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Body mass index and head circumference growth charts for the United Arab Emirates-the UAEMCGS 2 study

Y. M. Abdulrazzaq[2]✉, E. H. Aburawi[2], M. A. Abdulrahman[3], A. Alshamsi[4] & M. Zidan[1]

This study was undertaken to establish the UAE population's normal BMI and HC growth charts. BMI growth charts represent BMI values at each age and gender-specific percentiles. The UAE's development is unique in its cultural practices and genetic makeup; therefore, extrapolating health determinants from other nations to the UAE is unwise. It is, therefore, essential to have reference growth parameters for the UAE population. In this cross-sectional study, we measured BMI and Head Circumference in 20,998 infants and children, of both sexes, 0–18 years of age from all seven states that make up the United Arab Emirates (UAE), enabling us to construct the BMI and HC charts for the UAE. Using the LMS system BMI and HC charts were created. The prevalence of obesity ranged from 0 to 5.9% in males and from 0.8 to 6.6% in females at different ages. The mean BMI values for each age in both sexes were statistically significantly larger than those obtained in UAE children 30 years ago. Our study provides BMI and head circumference charts tailored to the growth patterns of UAE children.

Keywords BMI, HC, UAE growth chart, Weight, Height

Body Mass Index (BMI) is a widely used tool for assessing weight status and monitoring growth in children and adolescents. BMI growth charts visually represent BMI values relative to age and gender-specific percentiles, allowing healthcare professionals to identify individuals at risk of being underweight, overweight, or obese. While BMI charts are commonly used worldwide, it's essential to develop charts specific to the population being assessed to account for ethnic and regional variations in growth patterns and body composition. The BMI is currently the best available anthropometrically derived estimate of fatness in children. It has been used to depict fatness both in children and in adults acceptably. However, it does not accurately estimate the fat mass in the body. Body composition can differ in individuals with the same BMI.

With the rising concern over obesity-related health issues globally, understanding BMI trends within specific populations becomes imperative for public health interventions and policy formulations. The United Arab Emirates (UAE) has developed immensely both economically and in its urbanisation in the last 50 years[1,2]. As a result, improvements have occurred in all health indicators, including an increase in life expectancy at birth[2]. The negative side of this rapid development is the sedentary lifestyle and change in diet leading to an increased incidence and prevalence of non-communicable diseases (NCD)[3,4]. In the UAE according to a 2020 Ministry of Health Bulletin 17.3% of children, aged 5–17 years were obese, and 11.8% of the population aged 20–79 years had diabetes mellitus[5]. Because of the uniqueness of the trajectory of the development of the UAE in its cultural practices and the genetic makeup of its population, the extrapolation of determinants of health from other nations to the UAE is unwise. It is therefore essential to have standard growth parameters for the UAE population.

Cranial growth and brain development have been examined over the years using a standard procedure of the measurement of head circumference ([HC] or occipitofrontal circumference [OFC])[6–8]. This method of estimating brain development is a quick, simple, and economical screening method and does not expose children to radiation. With this easy method, pathological changes can be detected early. Therefore, it is easy to see the multidisciplinary interest in pediatric cranial circumference and braincase volume. In addition to its importance

[1]College of Medicine and Health Sciences, UAE University, Al Ain, UAE. [2]Health Informatics and Smart Health Department, Dubai Health Authority, Dubai, UAE. [3]Metabolic and Genetics Department, Tawam Hospital, Al Ain, UAE. [4]Department of Medical Education and Scientific Research, Dubai Health Authority, Dubai, UAE. ✉email: yousef@uaeu.ac.ae

in the differential diagnosis and therapy decisions for neurosurgical, maxillofacial- and plastic surgery[9,10], , it is also interesting to those studying evolution[11].

A BMI and HC growth chart was produced in a 1992 cohort[1,12], more than 30 years ago, it is now the time to create a new chart reflecting BMI and HC of the current population. We have shown in a recent paper that the heights and weights of children measured in this study are significantly higher in children of all ages than in children measured in 1992[13]. Human growth is associated with complex interactions between genetic and environmental factors. As an example, there was reported an increased body size and body mass index (BMI) in Japanese children, in growth before and after World War II (WW II)[14,15].

This study aimed to measure the head circumference and BMI of children from 0 to 18 years of age in the United Arab Emirates (UAE), thereby shedding light on prevalent weight categories and potential health implications, and producing a growth chart for BMI and HC. By examining BMI patterns, this research endeavours to contribute to the broader discourse on public health strategies tailored to the UAE's unique demographic landscape. This is part of a larger study – United Arab Emirates Multi Centre Growth Study (UAEMCGS) 2 study.

Methods

A stratified random sampling technique was employed to ensure the inclusion of participants from different demographic strata, including age, gender, and socioeconomic status. This sample included individuals from diverse socioeconomic backgrounds and all seven Emirates to ensure the charts' applicability to the entire population. Our measurements were conducted before the onset of the pandemic and during the period 2017/2018, 2018–2019, and 2019–2020. The only measurements made early in the year 2020 were the neonatal data collected from one hospital in Abu Dhabi. Most of the measurements were made in the years 2017 and 2018. This was a cross-sectional study to collect head circumference and BMI measurements from the selected sample of children consisting of preschool-age children [ages of 0 (birth, taken from hospitals), 3 Mo, 6 Mo, 12 Mo, 18 Mo, 24 Mo (from vaccination centres), 3, 4, and 5 years (from nurseries and kindergartens)], and school children aged 5–11 years (primary schools) and 11–18 years (secondary and high schools)[16]. The ages 4.50–5.49 were considered 5 years old; similarly, 9.50-10.49 years of age were considered 10 years old. In the early stages 0 was at birth, 3 months was between 2.5 and 3.49 months, 6 months was between 5.5 and 6.49 months. In this way all ages were considered. We ensured that at least 200 children were recruited in each age-sex group, which gives sufficient precision for the construction of growth charts.

The Ministry of Education was sourced for information on the schoolchildren registered for the school year 2017/2018, 2018–2019, and 2019–2020 distributed by sex, geographical area, and educational level. The study took longer than planned due to the COVID-19 pandemic that disrupted all normal activities in the country. Taking into account the range of facilities available and the feasibility of conducting the study, such as trained staff, transportation, and funding, we decided to include 200–500 children in each age and sex group from schoolchildren registered for that school year. The children's age, gender, head circumference, weight, and height were recorded as per standard procedures. This approach aimed to mitigate sampling bias and enhance the generalizability of findings to the broader UAE population. BMI was calculated using the standard formula: BMI = weight (kg) / (height (m))^2. Participants' head circumference, weight, and height measurements were obtained using calibrated instruments following standardized protocols to ensure accuracy and reliability. Participants' BMI was categorized according to the World Health Organization (WHO) classification criteria, which delineates BMI ranges into underweight (thin and severely thin), normal weight, overweight, and obesity categories. This classification system provides a standardized framework for interpreting BMI data and comparing results across different populations. The samples were taken from the cities of Abu Dhabi, Al Ain, Dubai, Sharjah, Ajman, Ras Al-Khaimah, Fujairah, and Umm al-Quwain, which cover the whole of the United Arab Emirates.

The measurement of length or height was made to the nearest 0.1 cm using an infant length board for infants and toddlers not able to stand without support and for all others a portable height gauge. Weight was measured to the nearest 0.1 kg using a scale with non-detachable weights in infants without clothes or with pre-weighed diapers, and in older children in light clothing. Head circumference was measured to the nearest 0.1 cm with a non-stretchable disposable paper tape.

The PI (Y.M.A.) trained research assistants to perform the measurements. This team included 2 trained female paramedical assistants for each centre (a total of 10). Each assistant measured weight, height, and head circumference independently from the others. Height and head circumference were measured by two persons to minimize intra-observer error.

LMSchartmaker and SPSS 24 statistical packages were used to analyse the data. LMSchartmaker was used to create growth charts for BMI and head circumference, with the estimated 3rd, 10th, 25th, 50th, 75th, 90th, and 97th age-sex specific percentiles. The growth chart distribution is characterized by the Box-Cox power λ (L), the median μ (M), and the coefficient of variation σ (S)[16,17]. Because of the lines' jagged appearance, we used splines to smooth these values across ages. In the construction of the charts, using penalized likelihood the three curves [representing the median (M), coefficient of variation (S) and skewness (L)] were fitted as Cubic Splines by non-linear regression, which ensured that the curve was continuous in the first and second derivatives. The extent of smoothing required was expressed in terms of degrees of freedom. This made them particularly useful for smooth curve fitting. Since we had 23 data points we used 7 knots to ensure a smooth curve. The knots were placed at ages 0, 6 months, 12 months, 3 years, 7 years, 12 years, and 17 years. There were more points in the early ages as these regions were more clustered.

We decided on the degree of smoothing after visual inspection of the estimated percentile curves. The resultant percentile curves were exported to Microsoft Excel spreadsheets, and percentile graphs were made for ages 0–18 years. We removed impossible outliers before finalising the charts. Incomplete or unclear forms and

'impossible' outliers were excluded. An example of an 'impossible outlier' is when instead of registering a weight of 2.5Kg for a newborn baby the data recorder mistakenly registers a weight of 25 Kg or 0.25 Kg misplacing the dot. Therefore rather than correct the mistake we chose to exclude this measurement. (Table 1)

Descriptive statistics, including means, standard deviations, and proportions, were used to summarize BMI and HC distributions within the UAE population. Age- and gender-specific BMI and HC percentiles were determined using established statistical methods. BMI and HC growth charts were developed separately for boys and girls aged 0 to 18 years. The charts display BMI and HC percentiles ranging from the 3rd to the 97th percentile at regular intervals of age. The WHO criteria[18] for underweight and overweight were used to calculate the percentage of children below the age of 18 years falling into each category According to WHO, the cut-off points are as follows: overweight: ≥1SD (equivalent to BMI 25 kg/m2 at 18 years), obesity: ≥2SD (equivalent to BMI 30 kg/m2 at 18 years), thinness: ≤2SD, severe thinness: ≤3SD. The Two-samples t-test was used to compare the means of BMI and HC of this study's growth chart with the means of BMI and HC charts for each of the CDC[19,20], WHO, and UAE growth charts (1992). These pairwise comparisons were made at different ages. However, the standard error of the means is reported instead of the standard deviation when we made these comparisons. The Fisher-Freeman-Halton Exact test was used to compare the prevalence of the BMI categories between the males and females for each age group. A p-value of < 0.05 was considered significant.

Inclusion and exclusion criteria

Children had to be nationals of the UAE, and born to a father of Emirati nationality, healthy, born full-term, with no health issues that could affect their growth, to be included in the study.

Children who had anaemia other than iron-deficiency anaemia, diabetes mellitus, congenital malformations, and debilitating chronic diseases like asthma, were excluded. Children whose mothers had health conditions that could affect the growth of their children in the neonatal period (e.g. diabetes mellitus) were also excluded.

Results

Mean values

Tables 2 and 3 show the sample size, mean + SE values for head circumferences, and BMIs at each age and in both sexes. Anthropometric measurements were taken in 20,998 children from all seven Emirates. About 5% of the measurements, which were outliers, were discarded. Growth charts for BMI and Head Circumferences were constructed using the above methods and are shown in Figs. 1, 2, 3 and 4. Growth charts were drawn for each sex and each age period. At birth, mean (± SD) BMI and head circumference were 13((± 0.09) Kg/m^2, and 34.4 (± 0.9) cm respectively in boys, and, 12.8 ((± 0.11)Kg/m^{2}and 34(± 1.1) cm respectively in girls. At 1 year of age,

	Boys	Boys weight (Kg)	Boys height (cm)	Girls	Girls weight (Kg)	Girls height (Cm)
Age (years)	Sample size	Discarded	Discarded	Sample size	Discarded	Discarded
.00	476	10	13	450	3	8
0.25	363	7	14	378	1	0
0.5	475	7	7	482	5	2
0.75	307	1	0	304	0	2
1.00	245	1	0	262	3	0
1.50	236	3	0	219	1	0
2.00	206	5	2	215	3	1
3.00	184	0	0	210	0	0
4.00	559	48	36	509	6	36
5.00	639	57	49	570	2	77
6.00	516	34	15	546	1	36
7.00	473	42	21	407	2	17
8.00	476	50	28	468	2	62
9.00	465	14	27	419	4	24
10.00	525	11	24	457	1	21
11.00	645	64	50	496	9	41
12.00	663	54	41	591	5	52
13.00	688	30	59	594	3	38
14.00	531	19	34	690	8	60
15.00	508	10	42	691	4	48
16.00	525	4	40	659	3	57
17.00	525	12	57	641	3	52
18.00	447	37	49	521	6	43
Total	10,219	510(4,99%)	608 (5.95%)	10,779	75 (0,73%)	677 (6.28%)

Table 1. This shows the sample size for each age, in girls and boys. The table also shows the number of samples discarded for each measurement at different ages.

Age		UAE 2020			CDC				WHO				UAE 1992			
		n	Mean	SE	n	Mean	SE	*p*-value	n	Mean	SE	*p*-value	n	Mean	SE	*p*-value
0	B	430	34.4	0.04	72	35.81	0.165	< 0.001	893	36.71	0.058	< 0.001	602	34.32	0.021	0.057
	G	473	34	0.05	71	34.7	0.266	< 0.001	842	34.71	0.059	< 0.001	583	35.42	0.034	< 0.001
3 m	B	104	39.4	0.12	95	41.2	0.123	< 0.001	NA	NA	NA	NA	NA	40.53	NA	NA
	G	102	40.6	0.15	99	40.47	0.121	0.502	NA	NA	NA	NA	NA	38.84	NA	NA
6 m	B	187	42.9	0.12	81	42.8	0.122	0.6163	419	43.72	0.065	< 0.001	NA	43.68	NA	NA
	G	195	42.7	0.12	82	42.7	0.133	1	444	42.4	0.063	< 0.016	NA	41.74	NA	NA
1 year	B	262	46.4	0.10	268	46.39	0.067	0.9335	417	46.35	0.063	0.6561	186	46.57	0.051	0.179
	G	242	46.1	0.10	230	45.2	0.110	< 0.001	453	45.04	0.061	< 0.001	168	45.38	0.051	< 0.001
1.5 yr	B	219	46.7	0.11	NA	47.79	NA	NA	444	47.77	0.064	< 0.001	NA	47.86	NA	NA
	G	235	46.3	0.1	NA	46.61	NA	NA	472	46.51	0.061	0.0602	NA	47.06	NA	NA
2 yrs	B	214	47.6	0.12	242	48.68	0.116	< 0.001	593	48.66	0.058	< 0.001	56	48.34	0.095	0.002
	G	203	47.5	0.13	249	47.54	0.076	0.782	598	47.47	0.056	0,8064	85	47.85	0.092	0.096
3 yrs	B	210	49.2	0.11	184	49.68	0.103	0.0017	531	49.68	0.069	0.0002	85	49.64	0.113	0.020
	G	184	49.1	0.13	155	48.63	0.106	0.007	487	48.63	0.069	0.0007	72	48.39	0.100	0.001
4 yrs	B	473	52.8	0.09	NA	NA	NA	NA	523	50.2	0.066	< 0.001	NA	NA	NA	NA
	G	553	51.5	0.007	NA	NA	NA	NA	472	49.3	0.069	0.0007	NA	NA	NA	NA
5 yrs	B	563	52.1	0.06	NA	NA	NA	NA	494	50.7	0.072	< 0.001	NA	NA	NA	NA
	G	637	51.8	0.06	NA	NA	NA	NA	504	49.9	0,067	< 0.001	NA	NA	NA	NA

Table 2. Comparison of the boys' and girls' mean HC between the UAE 2020 chart and other charts; CDC, WHO, and UAE 1992 Footnote: UAE 2020 = this study; CDC = Center for Disease Control USA; WHO = World Health Organization; UAE 1992 = growth charts created in children in 1992; B = boys; G = girls; HC = Head circumference; n = number; m = months; SE = Standard Error of the Mean; yr = years.

mean (± SD) BMI and head circumference was 17.4((± 0.08) Kg/m^2 and 46.4(± 1.6) cm respectively in boys, and 17.1 ((± 0.07) Kg/m^2 and 46.1(± 1.5) cm respectively in girls. There were no significant differences between the 2 sexes at these ages in any of the anthropometric measurements. At the age of 3 months, the HC of boys in the CDC data was larger than the ones in the present study. At the ages of 1–5 years, the differences were negligible. The BMI on the other hand shows significantly higher values in the present study than both the WHO data and the UAE 1992 data at all ages. Again, the CDC BMI data values are significantly higher than the present study data for all ages in both sexes.

Obese and overweight percentages

At one year of age the percentage of obese infants was 2.1% in girls and 2.8% in boys and overweight occurred in 12.3% of girls and 12.2% in boys. These values were not significantly different between the 2 sexes. At 5 years of age, 5.5% of girls were obese as against only 2.4% in boys, while the percentage of overweight was higher in boys (12.9%) than in girls (8.7%). The percentage of overweight and obese children combined was significantly greater in boys than in girls at the ages of 4 and 5 years, while the differences were not significant at the other ages. Only 1.7% of girls and 1.3% of boys were in the category of thinness. At 10 years of age, 4.9% of both boys and girls were obese and 13.5% of girls and 12.7% of boys were overweight. There were no underweight children in this age group. At adolescence (14 years of age) 4.8% and 4.2% of girls and boys respectively were obese and 13.9% and 12.9% of girls and boys respectively were overweight. There were no underweight boys or girls in this age group. Finally, at the age of 17 and 18 years combined, 5.3% of girls and 4.7% of boys were obese, and 10.75% and 14.55% of girls and boys respectively were overweight and this difference was not significant. There were also no underweight individuals in this age group (Table 3).

Comparisons

When comparing the present growth charts to the ones from CDC[19,20], WHO (https://www.who.int/tools/growth-reference-data-for-5to19-years/indicators/bmi-for-age), and our own 1992 growth charts (12), we found that the CDC charts showed significantly higher values for BMI at all ages in both boys and girls. The present study has shown significantly higher values for BMI at all ages than the values of BMI in the UAE 1992 Growth charts in both boys and girls. The overweight and obesity rates in children at 1 year of age were 12.3% and 2.1% respectively in females, and 12.2% and 2.8% respectively in males. At the age of 3 years, the percentages of overweight and obesity were 9.8% and 1.7% respectively in females and 11.7% and 1.5% respectively in males. At the age of 10 years, the rates of overweight and obesity were 13.5% and 4.9% respectively in females and 12.7% and 4.9% respectively in males. And at the age of 18 years the rates of overweight and obesity were found to be 12.9% and 4% respectively in females and 16.5% and 4.9% respectively in males (Table 4). When we calculated the percentages of overweight and obesity in children of all ages taking into consideration 1992 cut-off points at every age in both sexes we found that the rates of obesity were significantly higher in the present cohort. The rates of overweight were not significantly different in most of the ages in both sexes (Tables 5 and 6). To show

	UAE 2020			CDC				WHO				UAE 1992			
Age	n	Mean	SE	n	Mean	SE	*p*-value	n	Mean	SE	*p*-value	n	Mean	SE	*p*-value
0 b	441	13	0.09	NA	NA	NA	NA	893	13.4	0.047	< 0.001	602	14.62	0.055	< 0.001
g	458	12.8	0.11	NA	NA	NA	NA	842	13.3	0.048	< 0.001	583	14.44	0.042	< 0.001
3 m b	104	19.5	0.25	NA	NA	NA	NA	416	17.2	0.074	< 0.001	NA	14.96	NA	NA
g	101	19.7	0.16	NA	NA	NA	NA	447	16.7	0.076	< 0.001	NA	14.76	NA	NA
6 m b	183	18	0.13	NA	NA	NA	NA	419	17.3	0.078	< 0.001	NA	15.25	NA	NA
g	189	17.8	0.12	NA	NA	NA	NA	444	16.9	0.081	< 0.001	NA	15.04	NA	NA
1 year b	254	17.4	0.08	NA	NA	NA	NA	417	16.8	0.073	< 0.001	186	15.62	0.083	< 0.001
g	236	17.1	0.07	NA	NA	NA	NA	453	16.4	0.070	< 0.001	168	15.45	0.086	< 0.001
1.5 year b	207	17.2	0.07	NA	NA	NA	NA	444	16.1	0.066	< 0.001	NA	15.70	NA	NA
g	230	16.3	0.09	NA	NA	NA	NA	472	15.7	0.069	< 0.001	NA	15.61	NA	NA
2 year b	208	16.4	0.08	207	16.9	0.2	0.0205	593	15.7	0.057	< 0.001	56	15.58	0.139	< 0.001
g	203	16.2	0.08	214	16.4	0.1	0.1215	598	15.4	0.061	< 0.001	85	15.58	0.093	< 0.001
3 year b	205	16.5	0.08	181	16.8	0.2	0.1467	531	15.6	0.061	< 0.001	85	15.08	0.130	< 0.001
g	174	16.4	0.08	153	16.2	0.1	0.1156	487	15.4	0.068	< 0.001	72	15.23	0.108	< 0.001
4 year b	443	14.1	0.06	178	16.5	0.1	< 0.001	523	15.3	0.061	< 0.001	524	14.70	0.067	< 0.001
g	477	14.8	0.07	188	16.4	0.1	< 0.001	472	15.3	0.069	< 0.001	588	14.86	0.034	0.414
5 year b	464	13.9	0.06	180	16.5	0.2	< 0.001	494	15.26	0.065	< 0.001	662	14.57	0.030	< 0.001
	539	14.7	0.07	190	16.6	0.2	< 0.001	504	15.24	0.076	< 0.001	881	14.7	0.026	0.876
6 Yr b	470	14.7	0.07	168	16.8	0.2	< 0.001	295	15.31	0.088	< 0.001	478	14.56	0.038	0.078
g	466	14.8	0.09	180	16.7	0.2	< 0.001	307	15.27	0.103	0.0007	631	14.66	0.033	0.105
7 Yr b	363	16	0.14	193	17.3	0.3	< 0.001	400	15.48	0.082	0.0011	527	14.54	0.037	< 0.001
g	416	15.6	0.11	190	17.5	0.3	< 0.001	400	15.4	0.099	0.178	647	14.71	0.032	< 0.001
8 Yr b	378	15.8	0.10	217	18	0.3	< 0.001	400	15.74	0.089	0.6533	567	14.73	0.051	< 0.001
g	406	16.3	0.12	186	18.4	0.4	< 0.001	400	15.68	0.107	0.0001	745	14.98	0.046	< 0.001
9 Yr b	372	17.7	0.16	195	18.9	0.4	0.001	400	16.05	0.097	< 0.001	564	15.18	0.055	< 0.001
g	428	17.4	0.15	215	18.4	0.3	0.0009	400	16.1	0.116	< 0.001	730	15.54	0.047	< 0.001
10 Yr b	410	18.4	0.18	185	20.1	0.4	< 0.001	400	16.44	0.107	< 0.001	589	15.86	0.060	< 0.001
	490	19.3	0.17	186	19.8	0.4	0.1769	400	16.61	0.127	< 0.001	708	16.28	0.062	< 0.001
11 Yr b	436	18.6	0.17	172	20.7	0.5	< 0.001	400	16.94	0.116	< 0.001	615	16.72	0.069	< 0.001
g	543	19.3	0.16	205	21	0.5	< 0.001	400	17.25	0.136	< 0.001	730	17.09	0.071	< 0.001
12 Yr b	510	19.3	0.17	157	20.3	0.5	0.0157	400	17.53	0.126	< 0.001	510	17.64	0.089	< 0.001
g	584	20.3	0.17	154	22	0.4	< 0.001	400	18	0.147	< 0.001	809	18.0	0.079	< 0.001
13 Yr b	528	21.5	0.21	163	22.7	0.5	0.0107	400	18.23	0.136	< 0.001	631	18.51	0.084	< 0.001
g	601	21.8	0.19	138	22.7	0.5	0.0523	400	18.8	0.157	< 0.001	732	18.94	0.094	< 0.001
14 Yr b	596	22.8	0.20	166	22.5	0.5	0.516	400	19.01	0.144	< 0.001	568	19.35	0.085	< 0.001
g	483	23.1	0.23	169	23.7	0.4	0.1879	400	19.57	0.165	< 0.001	742	19.74	0.094	< 0.001
15 Yr b	604	22.4	0.20	165	24.4	0.7	0.0002	400	19.77	0.152	< 0.001	489	20.03	0.088	< 0.001
g	457	23.2	0.24	129	24	0.6	0.1483	400	20.21	0.173	< 0.001	841	20.38	0.082	< 0.001
16 Yr b	569	23.4	0.23	152	23.6	0.4	0.6837	400	20.5	0.158	< 0.001	530	20.66	0.089	< 0.001
g	479	23.2	0.23	170	25	0.6	0.0007	400	20.7	0.178	< 0.001	877	20.87	0.109	< 0.001
17 Yr b	555	23.5	0.21	156	25.1	0.6	0.0017	400	21.14	0.163	< 0.001	325	21.22	0.121	< 0.001
g	452	23	0.21	146	25.6	0.6	< 0.001	400	21.04	0.181	< 0.001	732	21.3	0.096	< 0.001
18 Yr b	448	24.5	0.26	129	24.6	0.7	0.8704	400	21.71	0.167	< 0.001	143	21.63	0.184	< 0.001
g	372	23.1	0.23	141	26.1	0.7	< 0.001	400	21.26	0.183	< 0.001	339	21.73	0.151	< 0.001

Table 3. Comparison of the boys' and girls' mean BMI between the UAE 2020 chart and other charts; CDC, WHO, and UAE 1992 Footnote: UAE 2020 = this study; CDC = Center for Disease Control USA; WHO = World Health Organization; UAE 1992 = growth charts created in children in 1992; B = boys; G = girls; HC = Head circumference; n = number; NA = not available; m = months; SE = Standard Error of the Mean; yr = years.

whether we could use the 1992 data as a basis to detect obesity and as an example, at the age of 3, in both sexes, the obesity and overweight rates combined were more than 65% of all children of that age.

Discussion

A WHO technical report in 1995[18] divided the BMI measurements into 4 categories: underweight, normal, overweight, and obese. An adult person is underweight if his/her BMI is in the range of 15 to 19.9, normal

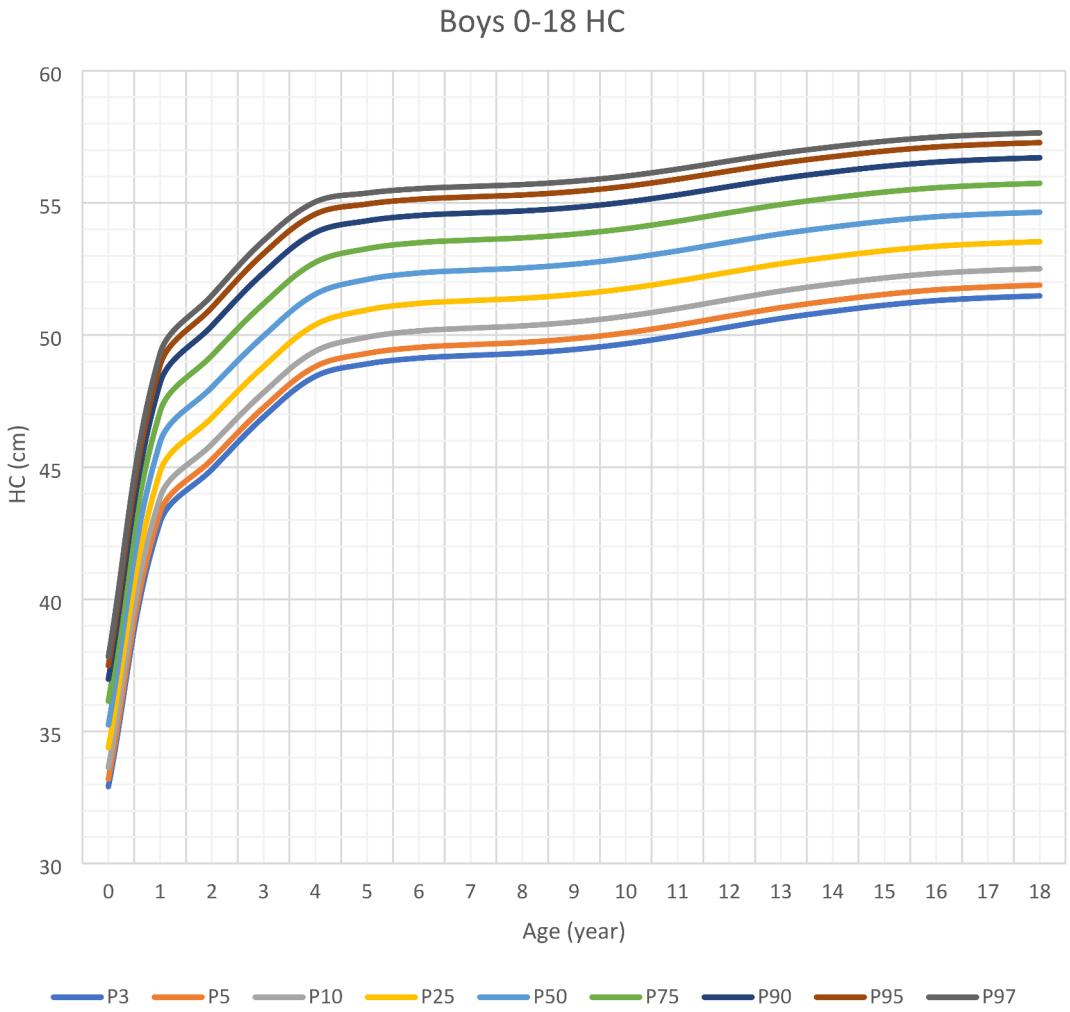

Fig. 1. Head circumference charts for boys aged 0–18 years. There is a rapid increase in the head circumference in the first year of life and then a slower rise up to the age of 4 years, following which the increase is very slow up to 18 years of age.

weight if the BMI is 20 to 24.9, overweight if the BMI is 25 to 29.9, and obese if it is 30 to 35 or greater. The BMI has now been established as the most common and most studied measurement and has been most commonly used in children because measurements can be made easily on infants and children. However, BMI has limited value when measuring body composition. Both lean mass and fat mass correlate very well with BMI. Despite this, BMI can only be used to follow short-term changes in body composition as changes in the BMI standard deviation score[21] in the short term can be attributed primarily to changes in fatness. It does not have the required accuracy as an absolute measure of fatness in individuals[21,22], although some studies do seem to suggest this[23–25]. Although there are shortcomings, most work on childhood obesity is based on BMI. The major limitation of the BMI is the inability to differentiate between muscle and fat. There has been little data on growth and obesity in United Arab Emirates (UAE) children except for the UAE skinfold or BMI standard reference charts (12). A large-scale epidemiological study ($n = 44{,}942$) conducted in Ras Al Khaimah, United Arab Emirates (UAE), confirmed obesity was steadily increasing in those aged 3–18 years; each year an additional 2.36% were classified as obese and 0.28% as extremely obese[26]. The United Arab Emirates Multicentre Growth Study 2 (UAEMGS 2) was undertaken to determine a range of anthropometric measurements and to construct growth charts for each of these measurements.

Consistent with global trends and previous studies[27,28], our BMI charts demonstrate rapid increases in BMI during infancy and early childhood, followed by a stabilization period during adolescence. Sex-specific differences are evident in older age groups, with boys generally exhibiting higher BMIs compared to girls at ages 17 and 18, but girls showing higher BMIs at ages 10–15 years, particularly during adolescence, echoing findings from studies in other populations[29,30]. These differences likely reflect variations in body composition and growth rates between the sexes.

There were a few studies done on BMI in the UAE one of which was on a sample of schoolchildren 5–17 years of age during the years 1998–1999. In that study prevalence of overweight and obesity was found to be 21.5% and 13.7% respectively[31]. Another study showed that in the 14–17 years age group, the prevalence of overweight and obesity was 19% and 13.3%, respectively, in boys and 16.9% and 17.6%, respectively, in girls[2]. However this study

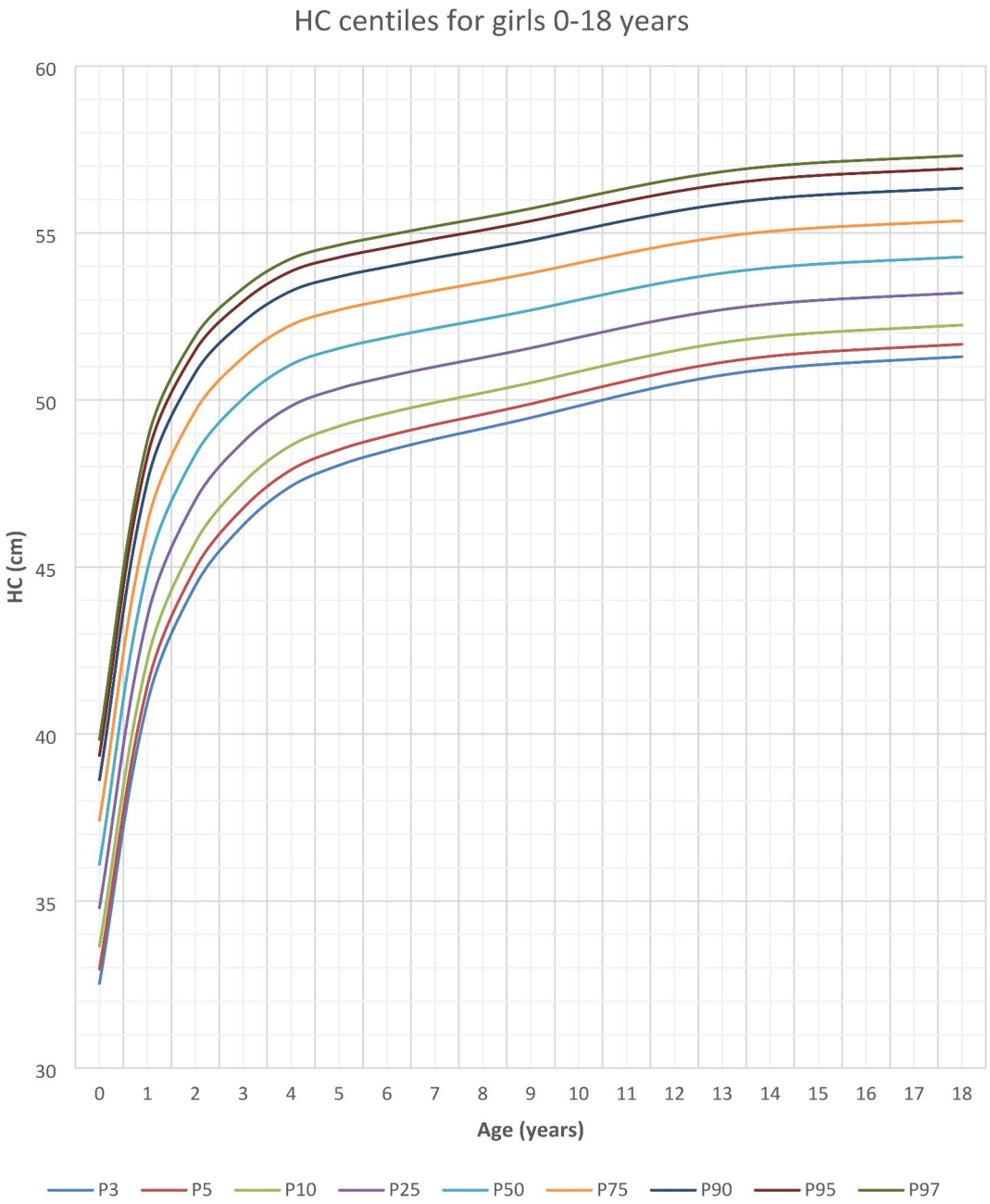

Fig. 2. Head circumference charts for girls aged 0–18 years. There is a rapid increase in the head circumference in the first year of life and then a slower rise up to the age of 4 years, following which the increase is very slow up to 18 years of age.

was not restricted to UAE nationals only but included the expatriate population as well, while the present study is limited to the UAE nationals only. In our previous study, we found the prevalence of obesity and overweight in the adolescent age group to be lower at 9.94% and 15.16%, respectively, in females and 6.08% and 14.16%, respectively, in males[12]. In the present study, the corresponding figures were 4.9% obese, and 13.7% overweight females, and 4.17% and 9.5% obese and overweight males respectively in the adolescent age group. In contrast to what we expected the rates of obesity and overweight had decreased in both adolescent boys and girls from the last study to this one. When using cut-off points from the 1992 data and calculating the rates of obesity and overweight we found impossible percentages with 65% overweight and obese children at the age of 3 years in both sexes, and similar figures in all ages in both sexes. In a recent publication[13] using data from the present cohort, we showed greater height and weight than those of the 1992 cohort at all ages in both sexes. Therefore, it is obvious from this analysis that there is a need for a new growth chart. Two more studies done before 2010 found the obesity rate to be 8% in both males and females and the overweight rate to be 16.5% and 16.9% in males and females, respectively in one study[3] and 14% overweight and 9% obesity in the other study[32]. Our overweight and obese rates for this age group were lower than in both these studies. In the present study the rates

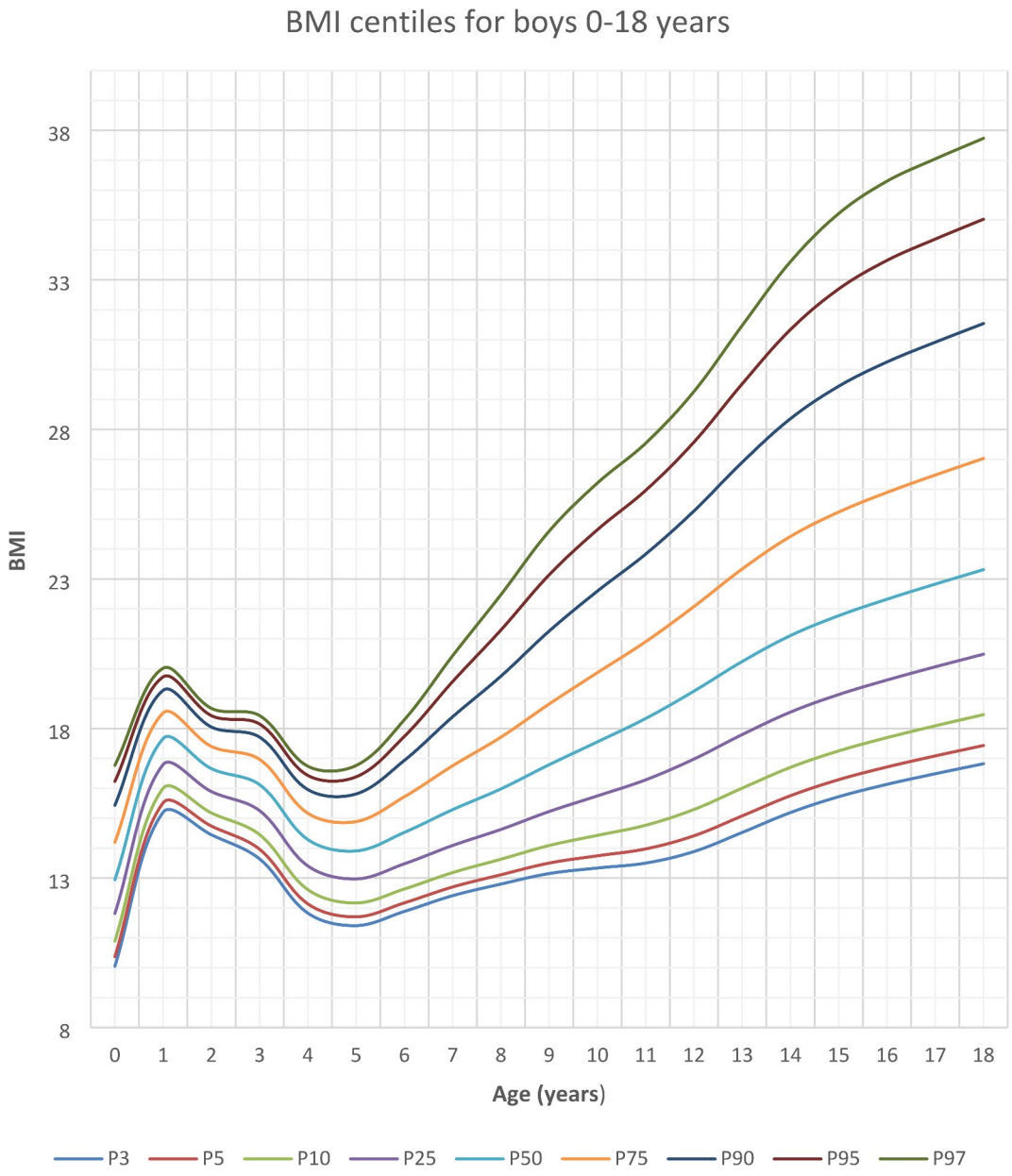

Fig. 3. The BMI in boys also rapidly increases in the first year of life. There is a period between the ages of 1 and 5 years when the BMI decreases. The BMI then increases with widely different values.

of overweight and obesity gradually increased with age in both sexes, following a similar trajectory but reaching slightly higher rates in the females. These changes were as expected. The impact of population nutrition on BMI would be difficult to estimate, and to provide an algorithm converting new values from old would be impossible. These children did not suffer from malnutrition and poor health therefore there were no constraints to growth. Therefore, these references show normal growth under optimal conditions and can be used in the whole country and by neighbouring countries that have similar diets and habits. We did not have mothers who smoked which would have added another negative factor to achieve optimal growth.

The CDC and WHO growth charts are widely used in many countries to assess the nutritional status and growth of children. These charts are based on large international samples, including different ethnicities, and reflect global trends. It is important to note that the CDC charts tend to reflect growth patterns that the dietary habits, lifestyle, and genetics of populations in the United States may influence. While the CDC and WHO charts are internationally recognized, they may not fully capture the specific characteristics or trends of certain regions, such as the UAE. However, the Comparison with UAE 1992 Growth Charts is particularly relevant because it involves a localized context, potentially reflecting regional dietary patterns, socioeconomic status, healthcare access, and physical activity levels that are specific to the UAE. Higher BMI values in the present study compared to the 1992 UAE growth charts could be due to changes in diet and lifestyle, and increases in height[13] over time. Since 1992, there have been significant changes in the UAE, including increased urbanization, globalization of

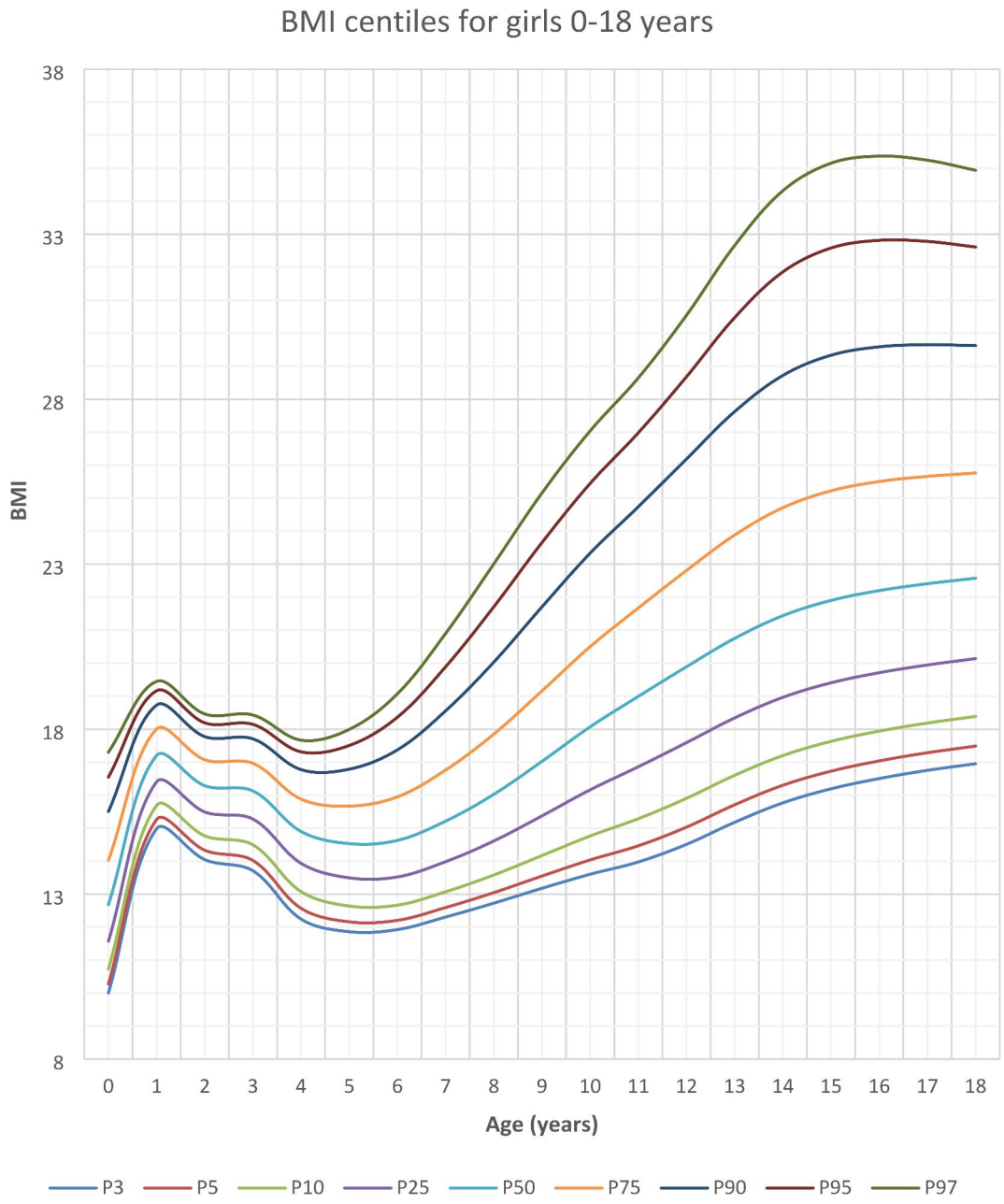

Fig. 4. The BMI in girls also rapidly increases in the first year of life. There is a period between the ages of 1 and 5 years when the BMI decreases. The BMI then increases with widely different values.

food patterns (such as the introduction of fast food), and changes in physical activity levels (with more sedentary behavior, especially among children). These changes could lead to higher BMIs today than in the past. Another reason could be health interventions or awareness: The current population may be more aware of health and fitness, leading to an increased focus on weight and height, which may affect the data. Another reason could be a potential improvement in healthcare and nutrition. Increased access to healthcare and improved nutrition over time could also contribute to changes in growth patterns, although this might not be enough to explain the magnitude of BMI changes observed.

The skull undergoes the greatest changes in the first 2 years of life[33], with the intracranial volume doubling during the first 6–9 months of life[9]. Subsequently, in the next 6 months it increases by another 20%[9]. Post-mortem studies and CT scans have shown a significant positive correlation between brain volume and head circumference in deceased neonates[34,35]. Similarly, this finding is in line with MRI studies of older children[8]. These studies have established the head circumference measure (HC) as a screening parameter for intracranial volume[36–38]. Analysis of head circumference charts reveals a steady increase in head size during infancy, consistent with findings from previous studies[39,40]. However, deviations from expected head circumference measurements may indicate underlying neurological abnormalities or developmental delays, aligning with the findings of studies

Age	Gender	BMI categories					*P*-value
		Severely thin (%)	Thin (%)	Normal (%)	Overweight (%)	Obese (%)	
0 month	Female	0.0	0.2	82.8	12.1	4.9	0.139
	Male	0.0	0.5	82.0	15.0	2.5	
3 months	Female	0.0	4.0	79.2	15.8	1.0	0.719
	Male	0.0	1.9	81.7	16.3	0.0	
6 months	Female	0.0	0.5	82.5	12.2	4.8	0.439
	Male	0.5	2.2	84.2	9.3	3.8	
9 months	Female	0.0	1.0	78.1	19.8	1.0	0.361
	Male	0.0	2.1	83.2	11.6	3.2	
1 year	Female	0.0	3.8	81.8	12.3	2.1	0.491
	Male	0.4	1.6	83.1	12.2	2.8	
2 years	Female	0.0	1.5	77.3	18.2	3.0	0.906
	Male	0.0	1.9	78.8	15.9	3.4	
3 years	Female	0.0	5.2	83.3	9.8	1.7	0.951
	Male	0.0	4.9	82.0	11.7	1.5	
4 years	Female	0.0	1.9	83.0	14.3	0.8	0.019
	Male	0.0	0.7	77.2	20.5	1.6	
5 years	Female	0.0	1.7	84.0	8.7	5.6	0.013
	Male	0.0	1.3	83.4	12.9	2.4	
6 years	Female	0.0	0.0	83.3	12.0	4.7	0.051
	Male	0.0	1.5	83.4	10.6	4.5	
7 years	Female	0.0	0.0	82.7	13.5	3.8	0.465
	Male	0.0	0.0	83.5	11.3	5.2	
8 years	Female	0.0	0.0	83.3	11.6	5.2	0.382
	Male	0.0	0.3	81.0	14.6	4.2	
9 years	Female	0.0	0.0	81.3	14.5	4.2	0.439
	Male	0.0	0.0	81.5	12.6	5.9	
10 years	Female	0.0	0.0	81.6	13.5	4.9	0.943
	Male	0.0	0.0	82.4	12.7	4.9	
11 years	Female	0.0	0.0	82.3	14.2	3.5	0.862
	Male	0.0	0.0	83.5	13.5	3.0	
12 years	Female	0.0	0.0	82.2	14.6	3.3	0.057
	Male	0.0	0.0	82.9	11.4	5.7	
13 years	Female	0.0	0.0	81.4	13.3	5.3	0,071
	Male	0.0	0.0	81.4	15.7	2.8	
14 years	Female	0.0	0.0	81.4	13.9	4.8	0.795
	Male	0.0	0.0	82.9	12.9	4.2	
15 years	Female	0.0	0.0	81.4	14.0	4.6	0.569
	Male	0.0	0.0	82.5	12.1	5.5	
16 years	Female	0.0	0.0	82.3	13.6	4.2	0.903
	Male	0.0	0.0	81.4	13.9	4.7	
17 years	Female	0.0	0.0	84.7	8.6	6.6	0.055
	Male	0.0	0.0	82.9	12.6	4.5	
18 years	Female	0.0	0.0	83.1	12.9	4.0	0.272
	Male	0.0	0.0	78.6	16.5	4.9	

Table 4. Different BMI categories of severe thinness = (3SD below the mean); thinness = (between 2 and 3 SD below the mean); normal = (between 2SD below and 1 SD above the average); overweight = (between 1 and 2 SD above the average); obese = (2 SD or more above the average), in UAE children aged from 0–18 years divided according to age and sex.

linking head circumference to brain development[41–43]. At birth, the head circumference measurements were taken up to 24 h after birth which may have resulted in lower HC values due to the resolving of scalp edema, hence the apparent lower values. Our charts provide reference values specific to the UAE population, enabling early detection and intervention in cases of abnormal head growth.

HC measurement in early childhood/infancy reflects brain volume and growth due to the open cranial sutures and fontanelles. It can be a valuable tool to analyse brain growth and development in this age group[44,45]. Studies

Age(year)	Gender	BMI	Severe thinness (%)	Thinness (%)	Normal (%)	Overweight (%)	Obese (%)
0	Female	Prevalence UAE 2020 Cutoff points	0.00	0.20	82.80	12.10	4.90
		Prevalence UAE 1992 Cutoff points	22.70	23.80	40.60	6.80	6.00
1	Female	Prevalence UAE 2020 Cutoff points	0.00	3.80	81.80	12.30	2.10
		Prevalence UAE 1992 Cutoff points	0.00	0.00	30.10	40.30	29.70
2	Female	Prevalence UAE 2020 Cutoff points	0.00	1.50	77.30	18.20	3.00
		Prevalence UAE 1992 Cutoff points	0.50	1.00	57.10	18.70	22.70
3	Female	Prevalence UAE 2020 Cutoff points	0.00	5.20	83.30	9.80	1.70
		Prevalence UAE 1992 Cutoff points	0.00	0.00	33.90	43.70	22.40
4	Female	Prevalence UAE 2020 Cutoff points	0.00	1.90	83.00	14.30	0.80
		Prevalence UAE 1992 Cutoff points	5.20	11.10	53.20	17.00	13.40
5	Female	Prevalence UAE 2020 Cutoff points	0.00	1.70	84.00	8.70	5.60
		Prevalence UAE 1992 Cutoff points	6.10	11.10	53.40	13.70	15.60
6	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	83.30	12.00	4.70
		Prevalence UAE 1992 Cutoff points	5.80	10.10	55.20	9.20	19.70
7	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.70	13.50	3.80
		Prevalence UAE 1992 Cutoff points	1.90	5.30	52.60	10.30	29.80
8	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	83.30	11.60	5.20
		Prevalence UAE 1992 Cutoff points	0.00	0.70	56.40	16.00	26.80
9	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.30	14.50	4.20
		Prevalence UAE 1992 Cutoff points	0.00	2.10	50.70	11.70	35.50
10	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.60	13.50	4.90
		Prevalence UAE 1992 Cutoff points	0.00	0.80	41.20	19.60	38.40
11	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.30	14.20	3.50
		Prevalence UAE 1992 Cutoff points	0.00	1.10	53.00	11.20	34.60
12	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.20	14.60	3.30
		Prevalence UAE 1992 Cutoff points	0.00	0.50	56.70	16.10	26.70
13	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.40	13.30	5.30
		Prevalence UAE 1992 Cutoff points	0.00	0.20	58.10	14.00	27.80
14	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.40	13.90	4.80
		Prevalence UAE 1992 Cutoff points	0.00	0.00	52.60	13.90	33.50
15	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.40	14.00	4.60
		Prevalence UAE 1992 Cutoff points	0.00	0.70	57.10	10.50	31.70
16	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.30	13.60	4.20
		Prevalence UAE 1992 Cutoff points	0.00	0.00	65.30	13.80	20.90
17	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	84.70	8.60	6.60
		Prevalence UAE 1992 Cutoff points	0.00	0.00	67.00	12.60	20.40
18	Female	Prevalence UAE 2020 Cutoff points	0.00	0.00	83.10	12.90	4.00
		Prevalence UAE 1992 Cutoff points	0.00	0.00	66.10	16.90	16.90

Table 5. Difference between the prevalence of overweight and obesity in the present cohort and the 1992 cohort when taking the cut-off points from the 1992 data, in female children at different ages.

evaluating the utility of HC measurements in childhood have produced mixed results. Many studies suggest HC monitoring when the measurements are above + 2 SDs[44,46,47]. In children at risk, including those exposed to alcohol during prenatal period[48], born as a preterm[49,50] and having very low birth weight[51], HC was shown to be related to cognition/development. Similar findings have been reported from typically developing children with evidences from a large multinational LMIC community based birth-cohort study[52], and from cohort studies in India[53], UK[54], and Uruguay[55]. An Indian birth-cohort study showed HC at birth was related to learning, memory and storage and visuospatial abilities around 10 years of age[53]. There have been many publications showing an association of head circumference and intelligence, one of them being a recent systematic review[56]. It is also associated with better school performance, and smaller HC at 2 years of age is negatively associated with cognition at both 2 and 5 years of age. A positive correlation was found between head circumference and Bayley scores at 18 months, and also a positive correlation between head circumference at discharge and at 5 months with the three domains of the Bayley[57]. The Head Circumference charts do exist for children up to 18 years of age [eg. Royal Hospital for Sick Children, Glasgow[58]. Therefore, although for normally growing children there is no necessity to monitor HC growth, for others like children with craniosynostosis and other conditions with abnormally small or large heads there is, and therefore there is a need for reference HC values for every age.

The BMI and head circumference charts developed in this study serve as valuable tools for healthcare providers in monitoring the growth and development of UAE children. By comparing individual measurements

Age(year)	Gender	BMI	Severe thinness (%)	Thinness (%)	Normal (%)	Overweight (%)	Obese (%)
0	Male	Prevalence UAE 2020 Cutoff points	0.00	0.50	82.00	15.00	2.50
		Prevalence UAE 1992 Cutoff points	9.50	20.00	63.00	6.80	0.70
1	Male	Prevalence UAE 2020 Cutoff points	0.40	1.60	83.10	12.20	2.80
		Prevalence UAE 1992 Cutoff points	0.40	0.00	33.50	31.10	35.00
2	Male	Prevalence UAE 2020 Cutoff points	0.00	1.90	78.80	15.90	3.40
		Prevalence UAE 1992 Cutoff points	0.00	0.50	57.20	26.90	15.40
3	Male	Prevalence UAE 2020 Cutoff points	0.00	4.90	82.00	11.70	1.50
		Prevalence UAE 1992 Cutoff points	0.00	0.00	34.10	45.90	20.00
4	Male	Prevalence UAE 2020 Cutoff points	0.00	0.70	77.20	20.50	1.60
		Prevalence UAE 1992 Cutoff points	0.00	0.90	94.10	4.70	0.20
5	Male	Prevalence UAE 2020 Cutoff points	0.00	1.30	83.40	12.90	2.40
		Prevalence UAE 1992 Cutoff points	13.60	14.90	55.00	11.00	5.60
6	Male	Prevalence UAE 2020 Cutoff points	0.00	1.50	83.40	10.60	4.50
		Prevalence UAE 1992 Cutoff points	4.50	7.70	58.70	12.60	16.60
7	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	83.50	11.30	5.20
		Prevalence UAE 1992 Cutoff points	1.10	3.30	42.10	12.70	40.80
8	Male	Prevalence UAE 2020 Cutoff points	0.00	0.30	81.00	14.60	4.20
		Prevalence UAE 1992 Cutoff points	0.00	0.50	56.60	20.60	22.20
9	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.50	12.60	5.90
		Prevalence UAE 1992 Cutoff points	0.00	0.30	44.10	19.10	36.60
10	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.40	12.70	4.90
		Prevalence UAE 1992 Cutoff points	0.00	1.00	48.50	14.40	36.10
11	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	83.50	13.50	3.00
		Prevalence UAE 1992 Cutoff points	0.00	2.80	55.30	9.40	32.60
12	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.90	11.40	5.70
		Prevalence UAE 1992 Cutoff points	0.00	2.90	54.90	20.20	22.00
13	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.40	15.70	2.80
		Prevalence UAE 1992 Cutoff points	0.00	0.80	47.90	12.10	39.20
14	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.90	12.90	4.20
		Prevalence UAE 1992 Cutoff points	0.00	1.70	43.50	15.10	39.80
15	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.50	12.10	5.50
		Prevalence UAE 1992 Cutoff points	0.00	2.00	53.60	12.90	31.50
16	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	81.40	13.90	4.70
		Prevalence UAE 1992 Cutoff points	0.00	4.60	54.10	11.20	30.10
17	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	82.90	12.60	4.50
		Prevalence UAE 1992 Cutoff points	0.00	1.60	56.00	11.90	30.50
18	Male	Prevalence UAE 2020 Cutoff points	0.00	0.00	78.60	16.50	4.90
		Prevalence UAE 1992 Cutoff points	0.00	4.20	52.90	9.80	33.00

Table 6. Difference between the prevalence of overweight and obesity of the present cohort and the 1992 cohort when taking the cutoff points from the 1992 data, in male children at different ages.

to population norms, clinicians can identify children at risk of health problems or developmental delays and intervene early to optimize outcomes. These charts also facilitate discussions with parents and caregivers about healthy lifestyle habits and preventive measures, aligning with the goals of previous interventions aimed at reducing childhood obesity and promoting early childhood development[59,60].

Moving forward, efforts should focus on disseminating these charts widely among healthcare professionals in the UAE and integrating them into clinical practice guidelines. Continuous data collection and analysis are essential to ensure the relevance and accuracy of growth references in an evolving population. Future research could also explore the impact of socioeconomic and environmental factors on growth trajectories in the UAE context, informing targeted interventions to address health disparities and promote equitable health outcomes for all children.

Potential limitations of the study are reliance on sampling biases, and inherent measurement errors in BMI calculation. In a multi-centre study or a study involving multiple researchers, differences in how weight and height are measured could introduce inconsistencies in the data. In the present study, standardized protocols were followed to ensure that all participants were measured in the same way to minimize such errors. Sampling bias can affect the generalizability of the study's results. If the sample does not accurately reflect the broader population, the study's findings may not apply to children and adolescents in the UAE more generally, especially those from underrepresented or disadvantaged groups. We have minimised this potential limitation by the

rigorous multi-stage random sampling technique we used. Measurement errors can lead to inaccurate BMI values, which might result in incorrect conclusions about the nutritional status or growth trends in the study population. If BMI values are inaccurately measured, this could distort the comparison with other growth charts, making the BMI values in the present study appear higher or lower than they actually are. Again we used two separate trained individuals to measure the same child to minimise this limitation.

Data availability

Original data and materials are available with the authors YMA and MZ.

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Author contributions

YMA contributed to the conception and design of the work, obtaining research funds, analysis of data, training of research assistants, interpretation of data, and drafting and editing the manuscript. EMA contributed to the conception of the work, acquisition of data, and editing of the manuscript. MAA contributed to the conception and acquisition of data. AAS contributed to the acquisition of data and overall responsibility over one centre. MZ contributed to the conception of the work, analysis of data, interpretation of data, and revision of the manuscript. All authors reviewed the manuscript.

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Declarations

Competing interest

The authors declare no competing interests.

Ethical approval

Ethical approval was received from relevant Institutional Review Boards or Ethics Committees to ensure compliance with ethical guidelines governing human subjects research in accordance with the Declaration

of Helsinki. The Ministry of Health Ethics Committee, DHA Ethics Committee Dubai, Tawam Hospital Institutional Review Board, Al Ain, Kanad Hospital Ethics Committee, Al Ain, and Corniche Hospital Ethics Committee, Abu Dhabi gave their approval for the study.

Consent for publication

All authors consented to the publication.

Informed consent

Informed consent was obtained from participants or their legal guardians before data collection and measures were implemented to safeguard their privacy and confidentiality throughout the study duration.

Additional information

Correspondence and requests for materials should be addressed to Y.M.A.

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