

REGULAR ARTICLE

Growth of children in Greenland exceeds the World Health Organization growth charts

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Keywords

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ABSTRACT

Aim: Previous studies have found high rates of stunted linear growth in Greenlandic children. We measured growth patterns in Greenland and compared them with international growth charts.

Methods: The study cohort comprised 279 healthy children aged 6–10 years in 2012. They participated in two pregnancy and birth cohorts in Greenland and longitudinal growth data as birth was extracted from their medical records. Growth reference ranges were estimated with the lambda-mu-sigma (LMS) method and compared with growth charts from Denmark and the World Health Organization (WHO).

Results: The children's mean length, weight and head circumference were significantly larger than the WHO growth charts ($p < 0.001$). We found that 21–28% of the children aged zero to one years exceeded the WHO growth chart for length by more than two standard deviations. For weight and head circumference, 9–16% of the children aged 0–10 years and 9–11% of the children from zero to two years exceeded the WHO charts by more than two standard deviations. The Danish references were exceeded to a lesser degree.

Conclusion: This study showed that the growth of Greenlandic children up to 10 years was no longer stunted. Major determining factors suggested are genetic admixture, maternal overweight, changes in nutrition and improved health.

INTRODUCTION

The children of the indigenous Inuit people of Greenland, Northern Canada and parts of Alaska have previously been characterised with stunted linear growth. Based on data collected from 1928 to 1997, Inuit children were characterised as shorter but with a similar weight to European or continental US children (1,2). Despite this, no specific growth charts for Inuit children have ever been published and current data for international comparisons are missing.

Long-term trends of increasing growth across generations have been observed worldwide and have been attributed to a number of factors, including improved nutrition and healthcare. Based on the assumption that children have similar growth patterns when they are raised in healthy and

Abbreviations

BMI, Body mass index; CLEAR, The climate changes, environmental contaminants and reproductive health cohort; ICD-10, International Classification of Diseases 10th edition; Ivaq, The Greenlandic Inuit child cohort; LMS, Lambda-mu-sigma; SDS, Standard deviation score; SD, Standard deviation; WHO, World Health Organization.

Key notes

- Previous studies have found high rates of stunted linear growth in Greenlandic children and this study compared growth of 279 healthy children with World Health Organization (WHO) and Danish references.
- The overall linear growth, weight and head circumference of the children exceeded the WHO growth standards but were closer to the Danish charts.
- Major determining factors suggested are genetic admixture, maternal overweight, changes in nutrition and improved health.

unconstrained environmental conditions, the World Health Organization (WHO) has introduced universal growth standards for children from birth to five years. These standards were based on data from healthy, breastfed, well-off children born to non-smoking mothers from six countries (3). A WHO growth reference for children 5–19 years was created using data from the US National Center for Health Statistics from 1977 (4). Over the past decade, the WHO growth curves have been fully or partly adopted by more than 100 countries, including Denmark (5). However, Danish and Swedish growth charts are commonly used in Greenland. Compared to European national references, the WHO growth standards and references have lower means and lower normal ranges or cut-offs that typically define abnormal growth (6–10).

The Danish growth references for individuals aged 0–20 years from 2014 identified a secular increase in final height of 1.4 cm for boys and 2.9 cm for girls since 1982. Furthermore, Danish children were, on average, shown to be taller, heavier and with a larger head circumference when they were compared to the WHO growth standards or references (7,8).

The aim of this study was to examine growth from birth to 10 years of age in Greenlandic children and to compare the growth of these children with the Danish and WHO growth charts.

PATIENTS AND METHODS

Study population and data collection

The children in the study sample were selected from two pregnancy and birth cohort studies in Greenland. The first was the Greenland Inuit Child Cohort (Ivaaq) of 400 children founded by the National Institute of Public Health, Center for Health Research in Greenland, Denmark, in 1999 (11). The second was the Climate Changes, Environmental Contaminants and Reproductive Health Cohort (CLEAR) of 600 children founded by the European Commission's 7th Framework Programme in 2002 (12). All 383 children who were included in these two cohort studies and came from the capital of Nuuk or the town of Ilulissat were identified at the age of 6–10 years in 2012. Of these, 21 could not be identified with certainty and were excluded and 51 children participated in both cohorts, leaving 311 unique children eligible for the analysis. The anthropometric measurements, demographic characteristics and medical histories of these children were retrieved from the medical records of the Queen Ingrid's Hospital and the primary healthcare clinic in Nuuk, from the Regional Hospital in Ilulissat and from the records of visiting nurses in both Nuuk and Ilulissat. Records from the child psychiatry healthcare system were not included. The following data were collected: town of residence, gender, gestational age, length measured lying down or height measured standing upright, weight and head circumference at birth and at each following contact visit, number of hospitalisations and outpatient consultations in the secondary healthcare sector and visits to primary healthcare clinics between birth and

15 October 2012. The type of feeding was not registered in the records, as data were not systematically recorded. For each hospitalisation and outpatient consultation, a diagnosis according to the WHO International Classification of Diseases 10th edition (ICD-10) was retrospectively recorded. Primary healthcare visits were categorised as illness-related, recommended preventive health check-ups or immunisation visits. We selected a random sample of every sixth child listed in the study sample and retrospectively coded each illness-related contact with primary healthcare using the ICD-10 classification. Based on all hospitalisations, outpatient consultations and primary healthcare visits, eight children with diseases known to affect growth such as chronic anaemia, cardiac or lung diseases and endocrine disorders were excluded, leaving 303 children in the study sample. None of the children had a diagnosis of precocious puberty, defined as breast Tanner stage 2+ in girls before eight years, or genital stage 2+ or testicles volume of 4 mL+ in boys before nine years. Finally, in accordance with the WHO criteria (4), 24 children born before a gestational age of 37, or after a gestational age of 42 weeks, were excluded, leaving a final sample of 279 children. Nationwide population data on Greenlandic children were obtained from governmental statistics (13).

To avoid overrepresentation of measurements from children with frequent healthcare contacts, we only included one measurement of length, weight and head circumference per month during the first year and only one measurement for every six months from the age of one year onwards in the analyses. Due to the retrospective study design, it was not possible to assess inter-observer or intra-observer measurement variations or to document the equipment used to measure length, height and weight. A common plastic centimetre tape measure was commonly used for head circumference measurements.

Data analysis

Because the contacts and measurements were not systematically scheduled at fixed ages, we retrospectively assigned the data into the following age clusters: birth, zero to three months, three to six months, six months to one year, one to two years, two to five years and five to ten years, in which the age intervals did not include the lowest value. For example, the age cluster one to two years ranged from one year up to two years, but did not include the children that were precisely one year old. These age clusters were a trade-off between providing enough detail and having a sufficiently large number of children for meaningful group comparisons. The intervals were more narrow during the first two years of life, when growth changes dramatically, and wider during childhood, when growth changes little. Length/height, weight, body mass index (BMI, kg/cm²) and head circumference were converted to z-scores, standard deviation scores (SDS), according to the current Danish growth references from 2014 (7,8) and the WHO growth standards for children up to five years of age and references for children from the age of five years onwards (3,4). The results were reported as the means and standard deviations

(SD) of the z-scores, with a 95% confidence interval within age groups. The proportion of Greenlandic children below -2 SD and above +2 SD according to the Danish and the WHO growth charts were calculated. Differences between the groups were examined with Pearson's chi-square test or two-sample *t*-tests as appropriate. Differences between the study sample and the Danish and WHO growth charts were tested within age groups with a one-sample *t*-test. When we compared the data with a reference chart, a z-score mean of zero, an SD of one and a 2.3% prevalence above and below the ±2 SD normal range were expected.

Finally, we estimated the growth reference curves of length/height, weight, BMI and head circumference by age in Greenlandic children with the Lambda-Mu-Sigma (LMS) method (14). The growth curves only included girls up to eight years of age and boys up to nine years of age, in order to limit growth to the pre-pubertal period. Longitudinal measurements were treated as independent cross-sectional observations, which were previously shown to have little effect on the estimated reference curve.

The statistical analysis was performed with SPSS statistics, version 22 (IBM Corp, Armonk, NY, USA) and R version 3.2.5 (R Foundation for Statistical Computing, Vienna, Austria).

Ethics

The study complied with the Declaration of Helsinki and was approved by the Greenlandic Committee on Health Research Ethics (ref. no. 2012-069391), the Danish Data Protection Agency (J. no. 2012-41-0735) and the Agency for Health and Prevention in Greenland.

RESULTS

We included 279 children from the two pregnancy and birth cohorts in the analysis: 132 were girls and 147 were boys and 175 lived in Nuuk and 104 in Ilulissat. The final cohort included 6% of the 4453 Greenlandic children born in the period 2002–2006. The median gestational age at birth was

39 weeks, the mean was 39.2 weeks and the range was 37–42 weeks. The mean birth length and weight were 51.6 cm and 3.7 kg in girls and 52.3 cm and 3.7 kg in boys. Data on head circumference were scarce at birth and above two years of age and that is why these age groups were not included in the analyses. In total, we recorded 178 hospitalisations, 459 outpatient consultations and 9944 visits to the primary healthcare sector, which was equal to an annual rate of 0.1 hospitalisations, 0.2 outpatient consultations and 4.1 visits to the primary healthcare sector per child. The mean age at 15 October 2012 was 8.8 years. After we excluded 494 over-represented contacts, the number of available measurements was 1888 for length/height (52% boys), 2035 for weight (53% boys) and 808 for head circumference (54% boys). The number of children and available measurements by age group and gender is listed in Table 1. The total number of measurements per child, after excluding extra contacts, ranged from 1 to 16. We were able to retrieve at least one measurement (range 1–9 measurements) before the age of one year in 272 children, then up to six measurements before the age of five years in 216 children and up to five measurements between 5 and 10 years of age in 258 children.

Overall, the Greenlandic boys were significantly taller and had a larger head circumference than the girls (*p* < 0.05). Weight was not significantly different between the girls and boys at birth, or between 2 and 10 years, but the boys were heavier than the girls between birth and two years (*p* < 0.05). Figure 1 shows the mean z-scores of length/height, weight, BMI and head circumference in the combined genders in relation to the WHO and the Danish growth charts. Separate data on the girls and boys are given in Tables S1a–S1b.

Compared to the WHO growth standards, the Greenlandic children had a significantly +1.28 SDS higher length at birth (Fig. 1). This pattern persisted during the first years of life, from +0.98 SDS in children aged zero to three months to +0.39 SDS when they reached the age of one to two years (*p* < 0.001 within each age group). The mean height normalised towards the WHO growth standard after

Table 1 Number of children in each age group and number of measurements for girls, boys and combined in each age group

Age group (years)	Children in each age group	Number of measurements in each age group											
		Length/height			Weight			BMI			Head circumference		
		Girls	Boys	Total	Girls	Boys	Total	Girls	Boys	Total	Girls	Boys	Total
Birth	264	120	141	261	122	142	264	120	141	261	0	0	0
0–0.25	235	162	189	351	185	220	405	162	187	349	118	150	268
0.25–0.50	209	148	163	311	162	182	344	148	163	311	118	134	252
0.50–1	155	86	102	188	98	121	219	86	101	187	62	79	141
1–2	181	96	91	187	100	95	195	95	91	186	64	57	121
2–5	142	91	92	183	93	96	189	91	90	181	13	10	23
5–10	258	194	213	497	202	217	419	193	212	405	0	3	3
Total	279*	897	991	1888	962	1073	2035	895	985	1880	375	433	808

*A total of 279 children aged 6–10 years in 2012 were included in the study sample.

Age intervals do not include the lowest value. For example, the day of a child's first birthday is included in 0.5–1.0 and not in 1.0–2.0.

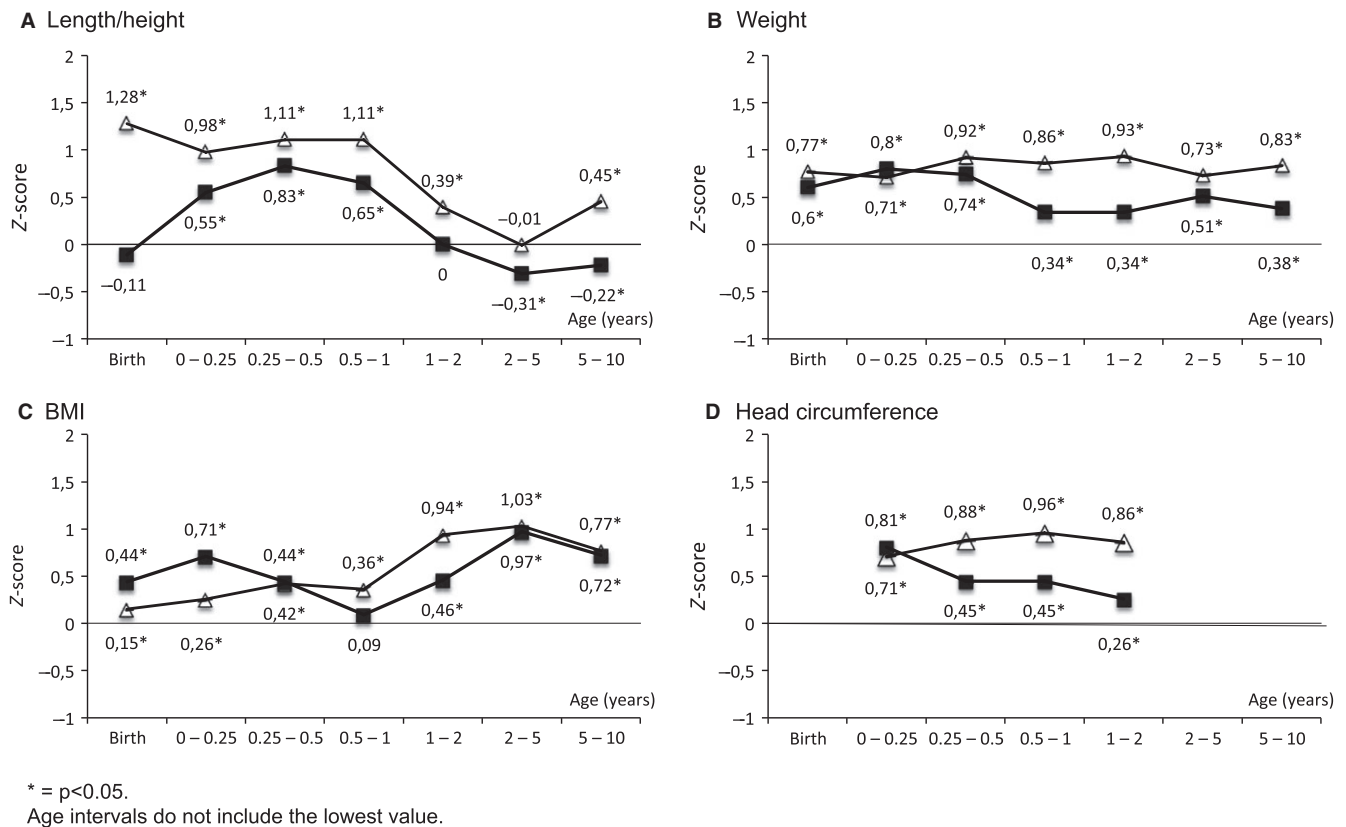


Figure 1 Z-scores of length/height, weight, BMI and head circumference in Greenlandic children according to the WHO (open triangles) and the Danish (closed squares) growth charts (both genders).

two years of age but was again +0.45 SDS higher when compared to the WHO references in the age range 5–10 years ($p < 0.001$). Compared to the current Danish growth references, length was comparable at birth, at -0.11 SDS, higher during the first year of life, with a maximum of $+0.83$ SDS between three and six months, and close again to the mean between one and two years of age and slightly below the mean from two years onwards, at -0.31 to -0.22 SDS ($p < 0.001$ within each age group). Weight was significantly and consistently higher at birth and through infancy and childhood when compared to the WHO growth charts, at $+0.71$ to $+0.93$ SDS ($p < 0.001$ within each age group), and the Danish growth charts, at $+0.34$ to $+0.80$ SDS ($p < 0.001$ within each age group), but the differences with the Danish references were smallest from six months onwards. The head circumference was also significantly larger compared to the WHO growth standards and the Danish growth references ($p < 0.001$ within each age group). As observed for weight, the difference in head circumference with the Danish reference was smaller in older children.

Tables 2–3 show the prevalence of children above $+2$ SD and below -2 SD, when compared to the WHO and the Danish growth data, respectively. The same analysis, but stratified by gender and including 95% confidence intervals, is presented in Tables S2a–S3b.

Compared to the WHO standards, 30.0% of the girls and 26.4% of the boys had a birth length that was above $+2$ SD, whereas only 0.8% of the girls and 0.7% of the boys had a birth length that was below -2 SD. This trend was maintained during the first years of life. For weight, 11.5% of the girls and 9.3% of the boys were above $+2$ SD and only 0.8% of the girls and 1.4% of the boys were below -2 SD of the WHO standards at birth. This trend continued up to 10 years of age. BMI showed a better agreement with the WHO standards at birth for both genders, with 2.7% below -2 SD and 2.3% above $+2$ SD. However, the prevalence of a BMI above $+2$ SD increased considerably thereafter, with a maximum of 18.7% in girls aged two to five years and 16.5% in boys aged one to two years. Correspondingly, the prevalence of a BMI below -2 SD decreased to 0.0% from six months of age onwards in girls and from one year of age onwards in boys. Head circumference was above $+2$ SD relative to the WHO standards in 7.6% of the girls and 10.0% of the boys aged zero to three months. The prevalence below -2 SD reached and remained 0.0% by three months in boys and by six months in girls. The prevalence of children with a head circumference above $+2$ SD ranged from 6.0 to 15.2% in boys and was up to 11.9% in girls. In general, observed differences were much smaller when length/height, weight and head circumference were compared with the Danish growth references.

Table 2 Percentage of Greenlandic children (both genders) above +2 SD according to the WHO and the Danish growth standards or references

Age (years)	Length/height			Weight			BMI			Head circumference		
	n	WHO	DK	n	WHO	DK	n	WHO	DK	n	WHO	DK
Birth	261	28.1	2.7	264	10.3	11.4	261	2.3	5.7	0	–	–
0–0.25	351	21.1	9.7	405	9.1	11.4	349	4.0	10.6	268	9.0	7.5
0.25–0.50	311	25.7	14.5	344	16.0	11.9	311	10.3	9.6	252	8.7	2.4
0.50–1	188	21.8	10.1	219	11.9	3.7	187	5.3	4.3	141	11.3	2.8
1–2	187	8.0	2.7	195	12.3	3.6	186	16.1	8.6	121	7.4	4.1
2–5	183	1.1	1.1	189	8.5	8.5	181	16.0	17.1	23	–	–
5–10	497	3.7	0.5	419	10.0	7.9	405	12.3	12.3	3	–	–

WHO = World Health Organization; DK = Denmark; n = Number of observations.
Age intervals do not include the lowest value.

Table 3 Percentage of Greenlandic children (both genders) below –2 SD according to the WHO and the Danish growth standards or references

Age (years)	Length/height			Weight			BMI			Head circumference		
	n	WHO	DK	n	WHO	DK	n	WHO	DK	n	WHO	DK
Birth	261	0.8	3.8	264	1.1	1.1	261	2.7	1.5	0	–	–
0–0.25	351	1.7	2.3	405	1.5	1.0	349	2.6	1.7	268	1.5	1.1
0.25–0.50	311	0.6	1.3	344	0.0	0.3	311	1.0	1.3	252	0.4	0.4
0.50–1	188	0.5	0.5	219	0.0	1.4	187	1.1	4.3	141	0.0	0.0
1–2	187	0.0	0.5	195	0.0	3.1	186	0.0	2.7	121	0.0	0.8
2–5	183	0.5	3.8	189	0.5	0.5	181	0.0	1.1	23	–	–
5–10	497	0.0	2.0	419	0.0	0.5	405	0.0	0.2	3	–	–

WHO = World Health Organization; DK = Denmark; n = Number of observations.
Age intervals do not include the lowest value.

Growth reference charts for length/height, weight, BMI and head circumferences in Greenlandic children were estimated using the same data as specified above, with over-represented contacts removed. Length/height and head circumference by age were normally distributed, whereas weight and BMI were increasingly positively skewed with age. The pre-pubertal growth reference charts for girls up to eight years and boys up to nine years of age are shown in Figures 2–5. Printable growth charts are provided in Figures S1–S4 and the corresponding LMS reference data for length/height, weight, BMI and head circumference in girls and boys are listed in Tables S4a–S7b.

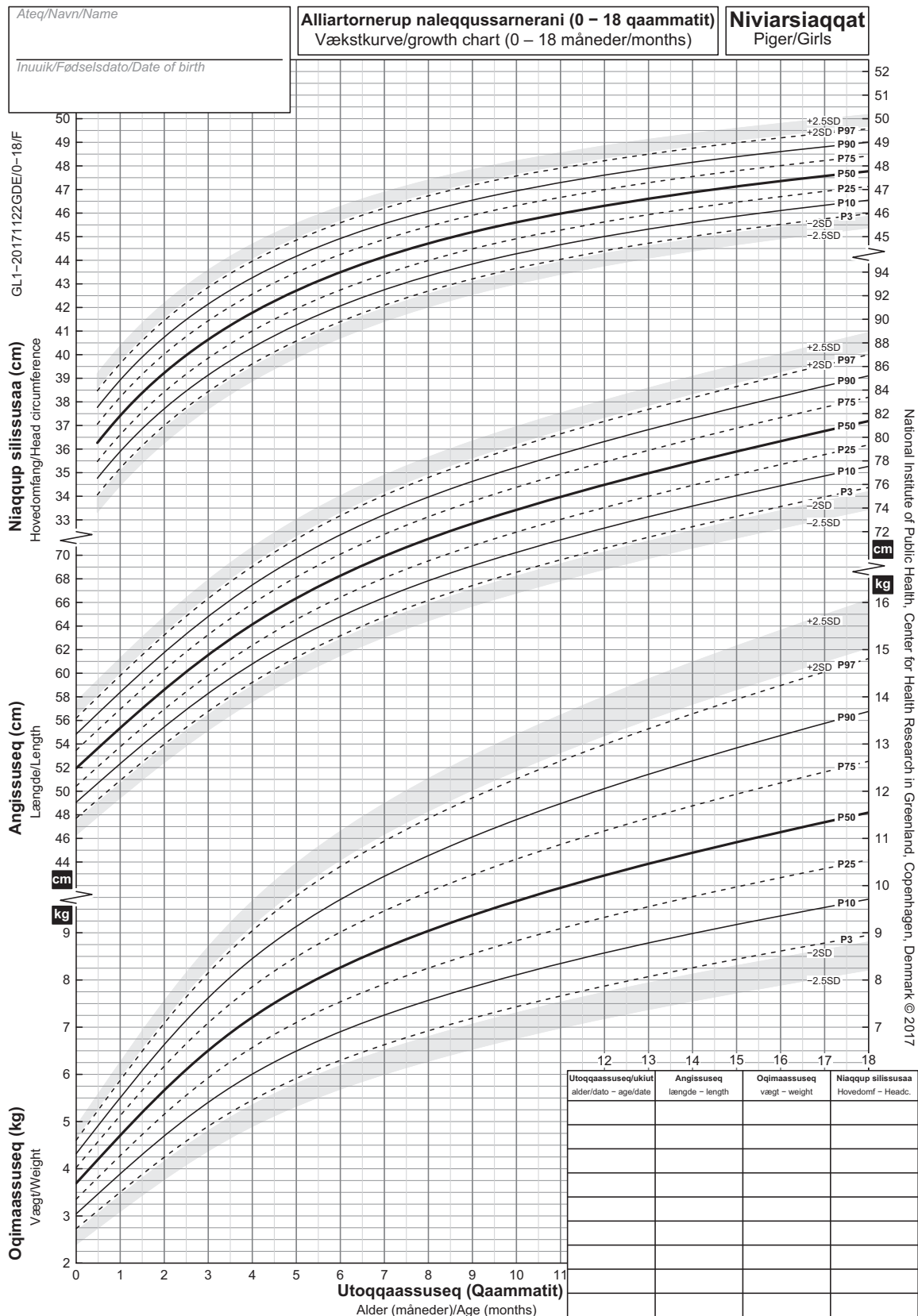
DISCUSSION

This study was the first to compare the growth of Greenlandic children with the WHO standards and references and with the new Danish growth references from 2014. The linear growth of children in Greenland, from the capital Nuuk and one of the major towns, Ilulissat, exceeded the WHO standards up to the age of two years and the WHO references from 5 to 10 years of age. Moreover, Greenlandic children had a higher weight during the most of their childhood and a larger head circumference up to two years of age when compared to the WHO standards. When we used the WHO growth standards and references, a higher

than expected proportion of children were above +2 SD for length during the first 12 months, for weight up to 10 years, for BMI from three months to 10 years and for head circumference from zero to two years. The anthropometric parameters were generally in better agreement with the recent Danish growth references.

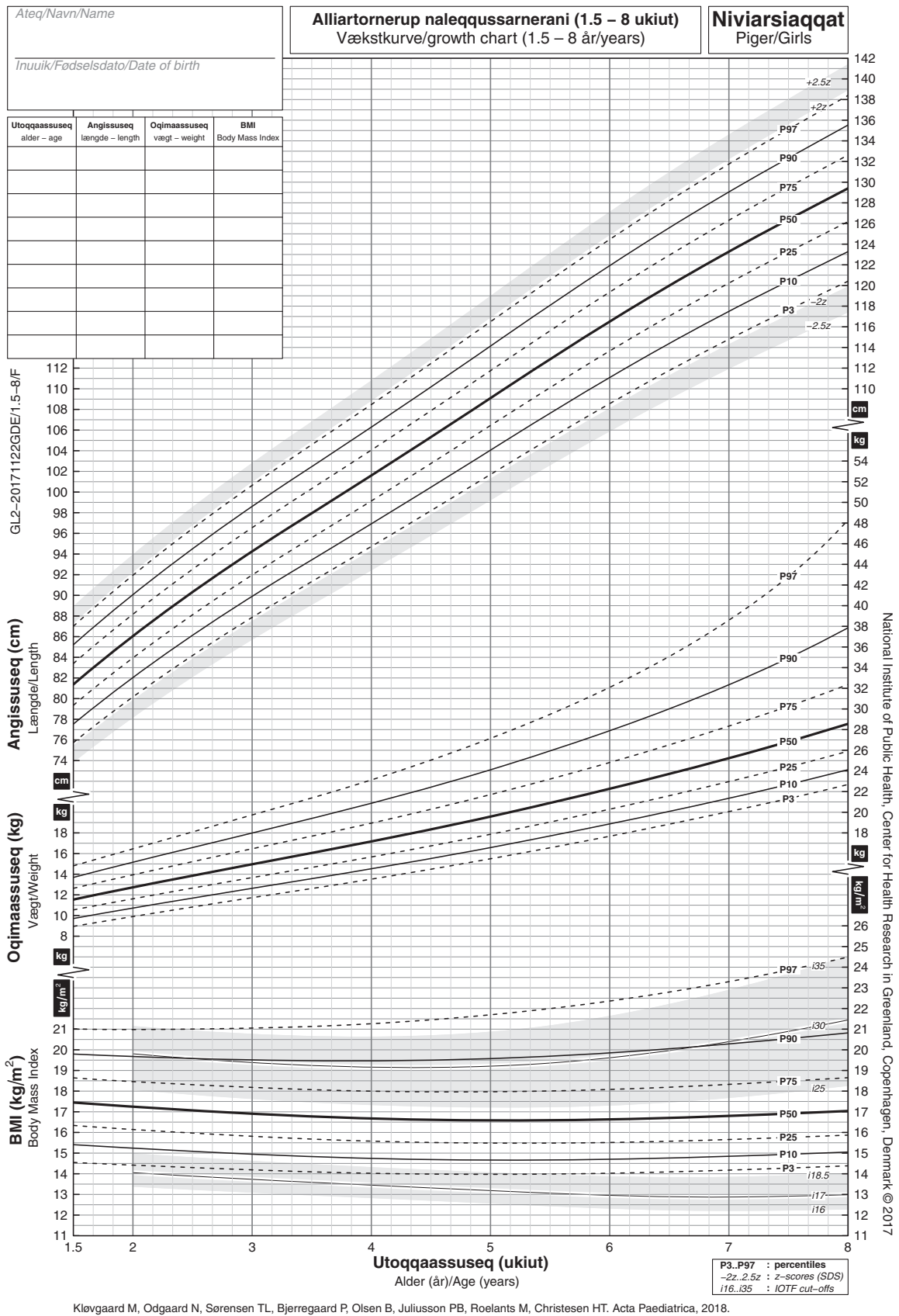
In the clinical setting, the growth of an individual child should always be interpreted in the context of parental height, nutrition, general health status and previous growth data. However, up-to-date growth references are an important framework for the clinical assessment of growth and also provide information about historical trends and differences in growth between populations of children from different countries.

The growth of children in Greenland in 2012 differed from older Inuit child growth studies, which usually found stunted linear growth (1,2). A strong long-term trend of increased height among preschool Inuit children was previously described by Galloway et al. (15), who compared growth among 658 Greenlandic children up to five years of age with the American Centers for Disease Control and Prevention 2000 reference charts, and could no longer detect the specific Inuit growth patterns described in earlier studies. Also, in a cross-sectional study from 1996–1997 on 589 healthy Greenlandic children aged 5–19 years, Becker-Christensen (16) found growth to be comparable with that



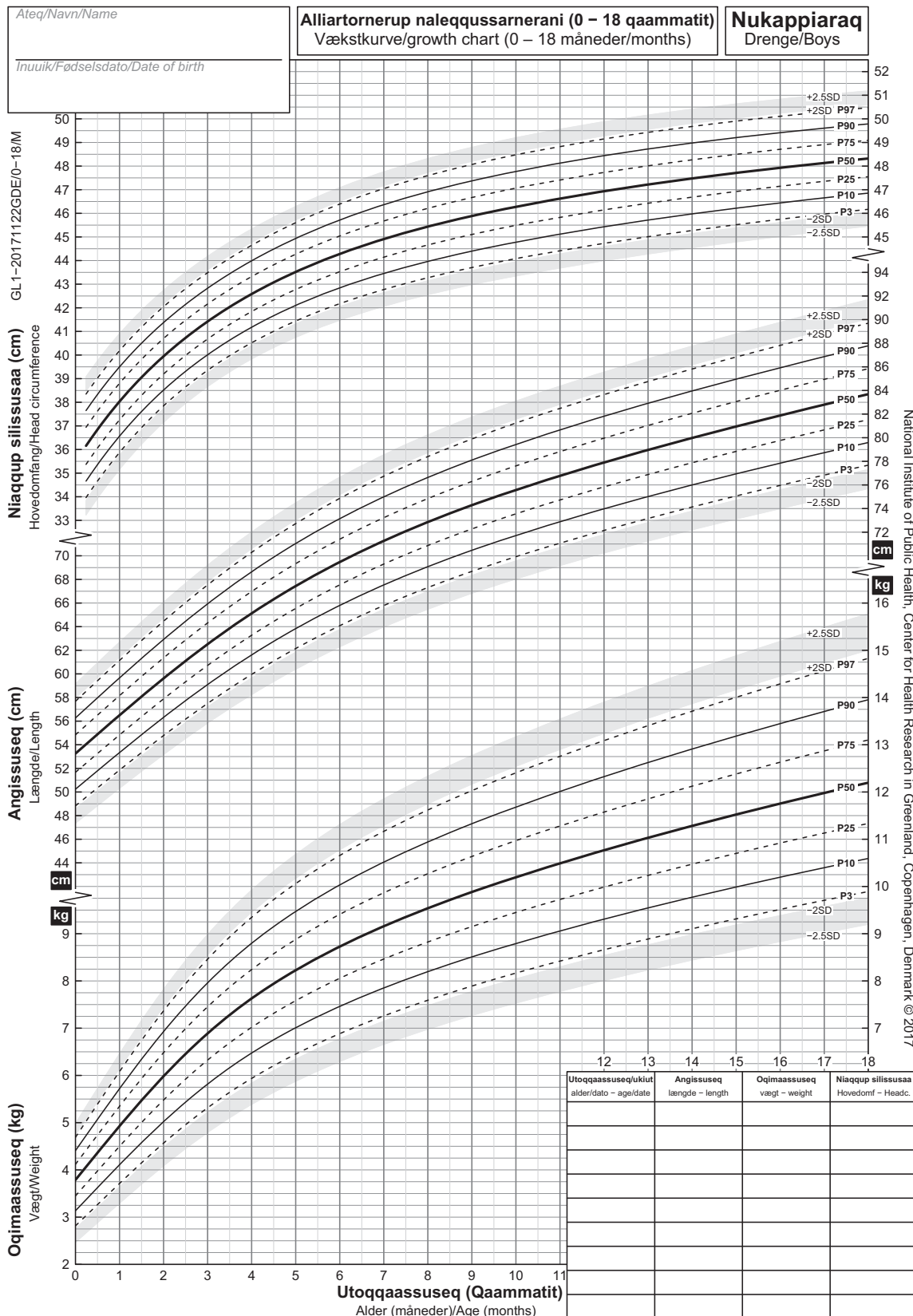
Kløjgaard M, Odgaard N, Sørensen TL, Bjerregaard P, Olsen B, Juliusson PB, Roelants M, Christesen HT. Acta Paediatrica, 2018.

Figure 2 Growth reference for Greenlandic girls: Length, weight and head circumference in girls from birth to 18 months.



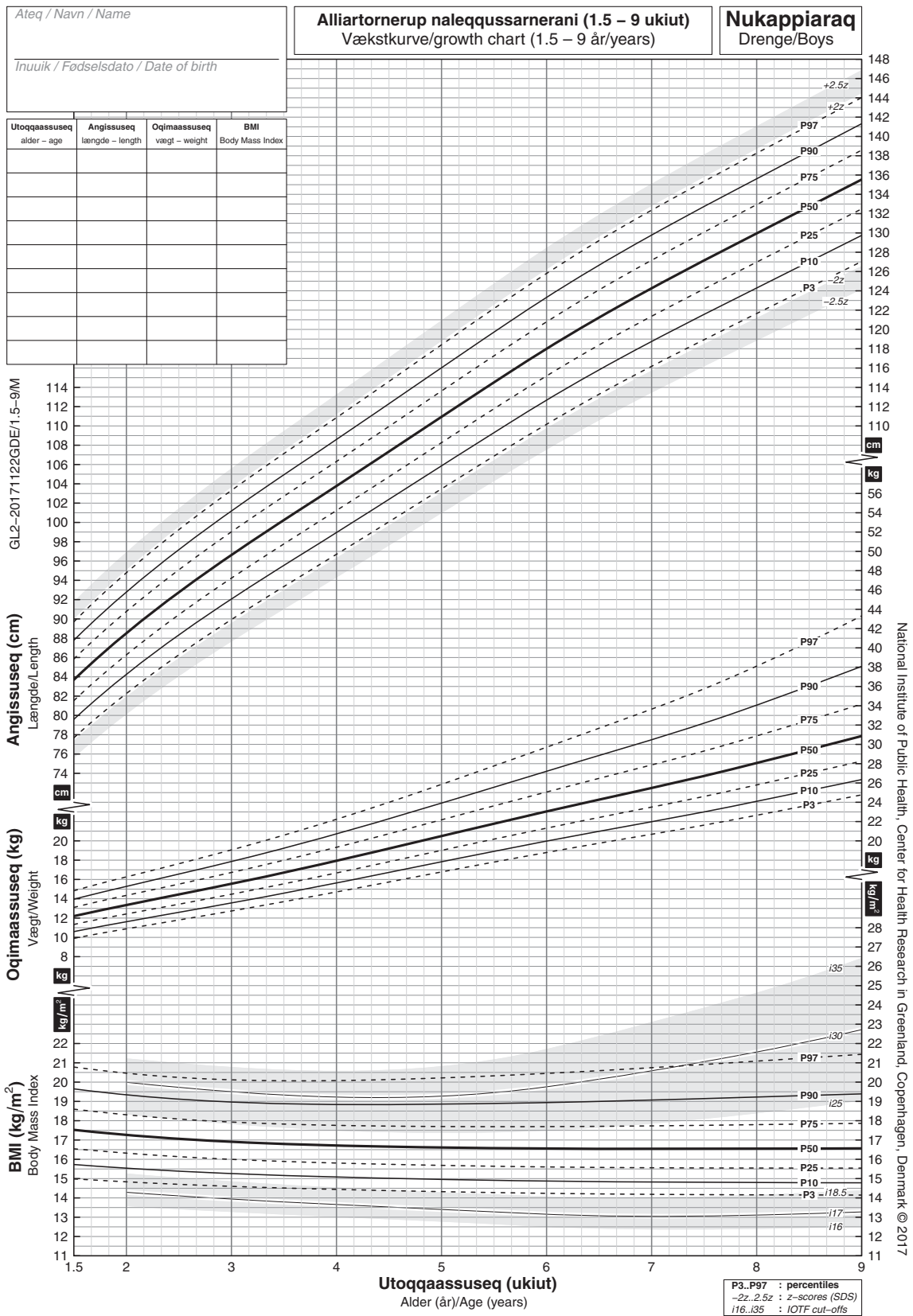
Kløvgaard M, Odgaard N, Sørensen TL, Bjerregaard P, Olsen B, Juliusson PB, Roelants M, Christesen HT. Acta Paediatrica, 2018.

Figure 3 Growth reference for Greenlandic girls: Length/height, weight and BMI in girls from 1.5 to 8 years.



Kløggaard M, Odgaard N, Sørensen TL, Bjerregaard P, Olsen B, Juliusson PB, Roelants M, Christesen HT. Acta Paediatrica, 2018.

Figure 4 Growth reference for Greenlandic boys: Length, weight and head circumference in boys from birth to 18 months.



Kløvgaard M, Odgaard N, Sørensen TL, Bjerregaard P, Olsen B, Juliusson PB, Roelants M, Christesen HT. Acta Paediatrica, 2018.

Figure 5 Growth reference for Greenlandic boys: Length/height, weight and BMI in boys from 1.5 to 9 years.

of Danish children until the age of 11 years in girls and 14 years in boys. Thereafter, growth stagnation was observed, which resulted in an average final height that was 7 cm shorter in girls and 5 cm shorter in boys. At 14 years of age, the standing height of the Greenlandic children had increased by 10 cm compared to data recorded 30 years earlier. The mean weight was higher in Greenland and menarche occurred three months earlier compared to Danish girls. The cross-sectional design could not take a possible ongoing and fast generational trend into account, which could mean that final height might have normalised as well in later birth cohorts. Our cohort provided a longitudinal reference, but without information on growth in puberty or final height. In a study that compared the growth in 555 Inuit children from Alaska in 2001 with the growth references of the US National Center for Health Statistics and the American Centers for Disease Control and Prevention, Indorf et al. (17) found a significantly larger head circumference, higher weight-for-age and higher weight-for-height between 1 and 12 months. This corresponded with the findings in our study, even though we compared our cohort with the WHO standards for children below five years of age.

Growth is multifactorial and the increased growth in Greenlandic children might have several explanations, including genetic admixture, maternal overweight and obesity, reduction in maternal smoking, changes in nutrition and improved overall health as discussed in the following sections.

Genetics and pregnancy factors

The Inuit genome has been found to have a genetic association with lower height and a genetic adaption to a diet rich of protein and fatty acids (18). However, genetic admixture with Caucasians has become so widespread that on average 27% of the modern Inuit genome in Greenland is of Scandinavian origin (19).

The higher birthweight and birth length compared to the WHO data and higher birthweight compared to the Danish data suggests differences in maternal and pregnancy-related factors. Maternal obesity and gestational weight gain are well-known causes of macrosomia at birth, whereas maternal smoking is associated with smaller size at birth, but with increased infant weight at follow up (20,21). In the CLEAR cohort, the average pre-pregnancy BMI was 25 kg/m² (12), suggesting that maternal overweight and obesity could be leading causes of large infant sizes at birth. In the CLEAR cohort, 73% of the mothers smoked before pregnancy (12) and in the Ivaq cohort, 44.1% of the mothers smoked during pregnancy (11). Despite the high prevalence of maternal smoking, the large birth size suggested a stronger effect of maternal overweight and obesity than smoking in these cohorts.

Nutrition and health

During the study period, the Greenlandic health authorities recommended that children should be exclusively breastfed or formula-fed up to six months of age and that they should

continued to be breastfed or formula-fed along with the introduction of complementary food up to one year of age. At six months of age, 61% of the children in the Ivaq cohort were still being breastfed, while 38% were breastfed for a shorter duration (11). Only 1% of the children in the Ivaq cohort were not breastfed at all. The CLEAR cohort did not contain data on breastfeeding, but we assume an equally high percentage as breastfeeding was a typical local custom not specific to the Ivaq cohort. Although comparisons of growth in breastfed and formula-fed infants may be hampered by differences in baseline characteristics between groups, formula-fed infants typically have a higher weight-for-height or BMI in low-income countries (22). As we observed both a higher length and a higher weight in infancy compared to the WHO standards for breastfeeding infants, this could be due to tracking of the larger size and weight at birth, rather than the impact of a sub-optimal feeding pattern.

The traditional Greenlandic diet, with a high content of n-3 fatty acids, had changed to a more westernised diet among many families (23). A lower consumption of traditional food and more frequent intake of sweets and soft drinks is now more widespread, especially in children living in the Greenlandic towns (24). In 2012, the prevalence of obesity among children aged three to five years, using a BMI above the 95th percentile of the American Centers for Disease Control and Prevention BMI reference, was 13% in Nuuk and 25% in the other Greenlandic towns and villages (15). Obesity in the adult Greenlandic population has also increased and figures published in 2014 showed these were 18% in men and 25% in women (25). We found increased weight, height and BMI among Greenlandic children that were compatible with nutrition-driven changes.

Regarding general health, the children in the study sample had an average of 3.6 annual contacts with the healthcare sector due to diseases, predominantly respiratory diseases. This was in agreement with another study of disease frequency and healthcare contacts that focused on the children in the Ivaq and CLEAR cohorts (26). During the same period, Danish children had an average of six contacts with the healthcare sector per year, with respiratory diseases being among the most frequent reasons for hospital admissions (26). Hence, we found no evidence of a higher disease burden in the Greenlandic children in this study sample compared to Denmark, which may also contribute to the comparable linear growth.

National versus WHO growth curves

The growth of Greenlandic children was, in general, closer to the Danish references than to the WHO charts. Although the WHO growth standards for children of up to five years of age are prescriptive, a higher number of Greenlandic children may be misclassified if those are used rather than the Danish references. This may have an impact on diagnosis and clinical decision-making, in areas such as thrive, obesity, short or tall stature and macrocephaly and microcephaly. The inclusion criteria in our study were comparable with the Danish 2014 references, except for

ethnicity (7), and the constructed growth curve of the Greenlandic children should therefore be considered as a reference. A noticeable difference to the WHO growth standards was the high prevalence of smoking in Greenlandic mothers. However, despite the fact that maternal smoking has a well-established impact on restricting growth the Greenlandic children were taller and heavier at birth when compared to the WHO standards. Yet, maternal obesity was also prevalent in our cohorts and tracking a larger size at birth well into infancy cannot be excluded. Furthermore, maternal BMI is a strong predictor of offspring BMI and overweight (27).

These findings highlight the potential impact of maternal weight status and the importance of considering this factor in future studies that aim to establish normative curves. In the light of the global trends of increasing overweight and obesity, normal ranges for maternal pre-pregnancy BMI and gestational weight gain may be added to the list of inclusion criteria that define optimal and unconstrained environmental conditions for growth and development. The current universal WHO growth standard may, therefore, already need to be updated with the inclusion of mothers with a normal BMI and to take into account the generational trends in countries that have recently experienced improvements in living conditions. This is because optimal growth seems to require more than one generation of beneficial circumstances to fully exploit the growth potential (7,28).

Others have found that updated national curves in European countries also have higher reference values compared to the WHO, especially for height and head circumference (7–10). In particular, the updated Danish growth references from 2014 showed an increase in final height compared to previous references (7,8).

The LMS reference curves for Greenlandic children may be valuable for comparisons among Inuit children, but the high prevalence of maternal and childhood overweight warrants caution, especially for weight and BMI. The areas that delineate a normal BMI, overweight and obesity on the charts are, however, extrapolated percentiles of the International Obesity Task Force BMI reference curve that correspond to a BMI of 25 kg/m² for overweight and 30 kg/m² for obesity at 18 years (29).

The head circumference of the Greenlandic infants was larger compared to the WHO standards. In a systematic review of variations in human growth, Natale and Rajagopalan found that head circumference varied far more than height and weight among different populations and that approximately 50% of the included populations had a mean head circumference that exceeded the WHO standard mean, even though a similar measuring technique was used (6). The head circumference in our cohort was more similar to the Danish data and a common plastic centimetre tape measure was used in both countries. Nevertheless, the Greenlandic children's head circumference was larger at up to one year of age when it was compared to the Danish references. This could be attributed to maternal overweight, which has also been observed for weight and height at up to

one year of age. Indeed, maternal obesity was independently and positively associated with larger head circumferences in their offspring in a Danish study from 2017 (30). This further stresses the need to exclude mothers with overweight and obesity when constructing a revised global growth standard for children.

Strengths and limitations

The strengths of our study included the longitudinal sample, the relatively large number of participants taking part in Inuit research, the prospectively sampled cohort data for the mothers and the review of all medical files to collect data on growth and health. The limitations included the retrospective collection of data, which did not allow us to document equipment, procedures or measurements variations within or between the observers. Due to the size of the study sample, which was based on data from Nuuk and Ilulissat, our findings may not be representative for other towns or settlements in Greenland, Canada or Alaska. Furthermore, the lack of systematically collected data on pubertal development, tempo and growth and the absence of data on final height data call for further follow-up studies.

CONCLUSION

This first comparison of linear growth of Greenlandic children up to 10 years of age with the WHO and Danish growth curves, showed that the growth of Greenlandic children was no longer stunted, contrary to previous reports. Compared to the WHO growth curves, the children were significantly taller for most ages were heavier up to the age of 10 years and had a larger head circumference from zero to two years. Correspondingly, more children were classified above +2 SD and fewer below -2 SD, when they were compared to the WHO growth curves. Agreement was usually better with the Danish growth references from 2014, which to some extent might be explained by the fact that these are more recent than the WHO growth charts. Maternal overweight and obesity seemed to be of high importance, stressing the need to include maternal BMI in future growth studies. Beside maternal overweight, potential explanations for the increased height, weight and head circumference in Greenlandic children included genetic admixture, nutrition-driven changes and improved health-care. The use of our proposed Greenlandic growth reference curves warrants caution, especially regarding overweight and obesity.

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CONFLICT OF INTEREST

The authors have no conflict of interests to declare.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the Supporting Information section at the end of the article:

Table S1a[b] Mean (SD) length/height, weight, BMI and head circumference and the corresponding mean (SD) z-scores according to the WHO growth standard (0–5 years)

or reference (5–10 years) and the Danish growth references in Greenlandic girls [boys].

Table S2a[b] Percentage (95% confidence interval) of girls [boys] above +2 SD according to the WHO and the Danish growth standards/references.

Table S3a[b] Percentage (95% confidence interval) of girls [boys] below –2 SD according to the WHO and the Danish growth standards/references.

Table S4a[b] Reference data (LMS parameters) and percentiles 3–97 of length/height in Greenlandic girls from 0–8 years [boys from 0–9 years].

Table S5a[b] Reference data (LMS parameters) and percentiles 3–97 of weight in Greenlandic girls from 0–8 years [boys from 0–9 years].

Table S6a[b] Reference data (LMS parameters) and percentiles 3–97 of the body mass index (BMI) in Greenlandic girls from 0–8 years [boys from 0–9 years].

Table S7a[b] Reference data (LMS parameters) and percentiles 3–97 of head circumference in Greenlandic girls [boys] from 0.25–2 years.

Figure S1 Length, weight and head circumference in girls from birth to 18 months.

Figure S2 Length/height, weight and BMI in girls from 1.5–8 years.

Figure S3 Length, weight and head circumference in boys from birth to 18 months.

Figure S4 Length/height, weight and BMI in boys from 1.5–9 years.