

# Mowat-Wilson Syndrome: Growth Charts

**Ivan Ivanovski**

Azienda Unita Sanitaria Locale di Reggio Emilia <https://orcid.org/0000-0002-0113-783X>

**Olivera Djuric**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Serena Broccoli**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Stefano Giuseppe Caraffi**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Accorsi Patrizia**

Azienda Socio Sanitaria Territoriale degli Spedali Civili di Brescia

**Margaret P Adam**

University of Washington

**Kristina Avela**

Yliopistopainon kirjapaino

**Magdalena Badura-Stronka**

Uniwersytet Medyczny imienia Karola Marcinkowskiego w Poznaniu

**Allan Bayat**

Syddansk Universitet

**Jill Clayton-Smith**

Manchester University NHS Foundation Trust

**Isabella Cocco**

Azienda Socio Sanitaria Territoriale degli Spedali Civili di Brescia

**Duccio Maria Cordelli**

Universita degli Studi di Bologna Scuola di Medicina e Chirurgia

**Goran Cuturilo**

Univerzitet u Beogradu

**Veronica Di Pisa**

Universita degli Studi di Bologna Scuola di Medicina e Chirurgia

**Juliette Dupont Garcia**

Universidade de Lisboa Faculdade de Medicina

**Roberto Gastaldi**

Istituto Giannina Gaslini

**Lucio Giordano**

Azienda Socio Sanitaria Territoriale degli Spedali Civili di Brescia

**Andrea Guala**

Ospedale Casteli

**Christina Hoei-Hansen**

Rigshospitalet

**Mie Inaba**

aichi human service center

**Alessandro Iodice**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Jens Erik Klint Nielsen**

Sjaellands Universitetshospital Roskilde

**Vladimir Kuburovic**

Medicinski fakultet Univerzitet u Beogradu

**Brissia Lazalde-Medina**

Instituto Mexicano del Seguro Social

**Baris Malbora**

Turkiye Cumhuriyeti Saglik Bakanligi Izmir Tepecik Egitim ve Arastirma Hastanesi

**Seiji Mizuno**

Aichi Human Service Center

**Oana Moldovan**

Centro Acedemico de Medicina de Lisboa

**Rikke S Møller**

danish epilepsy centre

**Petra Muschke**

Otto-von-Guericke-Universitat Magdeburg Medizinische Fakultat

**Valeria Otelli**

Agenzia di Tutela della Salute di Bergamo

**Chiara Pantaleoni**

Fondazione IRCCS Istituto Neurologico Carlo Besta

**Carmelo Piscopo**

Azienda Ospedaliera di Rilievo Nazionale Antonio Cardarelli

**Maria Luisa Poch-Olive**

Instituto Universitario de Ciencias de la Salud Fundacion Hector A Barcelo Facultad de Medicina - Sede La Rioja

**Igor Prpic**

Sveuciliste u Rijeci Medicinski fakultet

**Marin Reina Purificacion**

Universitat de Valencia

**Federico Raviglione**

Aziende Socio Sanitaria Territoriale Rhodense

**Emilia Ricci**

Universita degli Studi di Bologna Scuola di Medicina e Chirurgia

**Emanuela Scarano**

Universita degli Studi di Bologna Scuola di Medicina e Chirurgia

**Graziella Simonte**

Universita degli Studi di Catania

**Robert Smigiel**

Uniwersytet Medyczny im Piastow Slaskich we Wroclawiu

**George Tanteles**

cyprus institute of neurology and genetics

**Luigi Tarani**

Universita degli Studi di Roma La Sapienza

**Aurelien Trimouille**

Centre Hospitalier Universitaire de Bordeaux

**Elvis Terci Valera**

Sao Paolo University

**Samantha Schrier Vergano**

virginia medical school

**Karin Writzl**

Univerza v Ljubljani

**Bert Callewaert**

Universiteit Gent

**Salvatore Savasta**

Universita degli Studi di Pavia Facolta di Medicina e Chirurgia

**Maria Elisabeth Street**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Lorenzo Iughetti**

Universita degli Studi di Modena e Reggio Emilia - Sede di Reggio Emilia

**Sergio Bernasconi**

Universita degli Studi di Parma

**Paolo Giorgi Rossi**

Azienda Unita Sanitaria Locale di Reggio Emilia

**Livia Garavelli (✉ [livia.garavelli@ausl.re.it](mailto:livia.garavelli@ausl.re.it))**

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**Research**

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# Abstract

**Background:** Mowat–Wilson syndrome (MWS; OMIM #235730) is a genetic condition caused by heterozygous mutations or deletions of the *ZEB2* gene. It is characterized by moderate-severe intellectual disability, epilepsy, Hirschsprung disease and multiple organ malformations of which congenital heart defects and urogenital anomalies are the most frequent ones. To date, a clear description of the physical development of MWS patients does not exist. The aim of this study is to provide up-to-date growth charts specific for infants and children with MWS. Charts for males and females aged from 0 to 16 years were generated using a total of 2,865 measurements from 99 MWS patients of different ancestries. All data were collected through extensive collaborations with the Italian MWS association (AIMW) and the MWS Foundation. The GAMLSS package for the R statistical computing software was used to model the growth charts. Height, weight, body mass index (BMI) and head circumference were compared to those from standard international growth charts for healthy children.

**Results:** In newborns, weight and length were distributed as in the general population, while head circumference was slightly smaller, with an average below the 30<sup>th</sup> centile. Up to the age of 7 years, weight and height distribution was shifted to slightly lower values than in the general population; after that, the difference increased further, with 50% of the affected children below the 5<sup>th</sup> centile of the general population. BMI distribution was similar to that of non-affected children until the age of 7 years, at which point values in MWS children increased with a less steep slope, particularly in males. Microcephaly was sometimes present at birth, but in most cases it developed gradually during infancy; many children had a small head circumference, between the 3<sup>rd</sup> and the 10<sup>th</sup> centile, rather than being truly microcephalic (at least 2 SD below the mean). Most patients were of slender build.

**Conclusions:** These charts contribute to the understanding of the natural history of MWS and should assist pediatricians and other caregivers in providing optimal care to MWS individuals who show problems related to physical growth. This is the first study on growth in patients with MWS.

## Background

Mowat-Wilson syndrome (MWS; OMIM #235730) is a rare autosomal dominant disorder caused by haploinsufficiency in the *ZEB2* gene located on chromosome 2. It is characterized by distinctive facial features, moderate-to-severe intellectual disability, epilepsy, Hirschsprung disease and multiple congenital anomalies, including genital anomalies, congenital heart defects, agenesis of the corpus callosum and eye defects. Since the first report in 1998, more than 350 individuals have been described in the literature [1-8].

The incidence of MWS is estimated to be 1:50.000-70.000 live births [9].

Several studies have reported the presence of short stature in MWS patients. In a recent article [7], which included the clinical data of 87 patients with MWS, we demonstrated that basic growth parameters - weight, length or height, body mass index (BMI), head circumference - are often normal at birth, but have

a tendency to descend well below the normal range in childhood and later on. These results urged us to extend our study and construct growth charts specific for MWS.

Growth charts specific for a disease are fundamental instruments in order to monitor growth and observe deviations from normal patterns [10-20]. They allow clinicians to advise parents concerning growth expectations for their children, and they can be very useful even in a group of patients for whom growth anomalies are not the most severe problem. Moreover, these charts describe the natural history of the disease.

The aim of this study was to provide a growth reference for MWS patients. We collected the measurements of 99 MWS patients from 20 countries, and developed specific growth charts that describe the natural history of height, weight, BMI and head circumference in MWS.

## Methods

### Study population

Growth data of MWS patients previously published by our workgroup were incorporated into this study [7]. An invitation to participate in the study, explaining its purpose and design, was sent to all our colleagues who had a previous history of publications on MWS. Furthermore, the Italian Mowat-Wilson Association (AIMW) and the MWS Foundation forwarded the invitation to their members. To those who agreed to participate, we sent a specially designed questionnaire where they could insert the length/height, weight and head circumference measurements of patients at different ages. The collected data were reviewed and assembled in a password-protected database. Whenever we detected inconsistencies, probable errors or missing data, we contacted the family/referring doctor for corrections and further information, if needed. Only individuals with both clinical and molecular confirmation of the disease were included in the study. Two patients were excluded since the causative *ZEB2* variant could not be found despite molecular testing.

A total of 20 nationalities were represented in this study: 38 Italian patients, 16 from the USA, 7 from Poland, 6 from Japan, 5 from Denmark, 4 from Spain, 4 from the UK, 3 from Portugal, 3 from Finland, 2 from Croatia, 2 from Serbia, and 1 each from Albania, Brazil, Chile, Cyprus, France, Germany, Mexico, Turkey and Ukraine. None of the affected individuals originated from a consanguineous family. One Italian family comprised two affected siblings. None of the patients had ever been treated with growth hormone.

A total of 99 patients were included in the study, 53 females and 46 males, born between 1986 and 2016. A total of 2,865 measurements were available: 1,220 data points from 46 males and 1,645 data points from 53 females. These patients had a mean age of 12 years (range 4-20 years) in males and 13 years (range 3-23 years) in females at the time of assessment.

A total of 1,013 height measurements (573 for females, 440 for males), 1,110 weight measurements (631 for females, 479 for males), and 742 head circumference measurements (441 for females, 301 for males) were available. We gathered measurements from at least 2 time points in 97 patients, and from more than 4 time points in 89 patients. For each patient we had an average of 10.39 (SD 6.52) height measurements, 11.37 (SD 6.77) weight measurements, and 7.64 (SD 5.76) head circumference measurements (Additional file 1- Table 1).

Due to limited data availability, no growth curves could be generated for individuals with MWS past the age of 16 years.

Data from 1986 to 2019 were included. Height, weight and head circumference parameters were analyzed from birth until 23 years of age, both for males and females. BMI was calculated from these data, using the formula  $BMI = \text{mass}(\text{kg}) / (\text{height}(\text{m}))^2$ .

Distribution centiles for birth, weight, length and head circumference were computed including preterm and at term newborns, i.e. from 32 to 42 gestational weeks (mean 36.5), and presented separately for males and females.

The data after birth were divided into different age and sex groups, with 1-month intervals during the first year of life, 3-month intervals during the 2<sup>nd</sup> and 3<sup>rd</sup> years of life, and 6-month intervals between the 4<sup>th</sup> and 23<sup>rd</sup> years of life.

Our growth charts were compared with the reference percentiles for anthropometric measurements in healthy children provided by the Centers for Disease Control and Prevention (CDC), with a few exceptions: for neonatal anthropometric assessment we referred to the Italian Neonatal Study (INeS) growth charts, data on head circumference in males and females aged between 3 and 16 years were compared with the Tanner reference percentiles, and standard deviations of the head circumference in males and females aged between birth and 18 years were compared with the Nellhaus reference standard deviations [21-28].

## Statistical analysis

The growth charts were developed using the Generalised Additive Model for Location Scale and Shape (GAMLSS) [29,30] package for the R statistical computing software [31].

Centile estimation of anthropometric data  $Y$  (weight, length, BMI and head circumference) for any given age was:

$$Y \sim D(\mu, \delta, \nu, \tau)$$

$$g_1(\mu) = h_1(x)$$

$$g_2(\delta) = h_2(x)$$

$$g_3(v)=h_3(x)$$

$$g_4(\tau)=h_4(x)$$

$$x=age^\xi$$

where the distribution  $D$  represents the best general probability (density) function according to Akaike Information Criterion (AIC) and  $\mu$  the first parameter of the distribution (usually location),  $\delta$  the second parameter of the distribution (usually scale, coefficient of variation),  $v$  the third parameter of the distribution (usually shape, e.g. skewness),  $\tau$  the fourth parameter of the distribution (usually shape, e.g. kurtosis).

The  $g()$  functions represent appropriate link functions, the  $h()$  are non-parametric smoothing functions and  $\xi$  is a power transformation of age (Additional file 2 Table 2).

The more traditional LMS method developed by Cole and Green [32] can be fitted within this framework by assuming that the response variable has a Box-Cox Cole and Green distribution. [33,34] Additional file 2 Table 2 describes the model specifications by anthropometric measure and sex. The Q test was conducted to evaluate the fit of the model [35].

The estimated centiles by age and sex were converted back to Excel to create charts for each anthropometric variable, including the reference CDC growth charts for healthy children.

## Results

### Length, Weight and Head Circumference at Birth

Information on weight at birth was available for 47 females and 35 males. Information on length at birth was available for 47 females and 31 males. Information on head circumference at birth was available for 40 females and 26 males.

The average gestational age was 39 weeks, with a range between 32 and 42. Gestational age in MWS was completely comparable to that of the general population.

Weights at birth were found to be within the normal range in both males and females. The average weight in males was 3,288 g, with a range between 1,850 g and 4,500 g; the average weight in females was 3,340 g, with a range between 1,620 g and 4,060 g. The birth weight of all males was between the 2<sup>nd</sup> and 100<sup>th</sup> centiles for gestational age (mean 51<sup>st</sup> centile); the females' birth weight was between the 3<sup>rd</sup> and 100<sup>th</sup> centiles (mean 54<sup>th</sup> centile).

Length at birth was within the normal range for the vast majority of patients, both males and females. The average birth length in males measured 50 cm, with a range between 43 and 56 cm (range 2<sup>nd</sup> to 99<sup>th</sup>

centile, mean 44<sup>th</sup> centile). The average birth length in females was 49.1 cm, with a range between 41 and 54 cm (range <1<sup>st</sup> to 100<sup>th</sup> centile, mean 53<sup>rd</sup> centile).

Despite the fact that in both sexes the average head circumference at birth was within the normal range, most patients were under the 50<sup>th</sup> centile, with mean values at the 27<sup>th</sup> centile for males and 31<sup>st</sup> for females. In males, the mean was 33.2 cm, with a range between 28.5 and 36 cm (<1<sup>st</sup> to 96<sup>th</sup> centile); in females, the mean was 33.7 cm, with a range between 28.5 and 36 cm (<1<sup>st</sup> to 100<sup>th</sup> centile).

## **Length and height**

The mean number of longitudinal measurements per patient in males was 9.56 (SD 5.51). For 45 patients we had at least 2 measurements, and for 40 patients we gathered more than 4 measurements.

The mean number of longitudinal measurements per patient in females was 11.00 (SD 7.11). For 53 patients we had at least 2 measurements, and for 48 patients we gathered more than 4 measurements.

Up to the age of 2 months, the length of both males and females was within, or just below, the normal range. Subsequently, height in males began to increase more slowly. A significant reduction in the slope of the growth curves was noted after 7 years of age, as the height of boys affected by MWS became even more distant from the reference curves of the general population (Fig.1 and Additional file 3 Fig. RD1).

Mean height for male patients at the age of 9 years was 121 cm (<3<sup>rd</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 133 cm) and for female patients was 123.8 cm (3<sup>rd</sup> -5<sup>th</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 130 cm).

In females, from 2 months of age, height had a slower increase as in males, and subsequently diverged even further from the reference curves of the general population. A significant reduction in the slope of the growth charts was noted after 11 years of age, much later than in males. At this age, females affected by MWS became noticeably distant from the reference curves of the general population, but were slightly less distant than males (Fig.2 and Additional file 4 Fig. RD2).

We were not able to extend the growth charts over the age of 16 years due to the limited availability of measurements after this age. Furthermore, it is not yet possible to calculate the final height because MWS has only relatively recently been described and the data on adolescent and young adult patients is still very limited.

## **Weight and Body mass index**

The mean number of weight measurements per patient in males was 10.41 (SD 5.67). For 45 patients we had at least 2 measurements and for 41 patients we gathered more than 4 measurements.

The mean number of weight measurements per patient in females was 12.07 (SD 7.41). For 52 patients we had at least 2 measurements and for 50 patients we collected more than 4 measurements.

At age 0 to 36 months, compared to the reference group, the growth curves for weight were slightly lower than normal in both genders. Mean weight for male patients at age 5 years and 6 months was 16.800 kg (10<sup>th</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 19.500 kg) and for female patients was 15.400 kg (10<sup>th</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 19 kg).

After this age the growth charts flatten out considerably when compared to the normal reference group (Fig.3-4, Additional file 5 Fig.RD3, Additional file 6 Fig. RD4).

At the age of 16 years both male and female patients were considerably lighter (males: mean 48 kg 5<sup>th</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 61 Kg; females: mean 39 kg <3<sup>rd</sup> percentile, mean reference group at 50<sup>th</sup> percentile: 54 Kg). Most patients were of slender build, with normal body proportions.

BMI in the age range 0 to 6 years was slightly lower with respect to the normal reference group. Mean BMI for male patients at 6 years of age was 15 kg/m<sup>2</sup> (mean reference group: 15.4 kg/m<sup>2</sup>) and for female patients was 14.9 kg/m<sup>2</sup> (mean reference group: 15.3 kg/m<sup>2</sup>). Thereafter, between the ages of 6 and 16 years, the curve for BMI flattened out significantly in both genders, but in males the shift of the curve towards lower values was more pronounced and occurred earlier, already at the age of 7 years, while in females it became significant after the age of 9 years (Fig.5).

BMI of male patients aged 16 years (mean 17.2 kg/m<sup>2</sup>) was significantly lower compared to the reference group (mean 20.5 kg/m<sup>2</sup>). BMI of female patients aged 16 years (mean 17.1 kg/m<sup>2</sup>), was significantly lower compared to the reference group (mean 20.5 kg/m<sup>2</sup>).

## **Head circumference**

The mean number of head circumference measurements per patient in males was 6.54 (SD 4.79). For 39 patients we had at least 2 measurements, and for 31 patients we collected more than 4 measurements.

The mean number of head circumference measurements per patient in females was 8.54 (SD 6.23). For 51 patients we had at least 2 measurements, and for 41 patients we collected more than 4 measurements.

At birth, head circumference differed only slightly from the reference group in both genders. Indeed, during the first months of life, most measurements were between the 3<sup>rd</sup> and the 25<sup>th</sup> percentile of the curves for healthy controls. This changed significantly after 1 year of age: MWS patients had a significantly smaller head circumference between the ages of 1 and 2 years. Between the ages of 2 and 3 years the curves flattened out even more and the head circumference was significantly smaller compared to healthy controls.

Mean head circumference for male patients at age 3 years was 47 cm (5<sup>th</sup> percentile, <-2SD, mean reference group at 50<sup>th</sup> percentile: 50 cm) and for female patients was 46 cm (5<sup>th</sup> percentile, -2SD, mean

reference group at 50<sup>th</sup> percentile: 49 cm) (Fig. 6-7 and Additional file 7 Fig. RD5 Additional file 8 Fig.RD6).

It should be noted that not all children were microcephalic (at least 2 SD below the mean).

The curves for males and females continued to flatten out in the following age ranges, up to the age of 16 years. Adolescent male patients at the age of 16 years had a mean head circumference of 52 cm (<3<sup>rd</sup> percentile <-2 SD), the females had a mean head circumference of 49.8 cm (<3<sup>rd</sup> percentile <-2SD) (Fig.8-9).

## Discussion

Various genetic disorders are characterized by growth abnormalities. Specific growth charts developed for these conditions are useful for the clinical follow-up of these patients [10-20].

In this study, charts for height, weight, BMI and head circumference were created using a sample of 99 patients whose clinical diagnosis of MWS had been confirmed through genetic or cytogenetic testing.

Typically, children affected by MWS had normal length and weight at birth, and then showed a growth delay over time. The average head circumference was already slightly smaller than in the general population at birth (3<sup>rd</sup>-25<sup>th</sup> percentile) and showed a further delay during growth, leading to a mean head circumference in MWS patients below the 3<sup>rd</sup> centile of the general population. These results indicate that intrauterine growth retardation in MWS is not a consistent finding in terms of length and weight, and only plays a minor role in terms of head circumference.

In the males, since the age of 2 months, the slope of the growth curves for length underwent an initial decrease. A significant further decrease was noted after 7 years of age, as the values for height became markedly distant from the reference curves of the general population. In females we observed a similar tendency, but the delay in the height growth chart took place considerably later, after 11 years of age.

Through these length, weight and head circumference growth charts we demonstrate that postnatal growth retardation in MWS becomes evident after the second month of life, is quite pronounced after six months and, after 1 year of age, growth flattens out even further. Males tend to be thinner than females and they also tend to have a similar head circumference when compared to females.

In addition, we observed the absence of the growth spurt during adolescence, as has already been observed in other genetic diseases, such as Turner syndrome and *SHOX*-related conditions [36-37], but we do not yet have useful and sufficient data to calculate a final height, because the definition of MWS is quite recent and known adult individuals are still rare.

We also assessed BMI in MWS patients. BMI of male patients aged 16 years (mean 17.2 kg/m<sup>2</sup>) was found to be significantly lower when compared to the reference group (mean 20.5 kg/m<sup>2</sup>). BMI of female

patients aged 16 years (mean 17.1 kg/m<sup>2</sup>) was significantly lower compared to the reference group (mean 20.5 kg/m<sup>2</sup>).

A limitation of the present study is the small absolute number of available subjects, which slightly reduces the precision of the growth curves, particularly in the adolescence age range. Nevertheless, this cohort includes a large portion of all well-described MWS patients in the world, and including only MWS patients with a confirmed *ZEB2* defect significantly increases the reliability of our results by excluding any misclassification of cases.

## Conclusions

The growth charts we prepared for height, weight, BMI and head circumference may be used to assess the growth of MWS children compared to the general population.

Specific growth charts can be useful for pediatricians and clinicians in evaluating growth-related issues and in providing optimal care to MWS individuals. Furthermore, they contribute to our understanding of the natural history of MWS.

The growth charts presented here may be put to good use all over the world, however they ought to be used carefully in MWS individuals with other ethnic backgrounds. In circumstances such as these, it is essential to consider variations according to the area of origin.

## Abbreviations

MWS: Mowat-Wilson syndrome; BMI: Body mass index; SD: Standard deviation; AIMW: Italian Mowat-Wilson syndrome association.

## Declarations

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### AVAILABILITY OF DATA AND MATERIALS

The dataset is summarized in the additional files. The raw data used during the current study are available from the corresponding author upon reasonable request.

## **AUTHORS' CONTRIBUTIONS**

Il and SGC made substantial contributions to conception, design, analysis and interpretation of data; were involved in drafting the manuscript and revising it critically for important intellectual content; OD, SB and PGR were involved in statistical drafting of the manuscript, analysis and interpretation of the data; PA, MPA, KA, MBS, AB, JCS, IC, DMC, GC, VDP, JDG, RG, LG, AG, CHH, MI AI, JEKN, VK, BLM, BM, SM, OM, RSM, PM, VO, CP, CP, MLPO, IP, MRP, FR, ER, ES, GS, RS, GT, LT, AT, ETV, SSV, KW, BK and SS made substantial contributions to acquisition of data; MES, LI and SB were involved in drafting the manuscript and revising it critically for important intellectual content; LG made substantial contributions to conception and design and interpretation of data; was involved in drafting the manuscript and revising it critically for important intellectual content. All authors read and approved the final manuscript.

## **ETHICS APPROVAL AND CONSENT TO PARTICIPATE**

With resolution of the General Manager n. 0252 of 03.10.2017 was issued the authorization to start the study, pursuant to art. 7 of the L.R. n. 9/2017. In the session of 13.09.2017, the Provincial Ethics Committee issued its favorable opinion, as per note n. 89486 of 26.09.2017.

## **CONSENT FOR PUBLICATION**

Not applicable.

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## Additional Files

Additional file 1: Table 1 - Number of measurements for male and female patients for height, weight and head circumference in relation to the age groups.

Additional file 2: Table 2. Model specification parameters by anthropometric measures and sex.

Additional file 3: Fig. RD1. Raw data of length and height (cm) for males showing the construction of the charts with individual data points.

Additional file 4: Fig. RD2. Raw data of length and height (cm) for females showing the construction of the charts with individual data points.

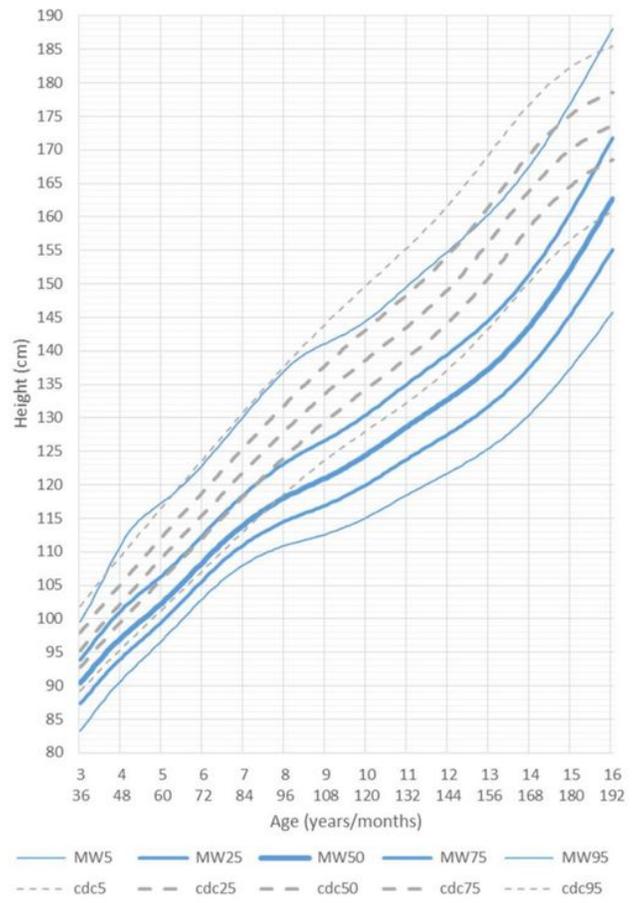
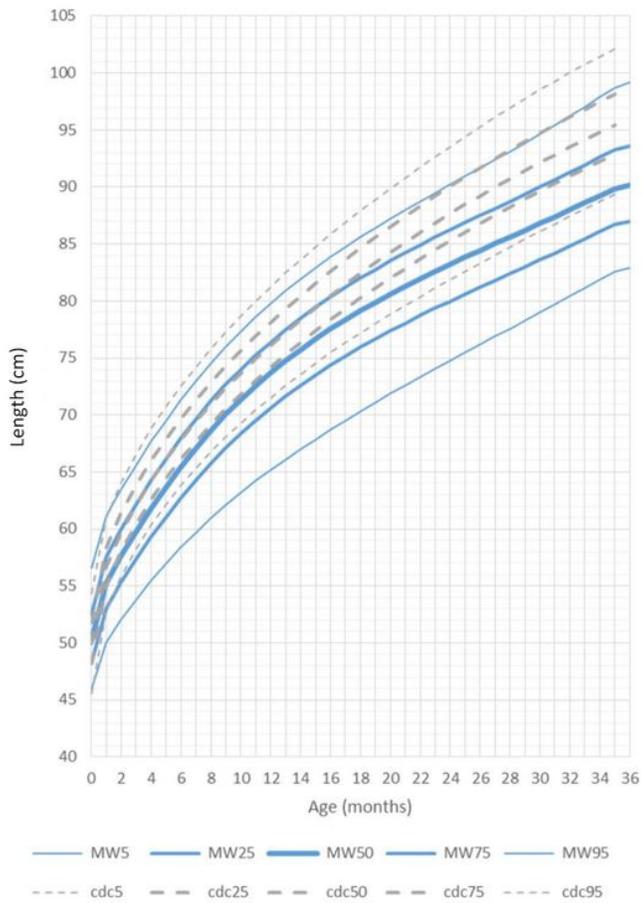
Additional file 5: Fig. RD3. Raw data of weight (Kg) for males showing the construction of the charts with individual data points.

Additional file 6: Fig. RD4. Raw data of weight (Kg) for females showing the construction of the charts with individual data points.

Additional file 7: Fig. RD5. Raw data of head circumference (cm) for males showing the construction of the charts with individual data points.

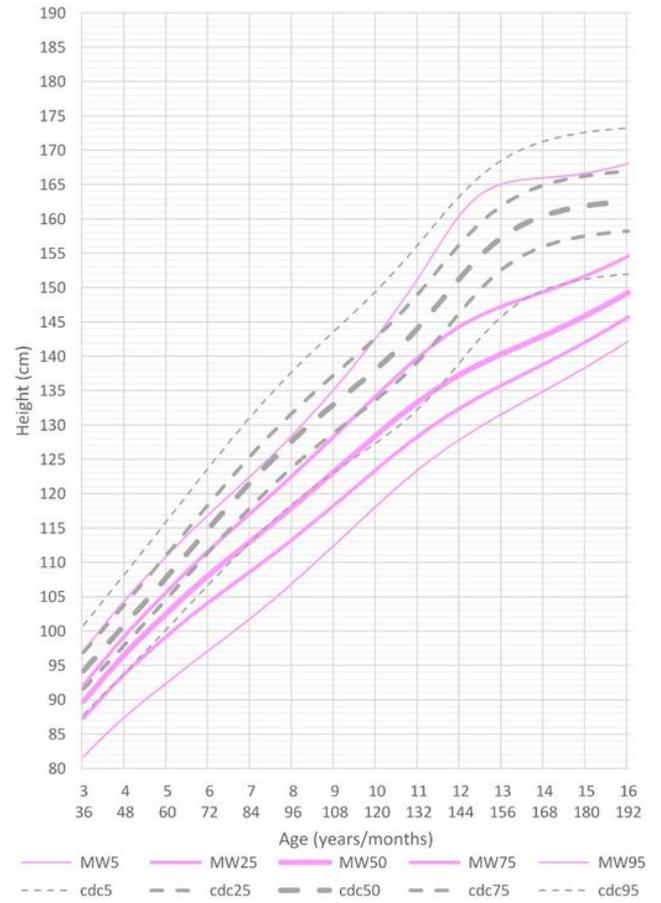
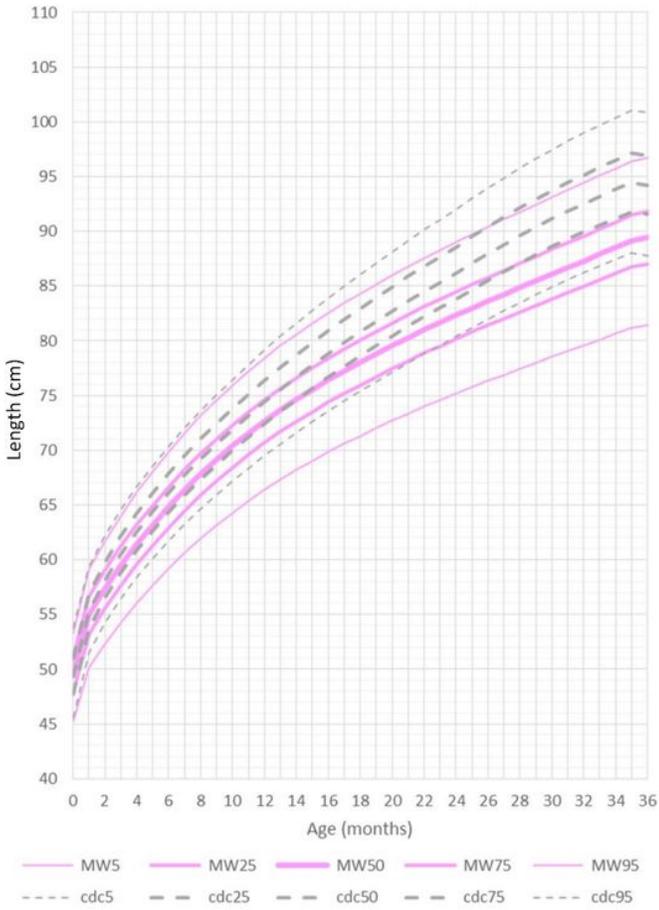
Additional file 8: Fig. RD6. Raw data of head circumference (cm) for females showing the construction of the charts with individual data points.

## Figures



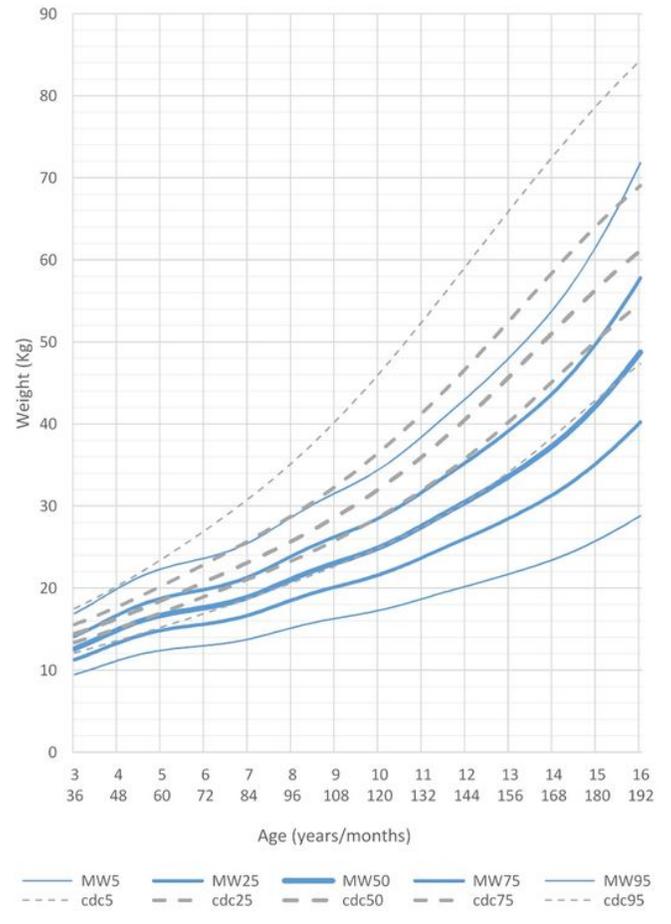
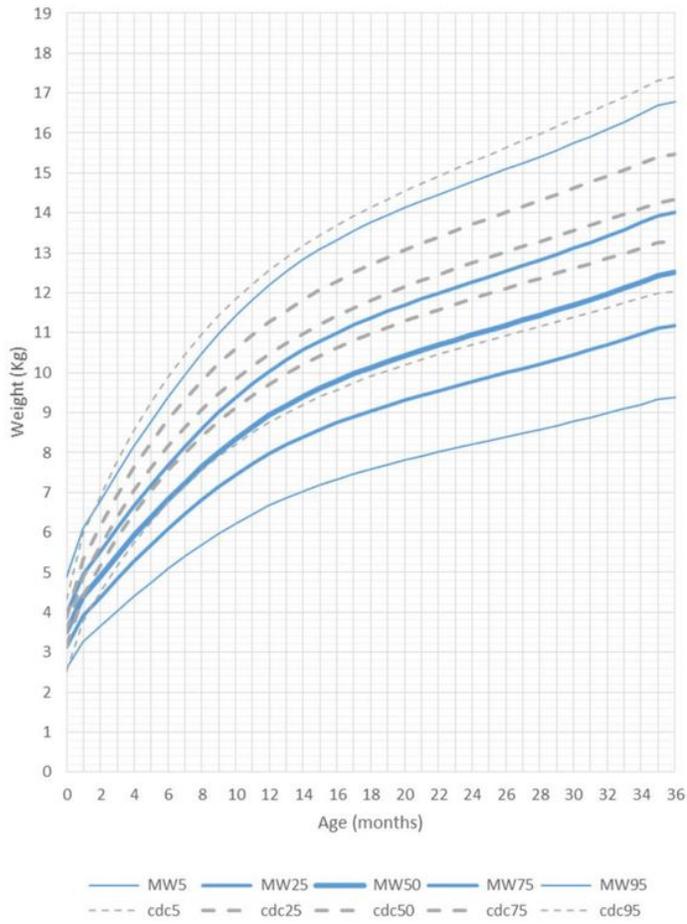
**Figure 1**

Constructed length and height growth charts for MWS patients in relation to the CDC reference charts (black) for males (blue).



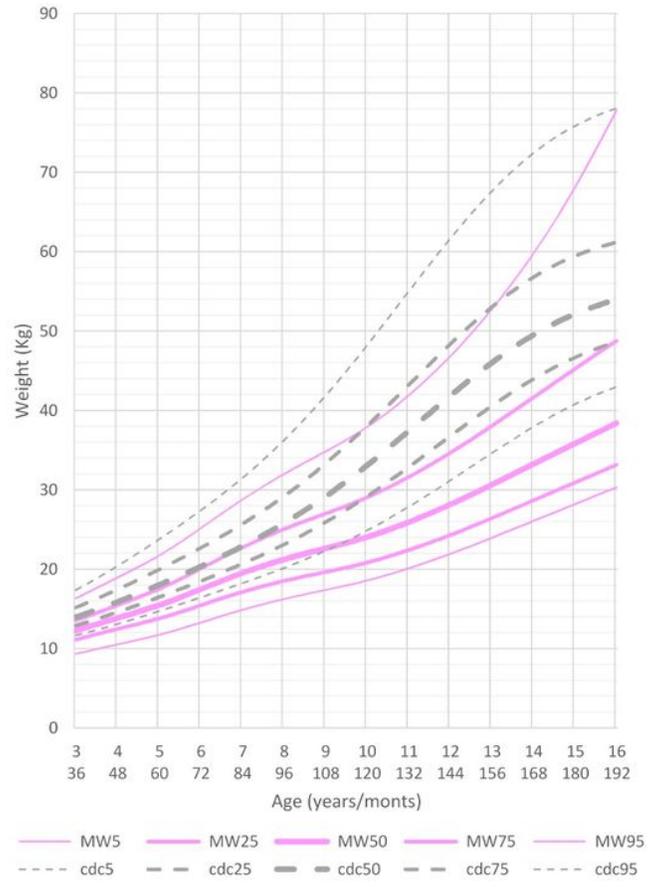
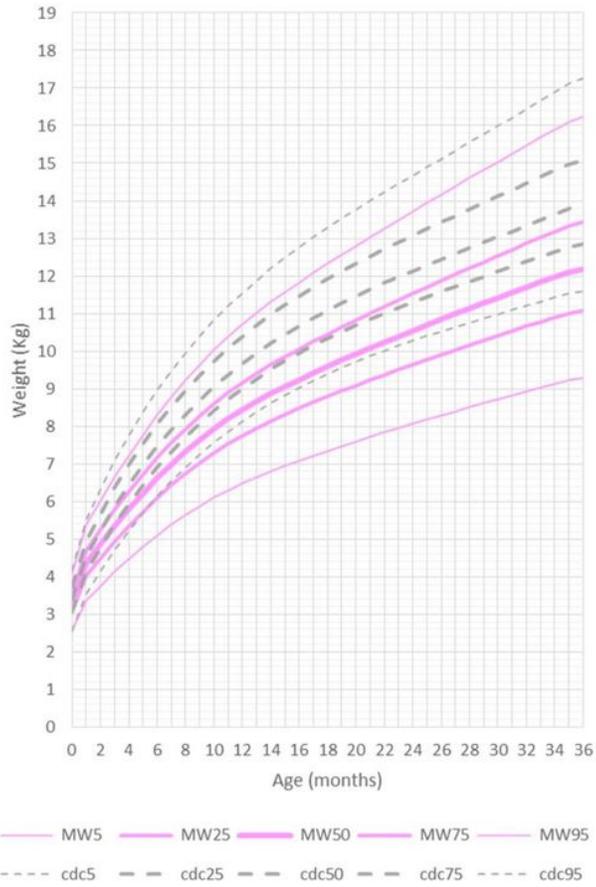
**Figure 2**

Constructed length and height growth charts for MWS patients in relation to the CDC reference charts (black) for females (pink).



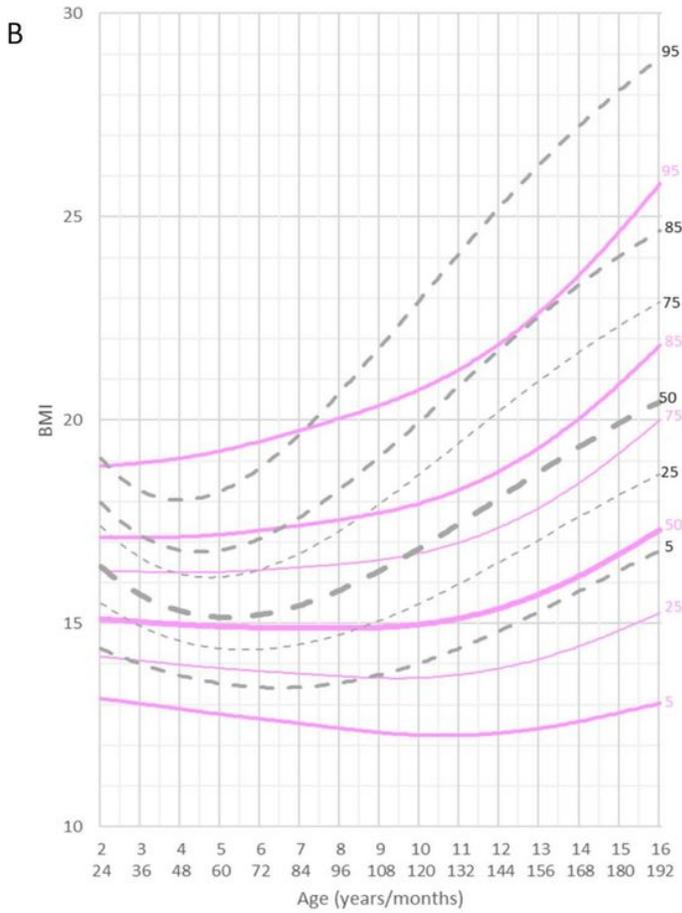
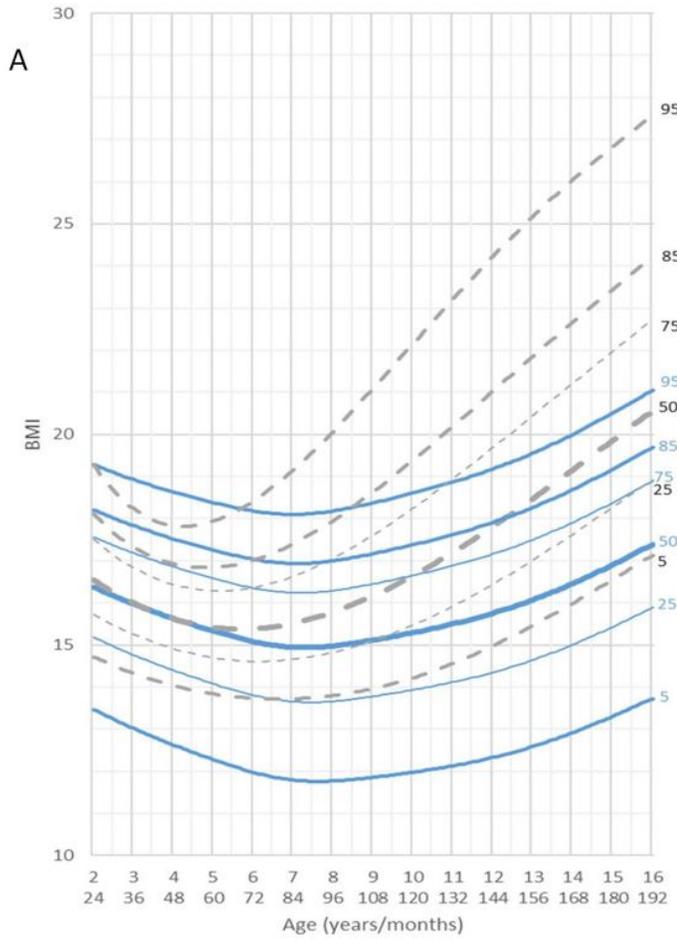
**Figure 3**

Constructed weight growth charts for MWS patients in relation to the CDC reference charts (black) for males (blue).



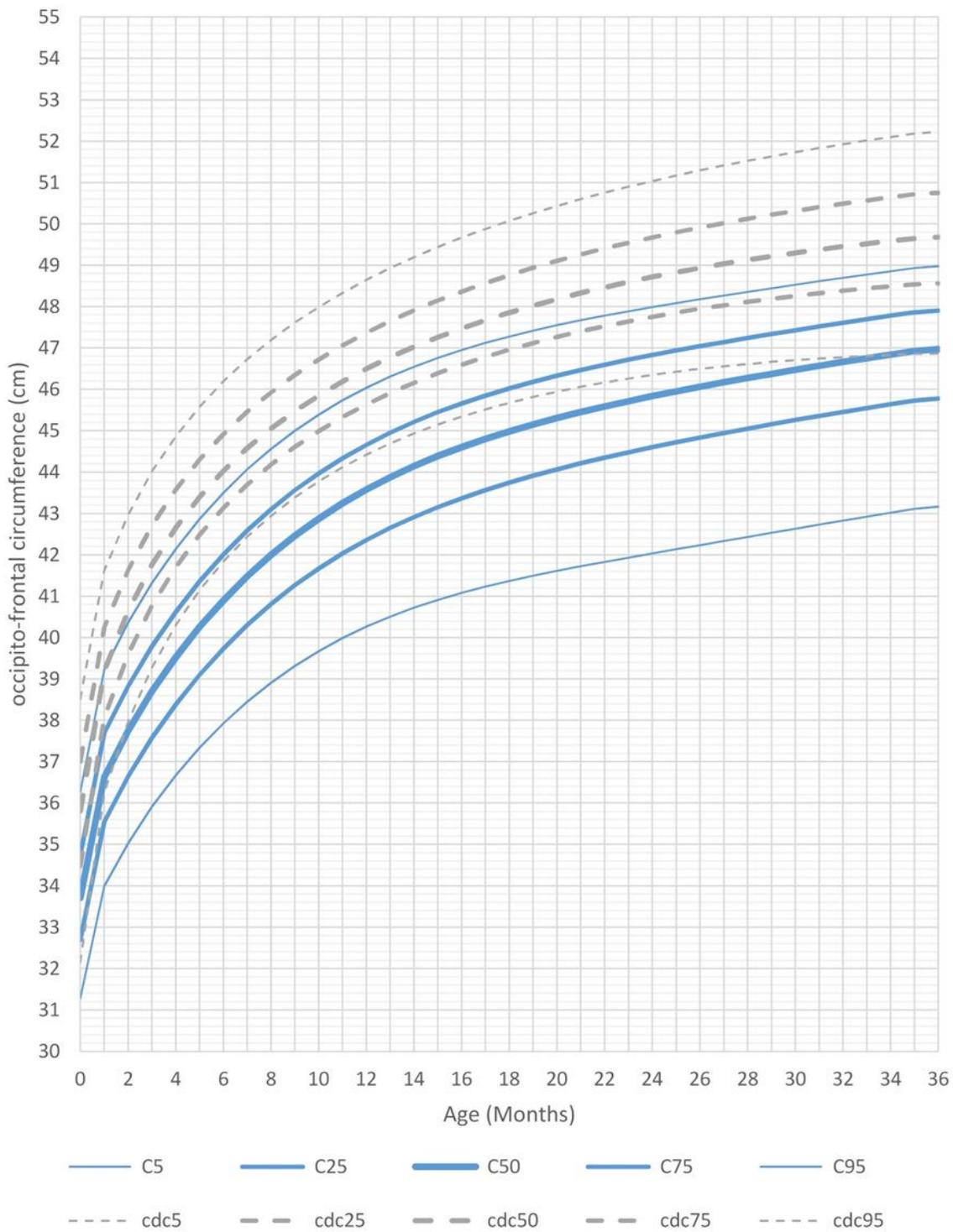
**Figure 4**

Constructed weight growth charts for MWS patients in relation to the CDC reference charts (black) for females (pink).



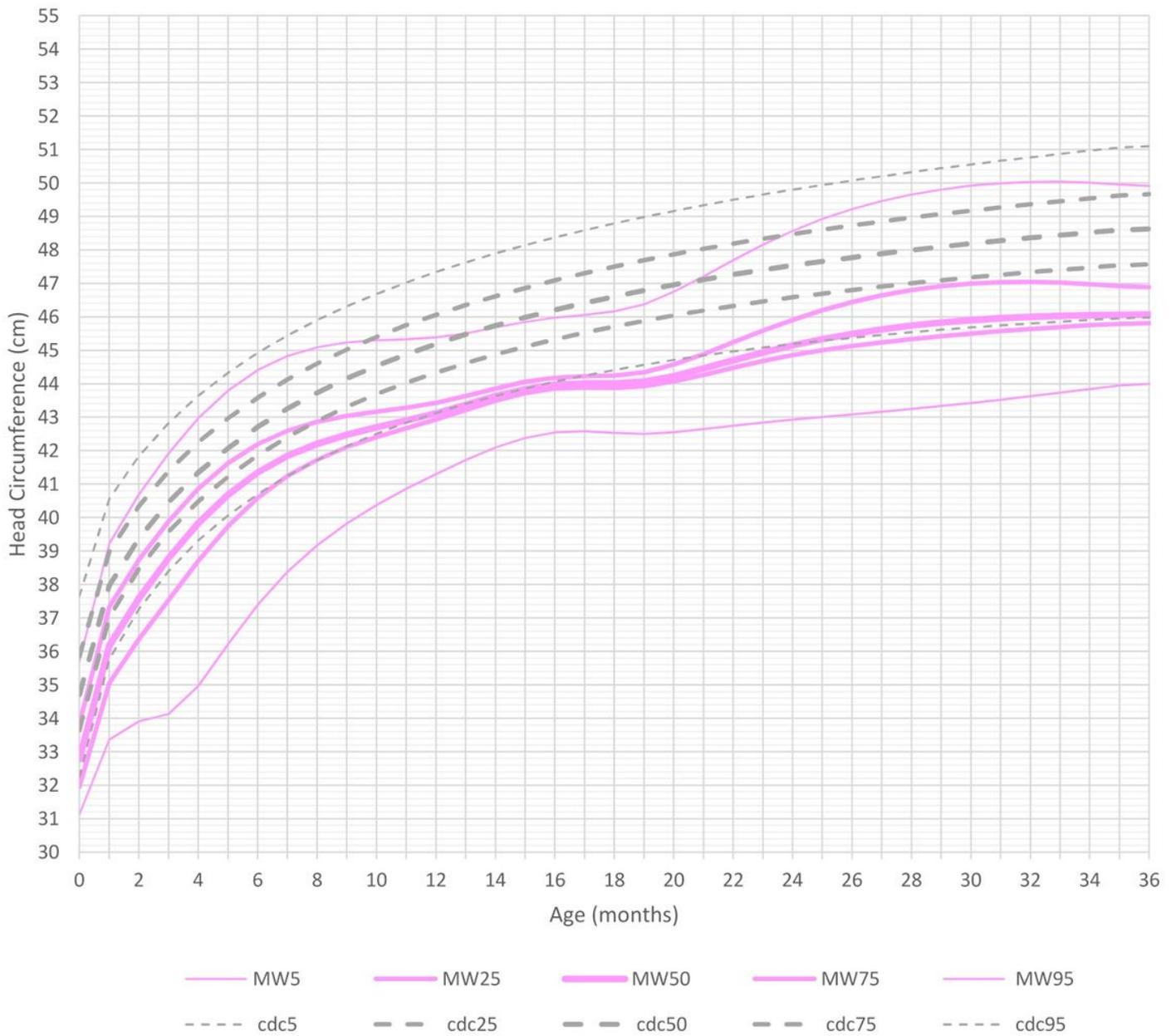
**Figure 5**

Constructed charts for the BMI (Kg/m<sup>2</sup>) for MWS patients in relation to the CDC reference charts (black) a for males (blue) b for females (pink).



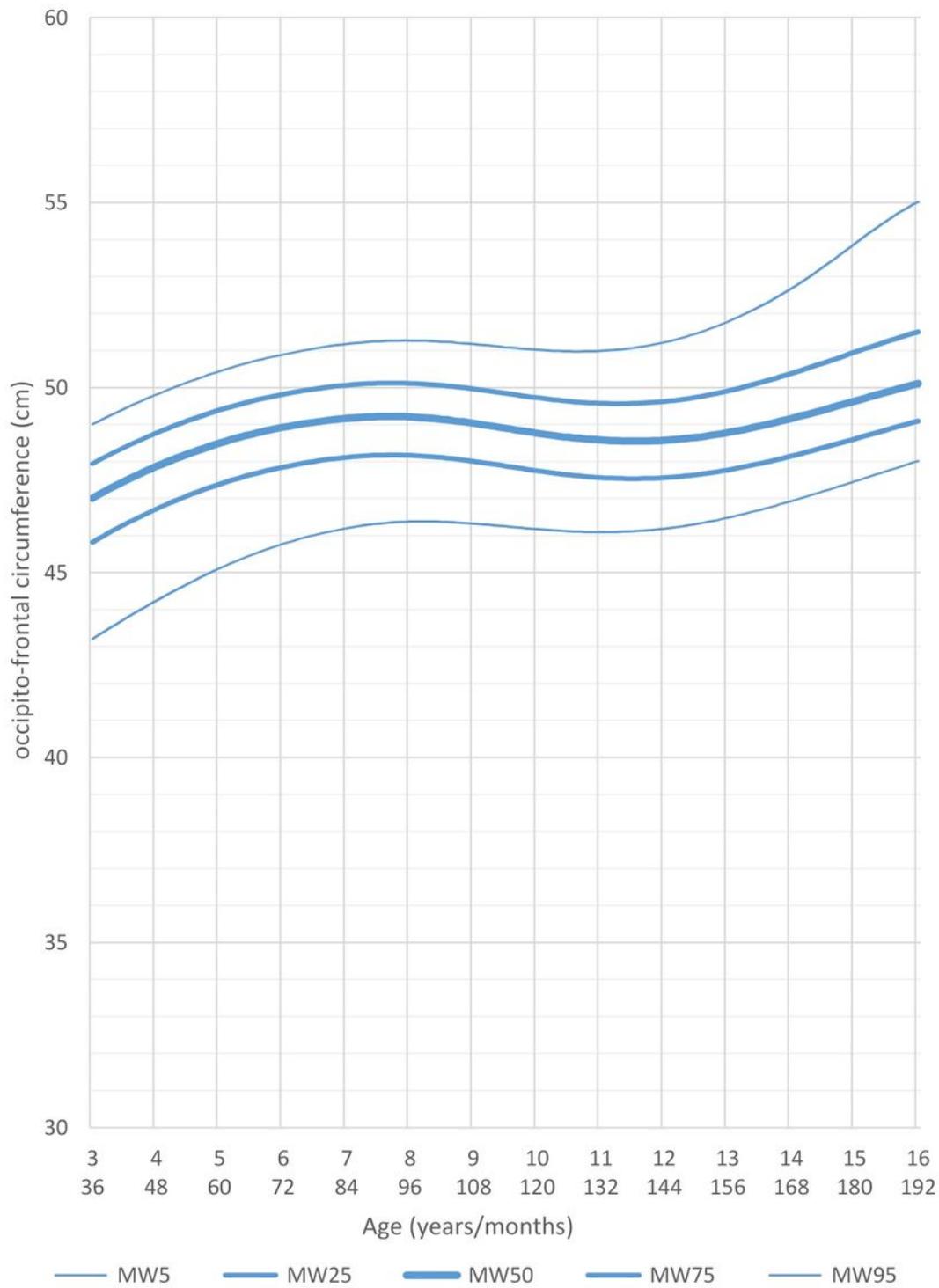
**Figure 6**

Constructed charts for the head circumference (cm) for MWS patients with age 0-3 years in relation to the CDC reference charts (black) for males (blue).



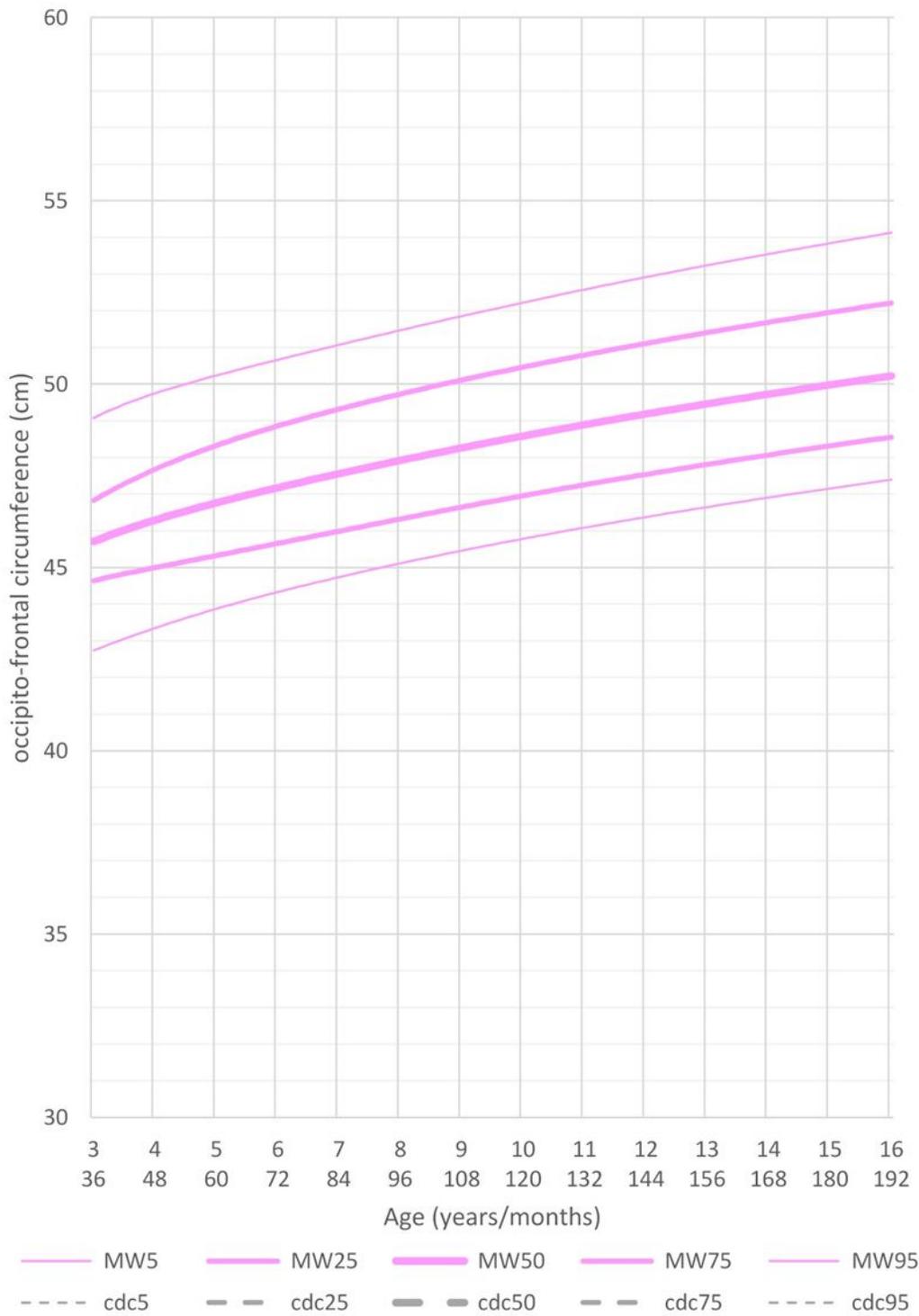
**Figure 7**

Constructed charts for the head circumference (cm) for MWS patients with age 0-3 years in relation to the CDC reference charts (black) for females (pink).



**Figure 8**

Constructed charts for the head circumference (cm) for MWS patients with age 3-16 years in relation to the Tanner reference charts (black) for males (blue).



**Figure 9**

Constructed charts for the head circumference (cm) for MWS patients with age 3-16 years in relation to the Tanner reference charts (black) for females (pink).

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Additional4Fig.RD2LENGTHHEIGHTFEMALES.tif](#)
- [ADDITIONAL8FIG.RD6HEADCIRCUMFERENCEFEMALES.tif](#)
- [Additionalfile2Table2rev20200501SGJMKLG.pdf](#)
- [Additional6Fig.RD4WEIGHTFEMALES.tif](#)
- [ADDITIONAL7FIG.RD5HEADCIRCUMFERENCEMALES.tif](#)
- [Additional5Fig.RD3WEIGHTMALES.tif](#)
- [Additional3.Fig.RD1LENGTHHEIGHTMALES.tif](#)
- [Additionalfile1Table1.docx](#)