameters for the L, M and S curves were calculated through the generalized additive models for location, scale and shape (GAMLSS) introduced by Rigby and Stasinopoulos in 2005 (Rigby et al., 2005). This model uses a distributional regression approach where all the parameters of the conditional distribution of the response variable are modeled using an explanatory variable (Rigby et al., 2005). The sex-specific growth charts were fitted as cubic splines and the age-related reference values were estimated per day and flattened until 20 years of age. We applied the worm plots introduced by Van Buuren and Fredriks to verify the appropriate amount of smoothness for the LMS parameters of our model (Van Buuren & Fredriks, 2001).

The growth trajectory based on the 50th percentile and the coefficient of variation based on S Curve were described in order to compare the CDC, WHO, Dutch and MULT height references (De Onis et al., 2007; Kuczmarski et al., 2000; Schönbeck et al., 2013; WHO Multicentre Growth Reference Study Group, 2006). The growth trajectories of our sample were compared with the WHO and CDC international growth references because they are recommended to be used worldwide (De Onis et al., 2007; Kuczmarski et al., 2000; WHO Multicentre Growth Reference Study Group, 2006). MULT height references were also compared with the Dutch growth references, because the Dutch population is a homogeneous group with lower growth variation, which has stopped growing having achieved its highest height and considered the tallest population in the world (Schönbeck et al., 2013).

For the efficiency analysis of these international growth references, the subject's height-for-age z-scores were calculated and it was classified their nutritional status according to CDC (stunting for height-for-age <5th percentile), WHO and MULT height references (stunting for height-for-age <-2 z-score; De Onis et al., 2007; Kuczmarski et al., 2000; WHO Multicentre Growth Reference Study Group, 2006). Lin's concordance correlation coefficient (CCC) was applied to verify the agreement among the z-scores and also the Cohen's kappa coefficient (K) was applied to analyze the agreement among the nutritional status classified by the CDC, WHO, and

MULT height references (Cohen, 1960; Lin, 1989). The CCC and K were applied to the entire sample, and separated by sex and age groups (0 to <2, 2 to <5, 5 to <10, 10 to <15 and 15 to ≤20 years). The children were divided into these age groups because children under 2 years old were measured in the supine position while children from 2 years old were measured upright (WHO Multicentre Growth Reference Study Group, 2006). The second age range (2 to <5 years) was defined because children under 5 years were the standard group of the WHO growth charts (2006), and the third age group (5 to <10 years) corresponds to the period before the puberty (WHO Multicentre Growth Reference Study Group, 2006; World Health Organization, 2018a). The fourth age group (10 to <15 years) corresponds to the early-middle adolescence period and, in this stage, the physical changes generally begin, usually with a growth spurt and soon followed by the development of the sex organs and secondary sexual characteristics (World Health Organization, 2018a). The fifth age group (15 to ≤20 years) is composed of the middle-late adolescence period and the beginning of the adulthood (World Health Organization, 2018a). All statistical analyses were performed in R version 4.0.1 for Windows and the AGD-package was used for estimating the MULT height-for-age reference values (R Core Team, 2022; Van Buuren, 2018).

3 | RESULTS

After the advantaged quintile was selected from our data pool, 15 292 measurements from 2611 children were used for the construction of the MULT height references, as shown in Table 1. The extracted values of the L, M and S are presented in Table 2, and the MULT height-for-age

TABLE 1 Number of observations from the advantage quintile included in the construction of the LMS parameters of the MULT height references

Age (years)	Boys (*n*)	Girls (*n*)
0 to <2	925	829
2 to <4	1027	1031
4 to <6	1173	1135
6 to <8	1016	1030
8 to <10	165	134
10 to <12	1005	1014
12 to <14	507	462
14 to <16	920	897
16 to <18	906	847
18 to ≤23	158	111
Total	7802	7490

Note: *n*, number of observations.

TABLE 2 MULT LMS reference values of height-for-age for boys and girls

	Boys			Girls		
Age (months)	L	M	S	L	M	S
0	1	51.53	0.0361	1	51.03	0.0393
1	1	55.49	0.0354	1	54.89	0.0391
2	1	58.75	0.0350	1	57.97	0.0367
3	1	61.72	0.0349	1	60.66	0.0346
4	1	64.22	0.0349	1	62.85	0.0335
5	1	66.33	0.0350	1	64.77	0.0328
6	1	68.18	0.0351	1	66.53	0.0324
7	1	69.68	0.0353	1	68.04	0.0323
8	1	71.03	0.0355	1	69.44	0.0324
9	1	72.23	0.0357	1	70.69	0.0325
10	1	73.41	0.0359	1	71.91	0.0328
11	1	74.53	0.0360	1	73.04	0.0330
12	1	75.64	0.0361	1	74.13	0.0333
13	1	76.79	0.0361	1	75.22	0.0336
14	1	77.91	0.0362	1	76.25	0.0338
15	1	79.06	0.0362	1	77.32	0.0340
18	1	82.43	0.0362	1	80.41	0.0345
24	1	88.14	0.0367	1	86.03	0.0352
36	1	96.34	0.0390	1	94.94	0.0375
48	1	103.47	0.0415	1	102.30	0.0398
60	1	110.10	0.0438	1	109.10	0.0416
72	1	116.75	0.0454	1	115.58	0.0432
84	1	123.00	0.0466	1	121.96	0.0443
96	1	128.12	0.0479	1	128.08	0.0453
108	1	133.54	0.0486	1	134.45	0.0457
120	1	139.52	0.0488	1	140.82	0.0454
132	1	145.81	0.0487	1	146.73	0.0448
144	1	152.34	0.0482	1	151.97	0.0437
156	1	158.96	0.0475	1	156.36	0.0426
168	1	164.94	0.0468	1	159.67	0.0416
180	1	169.72	0.0463	1	161.87	0.0407
192	1	173.40	0.0460	1	163.38	0.0400
204	1	176.04	0.0460	1	164.42	0.0393
216	1	177.69	0.0461	1	165.11	0.0388
228	1	178.64	0.0463	1	165.56	0.0383
240	1	179.18	0.0467	1	165.86	0.0379

Note: L, skewness; M, median height (50th percentile); S, coefficient of variation.

charts for boys and girls are available, respectively, in the Supplementary Information S1 and S2. The growth trajectory of the CDC, WHO, Dutch and MULT height references based on percentile 50th (M curve) and on the coefficient of variation is shown in the Figures 2 and 3. CDC, WHO and MULT growth references classified boys and girls with lower median height than the Dutch height references for all ages. However, when compared to WHO and CDC median height values, MULT growth references showed taller boys and girls in specific ages. For boys it is between the ages of 61–174 months and 196–240 months and for girls it is between the ages of 61–147 months and 181–240 months.

Applying Lin's concordance correlation coefficient (Table 3) there were found substantial agreement (CCC >0.95 and ≤0.99) between the WHO and MULT height references for the entire sample and for the majority of the age groups, with the exception of the age groups of 2–5 years and 5–10 years that presented an almost perfect agreement (CCC >0.99). When we stratified the analysis

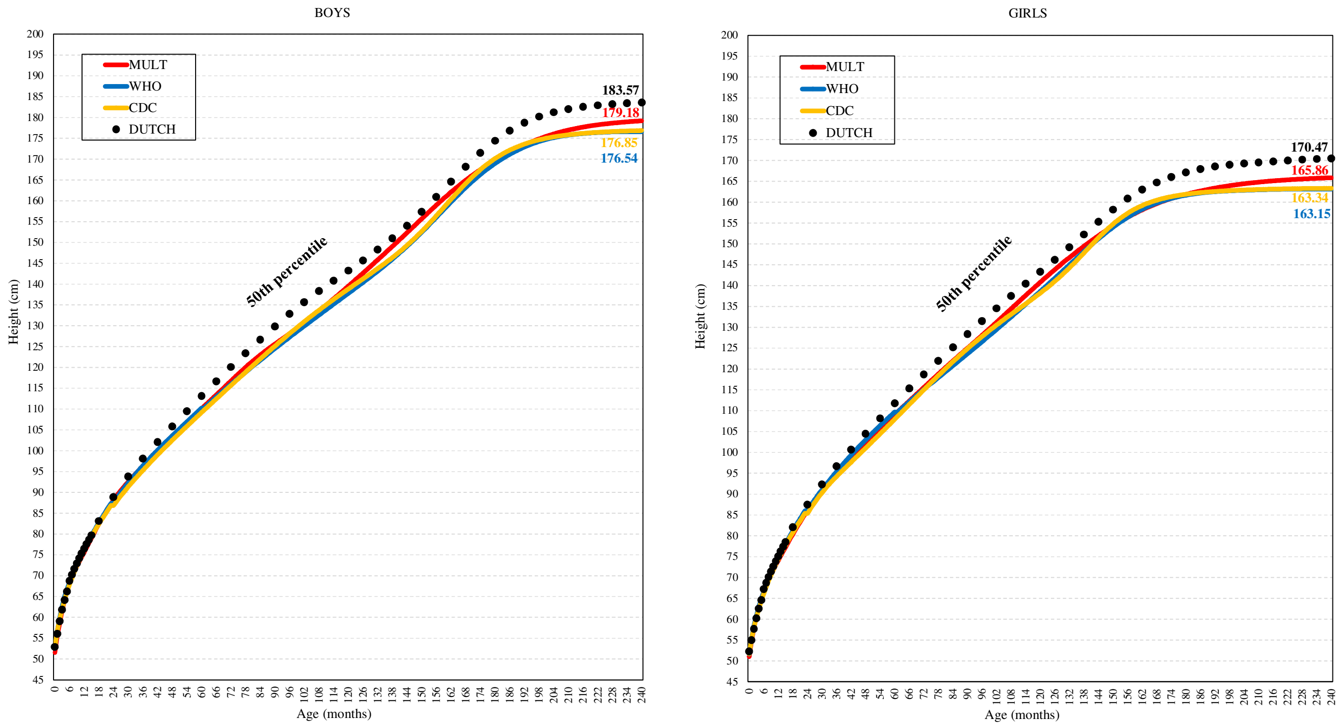

FIGURE 2 Median height (M curve) of the four height references in boys and in girls

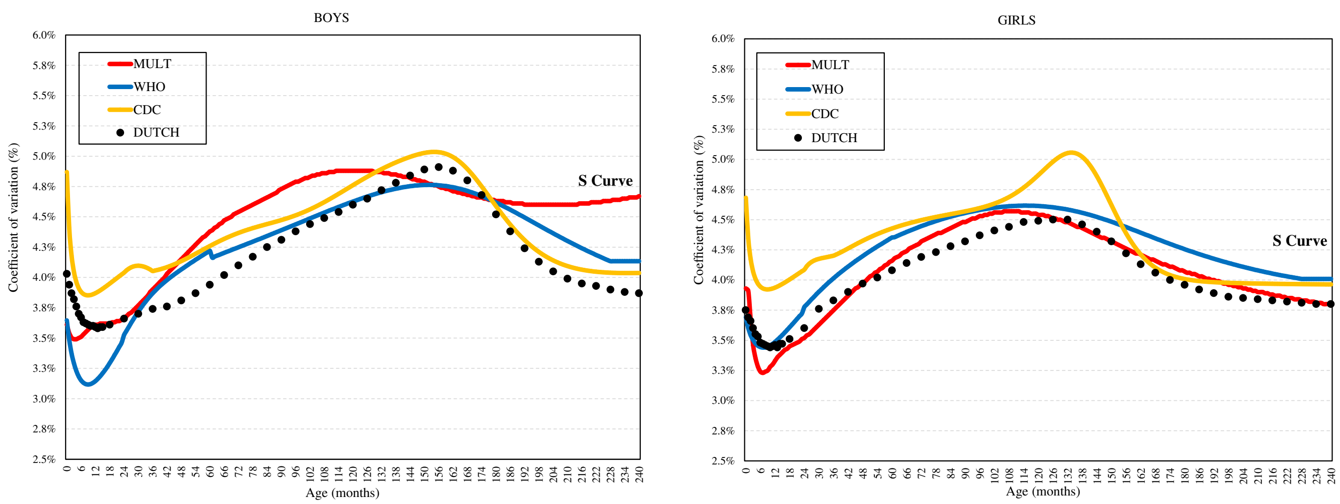

FIGURE 3 Coefficient of variation (S curve) of the four height references in boys and in girls

TABLE 3 Height-for-age *z*-score concordance (CCC) and nutritional status agreement (Kappa) among WHO, CDC and MULT height references, by age group and sex

	Entire sample 0 ≤ 20 years ($\overline{X}$ 9.04 years; *SD* ± 5.31 years)					**0 < 2 years ($\overline{X}$ 0.85 years; *SD* ± 0.42 years)**					**2 < 5 years ($\overline{X}$ 3.51 years; *SD* ± 0.79 years)**				
	n	**CCC**	**95% CI**	**Kappa**	**95% CI**	***n***	**CCC**	**95% CI**	**Kappa**	**95% CI**	***n***	**CCC**	**95% CI**	**Kappa**	**95% CI**
WHO x CDC															
Overall	91 063	0.988	0.988–0.988	0.748	0.742–0.754	11 140	0.972	0.972–0.973	0.964	0.958–0.970	10 494	0.961	0.960–0.962	0.936	0.923–0.949
Male	46 232	0.990	0.990–0.991	0.761	0.753–0.768	5494	0.971	0.970–0.972	0.976	0.970–0.983	5183	0.971	0.969–0.972	0.899	0.877–0.920
Female	44 831	0.985	0.985–0.985	0.733	0.724–0.741	5646	0.974	0.973–0.975	0.948	0.938–0.959	5311	0.952	0.950–0.955	0.975	0.963–0.986
WHO x MULT															
Overall	91 063	0.985	0.984–0.985	0.872	0.867–0.876	11 140	0.976	0.975–0.977	0.799	0.785–0.813	10 494	0.996	0.996–9.996	0.973	0.965–0.982
Male	46 232	0.981	0.981–0.981	0.866	0.860–0.873	5494	0.962	0.961–0.964	0.707	0.685–0.729	5183	0.999	0.999–0.999	0.952	0.935–0.968
Female	44 831	0.989	0.988–0.989	0.878	0.871–0.884	5646	0.990	0.990–0.991	0.904	0.890–0.919	5311	0.993	0.993–0.993	0.994	0.989–1.000
CDC x MULT															
Overall	91 063	0.985	0.984–0.985	0.800	0.795–0.805	11 140	0.983	0.983–0.984	0.787	0.773–0.801	10 494	0.975	0.975–0.976	0.909	0.894–0.925
Male	46 232	0.985	0.984–0.985	0.787	0.780–0.794	5494	0.990	0.990–0.991	0.719	0.697–0.740	5183	0.975	0.974–0.976	0.852	0.824–0.879
Female	44 831	0.985	0.984–0.985	0.815	0.808–0.822	5646	0.976	0.975–0.977	0.862	0.840–0.879	5311	0.976	0.975–0.977	0.969	0.956–0.982
	5 < 10 years ($\overline{X}$ 6.71 years; *SD* ± 1.22 years)					10 < 15 years ($\overline{X}$ 12.76 years; *SD* ± 1.38 years)					15 ≤ 20 years ($\overline{X}$ 16.70 years; *SD* ± 1.37 years)				
	n	CCC	95% CI	Kappa	95% CI	*n*	CCC	95% CI	Kappa	95% CI	*n*	CCC	95% CI	Kappa	95% CI
WHO x CDC															
Overall	27 382	0.989	0.988–0.989	0.689	0.678–0.700	27 685	0.996	0.996–0.996	0.714	0.703–0.725	14 362	0.998	0.998–0.998	0.646	0.630–0.662
Male	14 030	0.994	0.994–0.994	0.717	0.702–0.731	14 158	0.997	0.997–0.997	0.711	0.696–0.727	7367	0.998	0.998–0.998	0.669	0.648–0.690
Female	13 352	0.983	0.982–0.983	0.658	0.642–0.674	13 527	0.995	0.995–0.995	0.717	0.701–0.733	6995	0.998	0.998–0.998	0.615	0.591–0.640
WHO x MULT															
Overall	27 382	0.990	0.990–0.991	0.922	0.916–0.929	27 685	0.968	0.967–0.969	0.825	0.816–0.835	14 362	0.986	0.986–0.987	0.890	0.879–0.901
Male	14 030	0.993	0.993–0.994	0.979	0.970–0.9841	14 158	0.969	0.968–0.970	0.776	0.762–0.791	7367	0.995	0.995–0.995	0.962	0.953–0.971
Female	13 352	0.987	0.987–0.988	0.862	0.850–0.874	13 527	0.992	0.992–0.993	0.888	0.876–0.900	6995	0.977	0.976–0.978	0.805	0.784–0.827
CDC x MULT															
Overall	27 382	0.992	0.992–0.993	0.743	0.733–0.752	27 685	0.978	0.978–0.979	0.874	0.866–0.881	14 362	0.988	0.987–0.988	0.742	0.728–0.756
Male	14 030	0.991	0.991–0.991	0.703	0.689–0.718	14 158	0.975	0.974–0.975	0.925	0.910–0.933	7367	0.994	0.993–0.994	0.704	0.684–0.724
Female	13 352	0.994	0.994–0.994	0.784	0.771–0.797	13 527	0.983	0.982–0.983	0.810	0.797–0.824	6995	0.981	0.980–0.982	0.785	0.766–0.804

Abbreviations: 95% CI, 95% confidence interval; CCC, Lin's concordance correlation coefficient; kappa, Cohen's kappa coefficient; *n*, number of observations; *SD*, standard deviation; $\overline{X}$, average age in years (years).

by sex, the agreement was higher among girls (CCC >0.97) in all age groups, than in boys (CCC >0.96). The agreement between the WHO and CDC growth references was almost perfect (CCC >0.99) for subjects older than 10 years, and it was substantial (CCC >0.95 and ≤0.99) among subjects under 10 years old.

In the analysis of nutritional status, applying the Cohen's kappa coefficient (Table 3) there was an almost perfect agreement ($K > 0.80$) between WHO and MULT growth references for children from 2 years old, and it was particularly higher among children aged 2–5 years old ($K > 0.95$). Although the agreement was still higher among WHO and MULT height references, it was lower for subjects aged 10–<15 years and 15 to ≤20 years, when compared to children aged between 2 and 5 years old. The nutritional status according to the CDC growth references presented an almost perfect agreement ($K > 0.80$) with WHO for children under 5 years and with MULT height references for subjects aged 2 to <5 years and 10 to <15 years old.

4 | DISCUSSION

Regarding the mean height of the population, as expected, MULT height references show shorter boys and girls when compared to the Dutch height references, since the Dutch population is still the tallest in the world (Schönbeck et al., 2013). However, MULT height references show taller boys and girls when compared to WHO and CDC standard/reference growth charts, especially in the final stage of adolescence, which could indicate that the world's population is growing taller. Similar results have been found in the studies conducted in Australia, Germany and 28 European countries, which showed taller children and adolescents than the CDC and WHO reference populations, and a secular positive trend in height (Bonthuis et al., 2012; Hughes et al., 2014; Schaffrath Rosario et al., 2011).

Furthermore, a study involving 200 countries and territories conducted by the NCD Risk Factor Collaboration (NCD-RisC/2020) shows that although there are differences in the mean height of the population across the countries, this is changing, and the largest height gain in the past three decades is occurring in emerging economies countries (NCD-RisC, 2020). This height gain in the developing countries is due to the expressive improvement in their health system, sanitation, and in socioeconomic status, which have provided better growth conditions for children born in the 21st century (De Onis et al., 2007; Kuczmarski et al., 2000, 2002; WHO Multicentre Growth Reference Study Group, 2006; World Health Organization, 2018b). This explains why height references constructed with data of children born before 1990 s like the ones from CDC and WHO 2007 presented lower mean heights than those constructed with data of children who were born in the last decades (Bonthuis et al., 2012). MULT height references have an advantage when compared to WHO and CDC height references, since they present a predictive growth model constructed through recent longitudinal height data from multi-ethnic countries, with children and adolescents who likely overcome the secular trend in height, being a taller population than WHO 2007 and CDC reference populations. Additionally, in MULT height references there was an earlier pubertal growth spurt onset occurring in girls (9–13 years old) than in boys (10–15 years old). This was expected due to sexual maturation occurring first in girls, as pointed out in another study (World Health Organization, 2018a).

In our analysis, when compared to WHO, MULT height references show an almost perfect agreement in children aged 0–5 years old, especially between 2 and 5 years old, and substantial agreement for children of 5 years and older. This result supports the relevance of the MULT height references, because the WHO standards for under 5 years old are based on a highly selective sample of multi-ethnic children who lived in an ideal socioeconomic environment while for children older than 5 years it was based on the United States population from decades ago (De Onis et al., 2007; Schaffrath Rosario et al., 2011; WHO Multicentre Growth Reference Study Group, 2006). For this reason, the European Commission on Nutrition and the National Health Ministry of the Argentina only recommend the use of the WHO growth charts for children under 5 years old, since they are remarkably consistent between different ethnic groups in this age group (Orden & Apezteguía, 2016; Turck et al., 2013). Similar findings have been found in the Germany height references (KiGGS), where the mean height difference was lower in the age group 0–5 years than in the 5–18-year-old (Schaffrath Rosario et al., 2011), and a systematic review and studies conducted in Pakistan and India showed that the WHO growth reference charts for children older than 5 years appear to be inappropriate to Australian, Slovakian, Pakistani and Indian populations (De Oliveira et al., 2022; Iftikhar et al., 2018; Khadilkar & Khadilkar, 2015).

The positive association between height and socioeconomic status in children is well known and supported by several researchers (De Onis & Branca, 2016; Habicht et al., 1974; Komlos, 1993). Studies that analyzed the European growth during the eighteenth century pointed out that having more access to food and greater nutrition conditions explain better the variation in human height than just genetic factors (Komlos, 1985, 1993). An analysis of the height data during Habsburg monarchy, showed a decrease in the height variation among the ethnic groups due to the grain market inclusion and food distribution homogenization across the provinces (Komlos, 1985). Another study pointed out that in preschool children the height difference was more affected by environmental factors than by ethnic effects (Habicht et al., 1974). Corroborating this hypothesis, several researchers pointed out that the growth patterns are similar in children, despite their ethnicity, being more affected by their socio-economic status (Martorell, 1985; Martorell et al., 1988; Martorell & Habicht, 1986). These findings can indicate that the difference in height between different ethnic groups can be reduced through the equalization of the environmental factors, especially the economic conditions (Habicht et al., 1974; Komlos, 1985). In this sense, another study pointed out the biology of human development and the social-economic-political-emotional (SEPE) factors as determinants of growth (Bogin, 2021). According to the SEPE concept, the psychological-emotional phenotype is inherited by the children, allowing them to have a higher status in the society, which influences them to have a better environment to optimize their biological conditions to grow (Bogin, 2021). One explanation is that belonging to the prestigious social class in the society reduces the stress and stimulates the growth hormones in children, allowing them to achieve their optimal height (Bogin, 2021).

Concerning the ethnic differences in growth, a review of reported height in 53 population groups from Europe, Asia, Africa, America and Oceania concluded that there is limited interpopulation variation in the height of children and preadolescents, which supports consideration of a single growth reference for children and preadolescents to be used worldwide (Haas & Campirano, 2006). These authors also suggested a need for an appropriate international growth reference that considers the differences in growth during puberty when estimating the height reference values, which were applied in the MULT height references (Haas & Campirano, 2006). MULT height-for-age growth charts were constructed based on recent longitudinal data (1990s and 2000s) from multi-ethnic children and adolescents, which considers the differences across the ethnic groups and allowed us to verify their growth trajectory over the years.

We used the term stunting in our study, as it is commonly used by organizations such as WHO to categorized malnutrition in children. However, there is a concern about its use in some populations, since it can overestimate the prevalence of child malnutrition (Scheffler et al., 2021; Scheffler & Hermanussen, 2022; United Nations Children's Fund, World Health Organization, & The World Bank, 2021). Some authors have discussed the need to use other indicators for child malnutrition, such as the catch-up growth spurt that evaluates the growth trajectory of the child, being more sensitive to detect past undernutrition, than only stunting (Scheffler et al., 2021). The authors claimed that there was no association between stunting and undernutrition, indicating that short stature may not be a good indicator to detected undernourished children, as point out in another study (Scheffler et al., 2021; Scheffler & Hermanussen, 2022).

The strengths of this study are the standardized recent longitudinal data of representative sample from eight countries and two cities, contributing to a multiethnic population; the construction of the MULT height references based on the advantaged quintile of each country, which could provide economic condition to children to reach their optimal height distribution; and the use of the Cole's LMS method and GAMLSS, which are advanced techniques applied in the growth reference constructions and supported by several studies (Roelants et al., 2009; Schaffrath Rosario et al., 2011).

Nevertheless, there are some limitations, as the advantaged quintile was measured differently across the surveys and we did not evaluate the participant's health-related variables, namely breastfeeding. These factors could restrict the achievement of the healthy growth potential and contribute to an underestimation of height in our sample.

5 | CONCLUSION

For the first time, height references using data from 10 countries around the globe were developed. MULT height references presented a high agreement with WHO height references, especially for children under 5 years old, indicating that MULT height references could be a relevant tool to assess nutritional status of multi-ethnic populations.

AUTHOR CONTRIBUTIONS

Mariane Helen De Oliveira: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing—Original Draft, Writing—Review and Editing, Visualization, Funding acquisition. **Joana Araújo:** Conceptualization, Methodology, Investigation, Writing—Review and Editing, Supervision, Project administration, Funding acquisition. **Elisabete Ramos:** Methodology, Writing—Review and Editing. **Wolney Lisboa Conde:** Conceptualization, Methodology, Formal analysis, Writing—Review and Editing, Supervision, Project administration.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. The views expressed here are those of the authors. They are not necessarily those of YL, MCS, ELANA, EPITeen studies or the University of Oxford.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from UK Data Service, ISPUP and UERJ. Restrictions apply to the availability of these data, which were used under license for this study. MCS and YL data are available from UK Data Service online platform at URL [https://ukdataservice.ac.uk] and EPITeen and ELANA data are available from the authors with the permission of ISPUP and UERJ, respectively.

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SUPPORTING INFORMATION

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