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Table of contents

1. Introduction	4
1.1 Growth - definitions and measurement	4
1.2 Consequences of deviations in growth.....	5
1.3 Factors influencing growth.....	6
1.3.1 Genetical factors influencing growth.....	7
1.3.2 Environmental factors influencing growth	7
2. Methods and material	9
2.1 Data collection.....	9
2.2 Data processing	9
2.3 Statistical analysis	11
2.4 Ethics.....	11
3. Results	11
3.1 Birth weight.....	11
3.2 Body length and head circumference	13
4. Discussion	14
4.1 Strength.....	15
4.2 Limitations	16
4.3 Implications for the future	17
5. References	18
6. Summary	25
7. Supplemental material	26

1. Introduction

1.1 Growth – definition and measurement

Growth usually is defined as an increase in body length, weight and head circumference over time and growth restriction as “less rapid increase in size than expected” (Thureen, P. Hay & Hay Jr., 2008).

Multiple anthropometric parameters are used to assess growth of neonates. The parameter used most often is body weight, followed by body length and head circumference. Deviations in growth can reflect a wide range of medical issues of the infant like nutritional problems or diseases. It is of great importance to recognize growth problems promptly and reliably to initiate medical diagnosis and treatment.

Currently, growth of neonates is compared to data of birth weight, body length and head circumference percentile charts and for males and females separately. Nutrition is adjusted according to those charts. A large number of different anthropometric charts is available; all based on different populations, different ethnic groups and different region-specific singularities, such as malnutrition (Giuliani et al., 2015).

Growth charts used in clinics are typically the Fenton Growth Charts (Fenton & Kim, 2013), WHO Child Growth Standards (de Onis, Garza, Onyango, & Martorell, 2006) and charts from the U.S. Centers for Disease Control and Prevention (short: CDC) (Kuczmarski, Ogden, & Guo S.S., 2002).

The Fenton Growth Charts derived from a meta-analysis based on data from six studies and can also be used for preterm born neonates (22 to 50 weeks of gestation). The WHO growth charts and CDC charts can only be applied for term born neonates. Data for the WHO charts were collected from neonates born to mothers living under ideal socioeconomic conditions for optimal growth and children were breast-fed only (de Onis et al., 2006). The CDC charts were developed with data collected by National Center for Health Statistics (NCHS) in five cross- sectional, nationally representative health examination surveys conducted between 1963 and 1994 (Sondik et al., 2010). There are significant differences between the CDC and the WHO charts, because the sample of the CDC is on average heavier and shorter than the WHO sample (de Onis, Garza, Onyango, & Borghi, 2007).

The usual somatic classification of neonates is based on population specific birth weight percentiles. According to this classification, a hypotrophic neonate has a birth

weight < 10th percentile (small for gestational age; SGA), an eutrophic neonate has a birth weight between 10th and 90th percentile (appropriate for gestational age; AGA) and a hypertrophic neonate's weight is >90th percentile (large for gestational age; LGA) (Koffler, 1981, p.302). These selective percentiles were defined as a cut-off in the 1960s and seem to be arbitrary, as they do not represent clinically significant differences (Xu, Simonet, & Luo, 2010; Zeve, Regelman, Holzman, & Rapaport, 2016).

This way of classification labels 20% of newborns and fetuses as either too small or too big and thus many newborns undergo potentially unnecessary diagnostics. This means a lot of stress and worries for the expectant mother and father and is burdensome for the healthcare system. It would be more effective to have a higher specificity in classification of newborns. To address this problem, a customized gestation related optimal weight (GROW) standard was developed for fetal weight by Gardosi et al. to be able to detect fetuses at risk at an early stage of pregnancy. They used ultrasound data and found effects of maternal weight, height, ethnicity and parity on fetal weight (Gardosi, Francis, Turner, & Williams, 2018).

1.2 Consequences of deviations in growth

Research regarding the coherence of growth problems and medical issues shows homogeneous findings. There is strong evidence, that postnatal growth is a significant predictor for the further development of neonates. This is especially true for preterm born neonates. Inadequate growth not only leads to longer hospital stays and a higher mortality (Kajantie et al., 2005; Löser, 2010; Ozanne, Fernandez-Twinn, & Hales, 2004; Zeitlin et al., 2010), but also has implications for different aspects of the long-term development and diseases during adulthood (metabolic, cardiovascular, neuronal and cancerous) of preterm infants.

A cohort study has analyzed the relation of growth and the development of morbidities in extremely preterm infants (gestational age 24-32 weeks). For infants with diagnosed retinopathy of prematurity (ROP), bronchopulmonary dysplasia (BPD) and necrotizing enterocolitis (NEC), growth rates were significantly lower than those of healthy infants (Klevebro et al., 2016). Some researchers also found a correlation between low birth weight and intraventricular hemorrhage (IVH) and periventricular leukomalacia (PVL) (McIntire, Donald, Bloom, Steven, Casey, Brian, & Leveno, Kenneth, 1999; Zaw,

Gagnon, & da Silva, 2003), but others did not (Klevebro et al., 2016; Zeitlin et al., 2010). This can be due to different definitions of growth restriction that were used in the studies.

The head circumference of a neonate significantly correlates with brain growth in utero and neurodevelopment (Raghuram et al., 2017). Longitudinal studies have shown that the occipital-frontal head circumference has impact on the neurologic outcome in infancy and later life (Hack et al., 1991; Neubauer, Griesmaier, Pehböck-Walser, Pupp-Peglow, & Kiechl-Kohlendorfer, 2013; Sicard et al., 2017). Appropriate data about head circumference is also essential to identify primary macro- and microcephaly; conditions that benefit from early intervention (Tan, Mankad, Talenti, & Alexia, 2018; Von der Hagen et al., 2014).

Neonates classified as LGA suffer from less severe short-term consequences than neonates classified as SGA. They show for example more cases of shoulder dystocia and neonatal hypoglycemia (Weissmann-Brenner et al., 2012), while no adverse long-term effects were reported (Khambalia, Algert, Bowen, Collie, & Roberts, 2017).

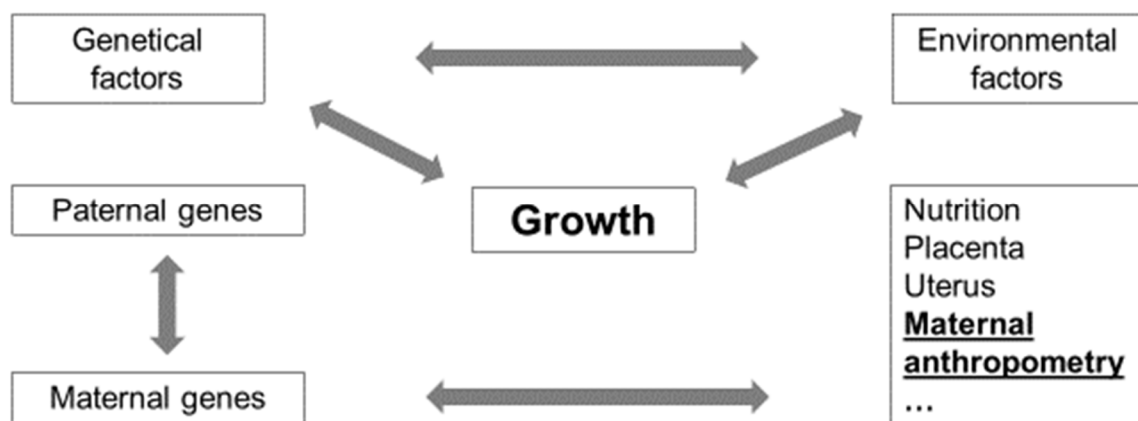


Figure 1. Factors influencing growth of neonates and interactions between those factors.

1.3 Factors influencing growth

Growth is a complex process underlying various factors influencing it (Figure 1). Aside from environmental factors there are genetical factors that have a high impact on growth and those factors interact. It is difficult to separate effects of fetal genes and

the maternal environment (Brooks, Johnson, Steer, Pawson, & Abdalla, 1995). To predict and compare the body dimensions of a newborn, it is necessary to know about the most important factors influencing it.

1.3.1 Genetical factors influencing growth

There are several studies that investigated the influence of genes on a child's anthropometry at birth. In twin studies and intergenerational studies, 25 to 50 percent of the variability in birth weight could be explained by heritability (Lunde, Melve, Gjessing, Skjærven, & Irgens, 2007). A Norwegian study determined the genetical variance explaining birth weight and body length as 31% and for head circumference as 27%. Gestational age was found to be influenced by genetics as well, which in turn has impact on size at birth (Lunde, Melve, Gjessing, Skjærven, & Irgens, 2007). The genetical effects of the father seem to be less remarkable than those of the mother (Kramer, 1987; Pomeroy, Wells, Cole, O'Callaghan, & Stock, 2015; Rice & Thapar, 2010). A study examined the contribution of paternal and maternal genes on birth weight and head circumference based on different genetic relatedness to the parents. Pregnancies were established via *in vitro* fertilization (IVF), egg donation and via sperm donation (Rice & Thapar, 2010). Their results suggest an interaction between the intrauterine environment and maternal genes and also a suppression of the paternal genes (Rice & Thapar, 2010).

1.3.2 Environmental factors influencing growth

There are several environmental factors like maternal health and postnatal nutrition, the uptake of harmful substances, the condition of the placenta, socioeconomic factors and even altitude of the living environment that have impact on fetus' or neonates' growth. This work focuses on the maternal anthropometry as one of the most important and easy to measure environmental factors.

It is generally recognized that maternal anthropometry (height and weight) influences the size of the neonate at birth (Kramer, 1987; Pölzlberger, Hartmann, Hafner, Stümpflein, & Kirchengast, 2017; Thame, Wilks, McFarlane-Anderson, Bennett, & Forrester, 1997). Effects were found in numerous investigations until today. An animal study about the influence of the maternal size has already been conducted in 1938 (Walton & Hammond, 1938). The subjects; large horses and small ponies, were used

for reciprocal crosses and the offspring's size was evaluated. The authors inferred that the size of the delivering mother influenced the offspring's size through the maternal environment and obscured genetic effects of the genetic mother.

The maternal height may play a genetical role, because the maternal genetical potential can be passed to the fetus, and as well have environmental influence through physical mechanisms (Kramer, 1987). Kramer focused on the assumption that nutrition correlates with maternal height and thus indirectly influences the newborns' weight.

Another approach about how maternal height has an environmental influence investigates the size of the uterus. Allen and colleagues transferred embryos of horses into the uteri of smaller ponies and vice versa. The transferred embryos showed a growth pattern according to the recipient mare (Allen, Wilsher, Turnbull, et al., 2002). Their results indicate that fetal growth and maternal size interact. Growth of the fetus is influenced by the equine chorionic gonadotrophin secreted by the placenta of the recipient mare and the hormones secreted by the fetal adrenal gland also affect the configuration of the placenta. An analysis that described the volume of the placenta during pregnancy and fetal growth supports this finding for the human species (Thame, Osmond, Bennett, Wilks, & Forrester, 2004).

Pomeroy et al. found that the head circumference of a neonate is stronger associated with the maternal height than with the paternal anthropometry. They argue that the association between head circumference, maternal height and pelvic dimensions prevents obstructed labor (Pomeroy et al., 2015).

It has been shown that there are differences in growth rates and mortality between ethnic groups (Chen et al., 2015; Kierans et al., 2008; Rochow et al., 2018; Thomas, Peabody, Turnier, & Clark, 2000). Those differences in birth weight and body length could originate from variances in maternal heights so that ethnicity is most likely a confounding or indirect factor related to maternal anthropometry (Kramer, 1987; Rochow et al., 2018). Rochow et al. found an average increase of 17 g for birth weight for each centimeter increase in maternal height. This means a variation of up to 425 g for the average term born neonate considering a difference of 25 cm within the same ethnic group ($25 \text{ cm} \times 17 \text{ g} = 425 \text{ g}$).

In our nowadays globalized civilization, it would be more useful to have growth charts based on maternal data rather than on regional or ethnic information. Considering the current findings about aberrant postnatal growth and its consequences, clinicians

should aim for an individualized classification, adapted to the individual needs and growth potentials of the infant. The improvement of anthropometric classification may lead to less overdiagnostics, lower mortality rates, earlier discharge from hospital and a better development for infants in the long term. The available research indicates that birth weight, body length and head circumference are significantly related to maternal anthropometry.

2. Material and methods

2.1 Data collection

For this study, anonymized data of 2,225,791 million newborns for birth weight and 2,225,348 million newborns respectively for body length and head circumference (singletons only) from the routine German Perinatal Survey from 1995 until 2000 were analyzed, which includes 87% of the German population (M. Voigt et al., 2020; Manfred Voigt et al., 2020). The federal states contributed differently to the data source; data from Baden-Wuerttemberg were excluded, because access for research has not been granted. Between 1998 and 2000, Bavaria, Brandenburg, Hamburg, Mecklenburg-Western Pomerania, Lower Saxony, Saxony, Saxony-Anhalt and Thuringia provided data (Figure 2). We included datasets with complete data about birth weight, length and head circumference, gestational age, sex, maternal weight and height (collected at the first obstetric visit) and country of origin.

2.2 Data processing

The aim of the studies was to compare the birth weights, birth length and head circumferences of neonates from mothers of different anthropometry. To achieve this, in a first step six maternal groups were generated according to the mothers' height (<158 cm, 158 to <163 cm, 163 to <168 cm, 168 to <173 cm, 173 to <177 cm and >177 cm). In a second step, neonates of those six groups were further divided according to the maternal weight into three equal sized subgroups, so that in the end, 18 groups could be compared. The groups were defined as follows: <158 cm (<53, 53-59, >59 kg), 158 to <163 cm (<57, 57-63, >63 kg), 163 to <168 cm (<60, 60-66, >66 kg), 168 to <173 cm (<63, 63-70, >70 kg), 173 to <177 cm (<66, 66-73, >73 kg), >177 cm (<71 kg, 71-79, >79 kg). The numbers were rounded (see supplemental Table 2-3). We

described mothers as “petite” (<158 cm and <53 kg) and mothers as “grande” (>177 cm and >79 kg.) and defined groups of “low weight” (<53 kg) and “high weight” (>79 kg) and “short stature” mothers (<158 cm) and “tall stature” mothers (>177 cm).

Neonates with birthweights below 10th percentile were assigned as SGA, those with birthweights above 90th percentile as LGA, the remaining neonates as AGA. To compare the percentiles and cutoffs calculated for the maternal groups with data without this specification, percentiles and cutoffs were also calculated for all data. Sex-specific percentiles were calculated from 31 to 42 weeks gestational age.

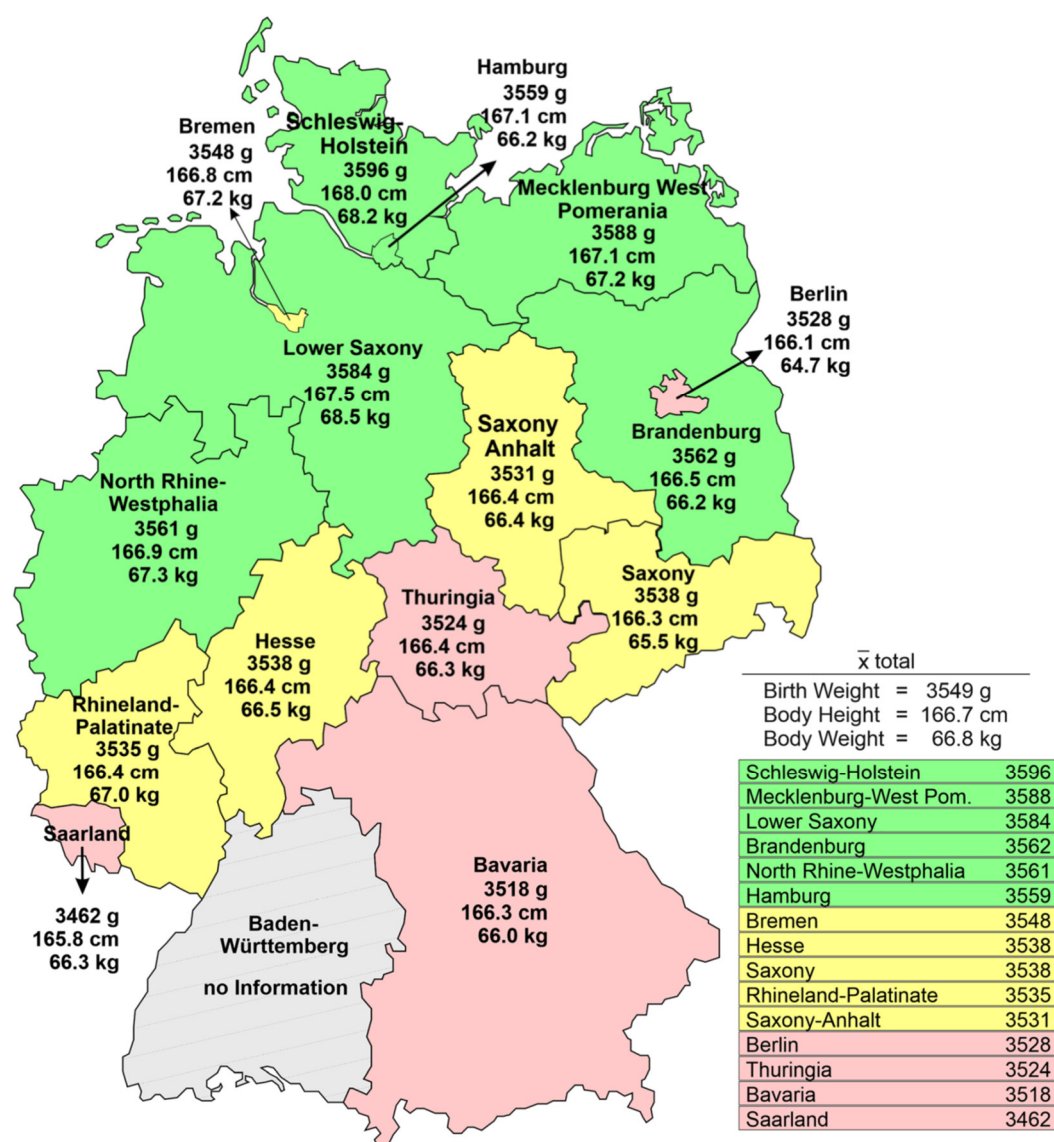


Figure 2. Map of included federal states of Germany and average birth weight, maternal height, and maternal weight for each state.

2.3 Statistical analysis

The percentiles were calculated using the “lms” function of the R package GAMLSS version 5.1-2. The generalized additive model for location, scale and shape (GAMLSS) was employed to identify optimal distribution functions (Rigby & Stasinopoulos, 2013; Rigby, Stasinopoulos, & Lane, 2005). The statistical analysis was performed using R, version 3.5.3 (2019-03-11; Vienna, Austria) for birth weight percentiles and version 3.6.2 (2019-12-12; Vienna, Austria) for head circumference and body length (R Development Core Team, 2019). Values for the percentiles were calculated for the midweek (e.g. 33 + 3/7). The percentiles from the 18 subgroups were compared to the whole dataset.

2.4 Ethics

Data collection was part of the mandatory quality assurance of the obstetric hospitals. This observational study has complied with all institutional policies and relevant national regulations. The ethics committee of the University of Rostock, Germany, has approved this study (approval no. A 2019-0108).

3. Results

3.1 Birth weight

The proportion of male neonates (51.4%) was slightly higher and the rate of preterm birth in total was 6.2%. Southern German states show lower birth weights, maternal height and weight than northern states (M. Voigt et al., 2020). The average birth weight was 3,549 g, maternal weight 66.8 kg, maternal height 166.7 cm.

Analysis showed differences concerning the countries of origin between the different maternal groups. Tall mothers have a high proportion of German origin (94.7%) and a small proportion of Asian origin (0.01%). In the group of short mothers, 10.7% originate from Asia and 56.6% from Germany.

The examination of data shows that median birth weight is increasing with maternal height and weight. The median birth weight of neonates differed up to 410 g between small and lightweight mothers (<158 cm and <59 kg) and tall and heavy mothers (>177 cm and >71 kg). This trend can also be seen comparing the different ethnicities. As an example, German mothers are on average taller than Asian mothers and gave birth to neonates with higher birth weights.

To compare the proportion of neonates classified as SGA, AGA and LGA, the newborns were classified according to the percentile data. In the group of tall mothers, the percentage of newborns classified as LGA is 26% while in short mothers it is 2% only (M. Voigt et al., 2020). Compatibly to this, in the group of short mothers, the proportion of newborns classified as SGA is 22% and in tall mothers only <4%. Mothers with a medium stature (163 to 167 cm and 60 to 66 kg) showed SGA and LGA rates proximate to 10% (ibid., Figure 3).

Birth weights increased with increasing gestational age up to 39.5 weeks, beyond that point, weights were decreasing. The highest birth weights were recorded at term age (5,990 g for male newborns and 5,980 g for female newborns at 39.5 weeks of gestation). The analysis also showed that preterm birth occurred more often in short and lightweight mothers than in tall and heavyweight mothers (rate of preterm births: 4.3% vs. 8.3%, see supplemental Table 1). Comparing the values of the major percentiles at 40 weeks of gestation, differences between neonates of petite and tall mothers can be found. Those differences account for up to 760 g for the 97th percentile, 580 g for the 50th percentile and 450 g for the 3rd percentile (ibid.).

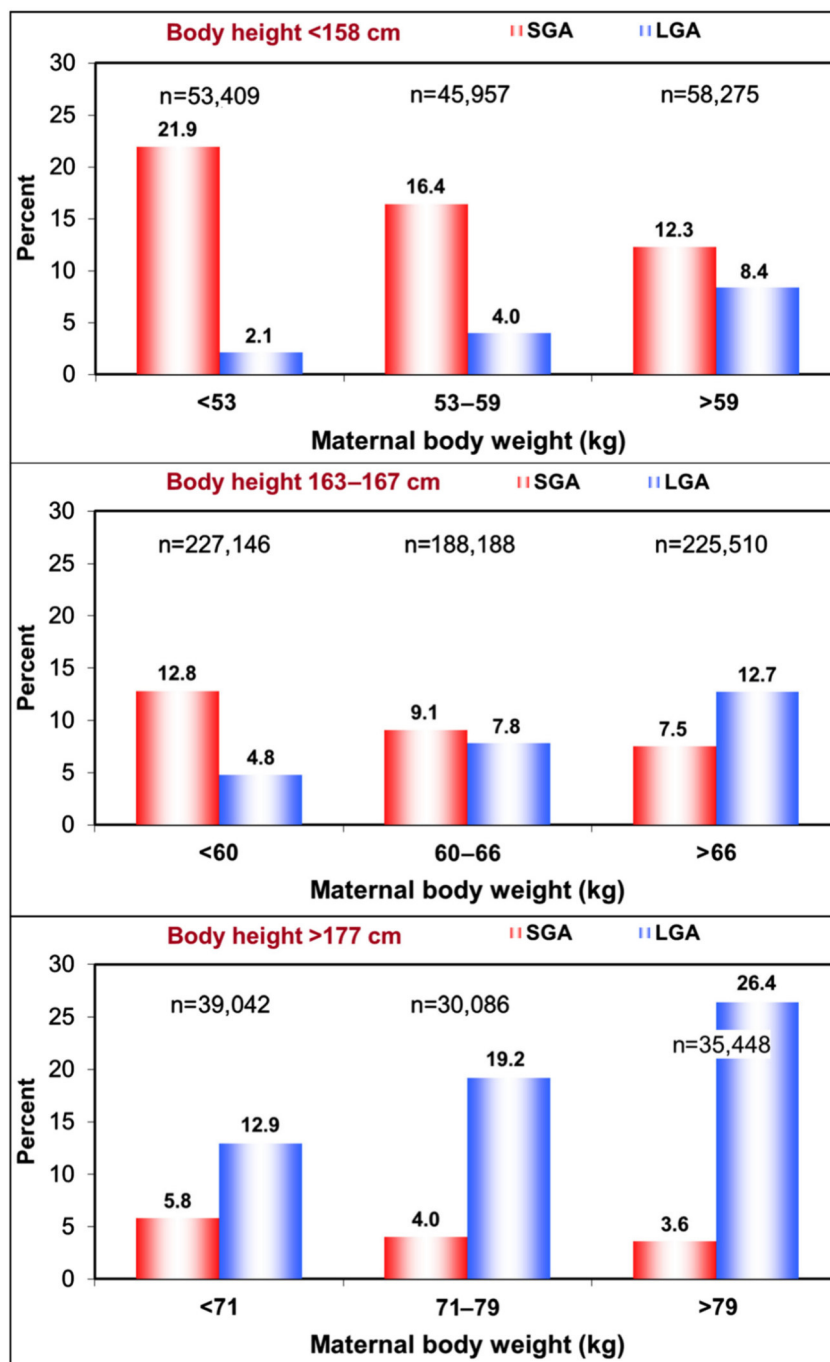


Figure 3. Number of infants who are classified as small for gestational (<10th percentile) or large for gestational age (>90th percentile) in different maternal height and weight groups when percentile values are calculated from the whole population and not accounting for the maternal anthropometry.

3.2 Head circumference and body length

The average head circumference was 34.9 cm for females and 35.6 cm for males. The average body length was 51.7 cm for females and 52.5 cm for males. We found

significant differences in the body length. For example, the mean body length for the 50th percentile differed up to 2.7 cm between short and tall mothers. For head circumference, the difference was 1.2 cm. For the 97th percentile, the difference was 3.2 cm in body length and 1.2 cm in head circumference (Figure 4). Data shows, that the differences between tall and short stature mothers become large with raising gestational age (Manfred Voigt et al., 2020). See supplemental Table 4-8 for more detailed data.

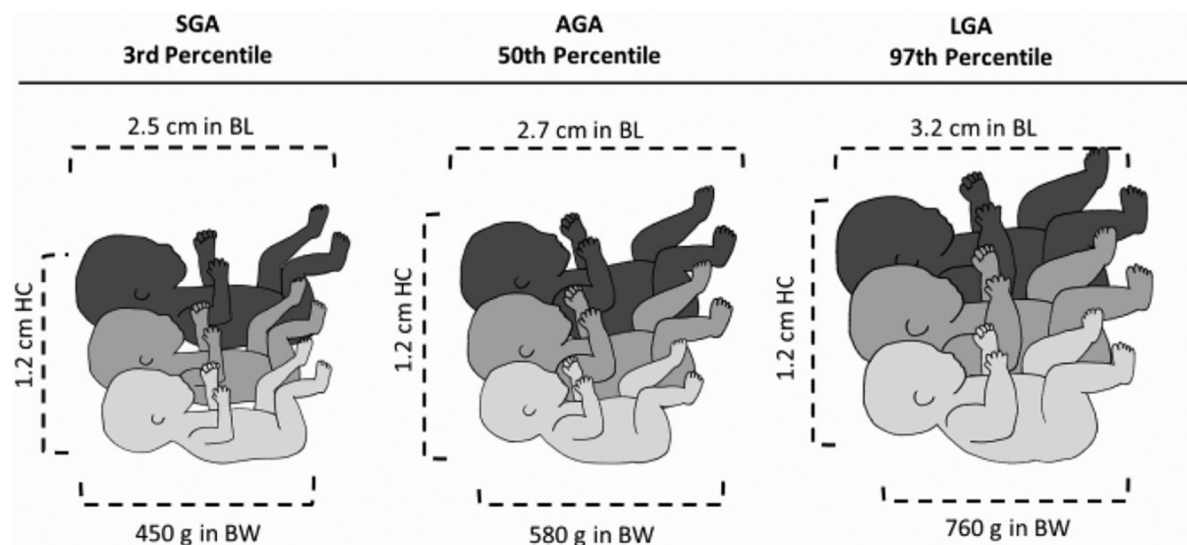


Figure 4. Differences in birthweight (BW), body length (BL), and head circumference (HC) between small (SGA), appropriate (AGA) and large (LGA) for gestational age infants for mothers with short (light grey), medium (medium grey) and tall stature (dark grey).

4. Discussion

We developed individualized percentile charts for birth weight, head circumference and body length stratified by maternal height and weight. The results indicate that maternal stature has a strong effect on all birth percentile values (M. Voigt et al., 2020; Manfred Voigt et al., 2020). The same relationship has been investigated for maternal body constitution and fetal growth by using data obtained by ultrasound measurements (Gardosi et al., 2018) and showed the same correlation. Most probably, this effect is caused by differences in the intrauterine size and genetical predispositions leading to different growth potentials.

Regarding the analysis of birth weight, we found significant differences between neonates of petite vs. grande mothers. The differences are big enough to lead to misclassification of newborns without involving maternal anthropometry (M. Voigt et al., 2020).

Eventually, it could be said that “shorter and lightweight mothers gave birth to neonates with lower birth weights, shorter body length and smaller head circumference than mothers of taller and heavier stature”. Or in other words, it is natural that a short and lightweight mother has a newborn with a lower birthweight compared to a tall and heavy-weight mother having a newborn with higher birthweight. These differences are clinically significant and may influence an infant’s classification (SGA, AGA, LGA) at birth and further postnatal treatment (M. Voigt et al., 2020).

Without involving maternal stature, a newborn of a petite mother could be classified as SGA, but actually reached a weight according to his/her natural growth potential and should be classified as AGA. Vice versa, a newborn of a grande mother could be misclassified as LGA, but, considering maternal anthropometry, would be classified as AGA. Differences within the same percentile for birth weight between petite and tall mothers were found to be up to 800 g, for body length 3.2 cm and for head circumference up to 1.2 cm.

The rate of preterm born neonates was found to be higher in the group of short and lightweight mothers than in the group of tall and heavyweight mothers. Recent findings about mothers with low Body Mass Index (BMI) having a higher rate of preterm born neonates support this result (Liu et al., 2016). This can be due to a smaller intrauterine environment of shorter mothers, as evidence from several studies shows (Allen, Wilsher, Stewart, Ousey, & Fowden, 2002; Brooks et al., 1995).

4.1 Strength of the studies

At the time of publishing, these were the first analyses on this topic. Our study contained a large sample size with datasets of 2.1 million neonates and their mothers. This allowed us to calculate percentiles for 18 different maternal height and weight groups for males and females (M. Voigt et al., 2020). Neonatal data could be provided on a day-specific basis, which enabled us to estimate the percentiles precisely (M. Voigt et al., 2020). It has been shown that the rate of SGA is overestimated at the beginning of each gestational week and is underestimated at the end of each

gestational week when weekly percentile values are used for percentile calculation (Manfred Voigt et al., 2010).

By involving maternal anthropometry in the classification of newborns, we can improve the identification of newborns with higher perinatal risk and thereby reduce costs for the health care system. The novel classification may also have influence on the antenatal health care. A corrected estimation of fetal weight at gestation could avoid unnecessary interventions, such as tests for gestational diabetes due to misclassified fetuses as LGA or intrauterine growth restriction (IUGR). This also reduces stress and anxiety for the prospective parents (M. Voigt et al., 2020).

As research already showed, neonatal body measurements are better explained by maternal anthropometry than by ethnicity (Rochow et al., 2018). Therefore, our charts can be used worldwide and represent the nowadays globalized world with the tendency towards mixed ethnicities.

4.2 Limitations of the studies

Our data set reaches back to the early 2,000s. There is evidence that birth weights and body heights increase over time (Fryar, Kruszon-Moran, Gu, Carroll, & Ogden, 2021), so that our analysis could be obsolete. However, comparison of data from the years 2007-2011 vs. 1995-2000 did not show a significant difference (M Voigt et al., 2014), so that we do not expect a significant effect in our cohort.

A limitation of our studies is the descriptive quality of the analysis. No longitudinal data about the further development or health status of the newborns were available, so that it is not possible to conclude on perinatal risks. To establish recommendations for new cutoff values for the somatic classification into SGA, AGA and LGA, data about mortality and morbidity in context with maternal anthropometry are essential. It can be assumed that the consideration of maternal height and weight improves to define the most at-risk population of newborns. This issue has to be investigated further on the basis of long-term data.

Data about maternal weight and height were collected at the first obstetric visit. The German guidelines for motherhood recommend a first obstetric visit as soon as possible (Bundesausschuss & Gemeinsamer Bundesausschuss, 2009). Typically, this first visit takes place between the 4th and 8th week of pregnancy. At this point, maternal weight gain lies under 2.5 kg for the 50th percentile for women with normal BMI (Santos

et al., 2018). This effect is negligible and would occur as a systematic deviation for all maternal weight data. Whether maternal weight and height were actually measured or asked, is not clear. The exact point of time of the data collection during pregnancy was not recorded. The results would be more precise when these data were standardized. Another limitation of the analysis is that no data about paternal anthropometry data were available and therefore could not be included. An Australian study found an association between parental anthropometry and head circumference and length of trunk and limb (Pomeroy et al., 2015). The percentile values based on the body measurements at birth represent a snapshot of the neonates' status at birth and can be used to identify SGA and LGA neonates. They should not be confused with growth trajectories or growth curves.

4.3 Implications for the future

This work contributes to the development of globally usable, specific birth weight, length and head circumference percentile charts. It would be desirable for future use of data to construct an online program or application where maternal and neonatal data could be entered and the according percentile would be calculated, so that it could be used easily and widely by clinicians. It can be assumed that novel percentile charts based on the maternal anthropometry rather than on the entire range of diverse statures have a higher specificity and thus better predict perinatal morbidities and mortality. To test this, further studies comparing the two approaches are needed.

To evaluate body measurements of preterm born neonates according to maternal anthropometry, more research has to be conducted, as the existing data cannot be transferred. Recent research showed that commonly used percentile charts are not sufficient in describing the growth of preterm born neonates, because their growth trajectories are skewed by the causal pathologies that lead to preterm birth (Rochow et al., 2019) .

In summary, our analysis revealed that maternal anthropometry has a significant impact on the classification of newborns as LGA, AGA and SGA. Growth charts using maternal data show higher specificity than growth charts that do not include those data.

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6. Summary

Research has already shown that the maternal anthropometry affects birth weight. The impact on birth weight, body length and head circumference percentiles was not yet investigated. The aim of our observational studies was to develop individualized percentile charts (birth weight, body length and head circumference) for neonates based on maternal weight and height. To achieve this, we analyzed data of 2.2 million newborns stratified by maternal height and weight from the German Perinatal Survey. The percentiles based on 18 groups stratified by maternal anthropometry for both sexes showed significant differences between identical original percentiles. The differences were up to almost 800 g between identical percentiles for petite and grande mothers. Birth length differed by several centimeters for the same percentiles between groups of short and tall stature mothers, whereas birth head circumference differed up to 1.2 cm.

Our analysis showed that maternal anthropometry has a significant effect on the classification of newborns as LGA (large for gestational age), AGA (appropriate for gestational age) and SGA (small for gestational age). Individualized charts show higher specificity than percentile charts that do not include those data and provide more individual prediction of perinatal risks.

7. Supplemental material

Table 1: Baseline characteristics (birth weight) of newborns, preterm infant's gestational age is 32+0/7 until 36+6/7 weeks.

Maternal group	Number of infants			Number of preterm infants		Duration of pregnancy (weeks)	
	all	male	female	male n (%)	female n (%)	male	female
all	2,225,791	1,144,479	1,081,312	76,507 (6.7)	62,173 (5.7)	39.5 ± 1.6	39.6 ± 1.6
> 177 cm / > 79 kg	35,047	18,137	16,910	930 (5.1)	735 (4.3)	39.8 ± 1.6	39.9 ± 1.5
> 177 cm / 71 – 79 kg	29,723	15,364	14,359	728 (4.7)	593 (4.1)	39.8 ± 1.5	39.8 ± 1.5
> 177 cm / < 71 kg	38,600	19,795	18,805	1,201 (6.1)	901 (4.8)	39.6 ± 1.6	39.7 ± 1.5
173 – < 177 cm / > 73 kg	93,899	48,528	45,371	2,661 (5.5)	2,119 (4.7)	39.8 ± 1.6	39.8 ± 1.5
173 – < 177 cm / 66 – 73 kg	78,210	40,427	37,783	2,227 (5.5)	1,760 (4.7)	39.7 ± 1.6	39.8 ± 1.5
173 – < 177 cm / < 66 kg	87,866	44,870	42,996	2,781 (6.2)	2,326 (5.4)	39.6 ± 1.6	39.7 ± 1.5
168 – < 173 cm / > 70 kg	221,958	114,375	107,583	6,805 (5.9)	5,507 (5.1)	39.7 ± 1.6	39.8 ± 1.6
168 – < 173 cm / 63 – 70 kg	207,327	106,935	100,392	6,194 (5.8)	4,934 (4.9)	39.6 ± 1.6	39.7 ± 1.5
168 – < 173 cm / < 63 kg	235,538	121,190	114,348	8,227 (6.8)	6,634 (5.8)	39.5 ± 1.6	39.6 ± 1.5
163 – < 168 cm / > 66 kg	222,133	114,640	107,493	7,378 (6.4)	5,898 (5.5)	39.6 ± 1.7	39.7 ± 1.6
163 – < 168 cm / 60 – 66 kg	178,745	91,979	86,766	5,858 (6.4)	4,833 (5.6)	39.6 ± 1.6	39.6 ± 1.6
163 – < 168 cm / < 60 kg	224,069	114,393	109,676	8,627 (7.5)	7,063 (6.4)	39.4 ± 1.7	39.5 ± 1.6
158 – < 163 cm / > 63 kg	145,241	74,766	70,475	5,309 (7.1)	4,399 (6.2)	39.5 ± 1.7	39.6 ± 1.6
158 – < 163 cm / 57 – 63 kg	119,725	61,632	58,093	4,394 (7.1)	3,496 (6.0)	39.5 ± 1.7	39.6 ± 1.6
158 – < 163 cm / < 57 kg	152,712	78,056	74,656	6,373 (8.2)	5,278 (7.1)	39.3 ± 1.7	39.4 ± 1.6
< 158 cm / > 59 kg	57,227	29,479	27,748	2,431 (8.2)	2,005 (7.2)	39.4 ± 1.8	39.5 ± 1.7
< 158 cm / 53 – 59 kg	45,253	23,149	22,104	1,887 (8.2)	1,545 (7.0)	39.4 ± 1.7	39.5 ± 1.6
< 158 cm / < 53 kg	52,518	26,764	25,754	2,496 (9.3)	2,147 (8.3)	39.2 ± 1.7	39.3 ± 1.7

Table 2: Percentile values for birth weight for gestational age (22 to 43 weeks) of males – based on the complete dataset.

		Birth weight percentile – Male newborns						
		Complete dataset						
		Birth weight (g)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
22	195	432	474	513	558	609	670	762
23	510	472	523	571	624	684	751	841
24	655	506	572	634	703	777	855	951
25	779	528	617	700	790	883	976	1,084
26	909	543	662	772	889	1,005	1,116	1,237
27	1,127	564	718	858	1,003	1,145	1,276	1,413
28	1,455	605	791	960	1,134	1,302	1,454	1,610
29	1,746	683	895	1,087	1,285	1,475	1,648	1,826
30	2,088	806	1,037	1,244	1,457	1,663	1,851	2,047
31	2,814	955	1,202	1,423	1,649	1,869	2,072	2,286
32	3,809	1,120	1,384	1,619	1,859	2,094	2,314	2,549
33	5,848	1,315	1,594	1,841	2,093	2,342	2,577	2,833
34	9,705	1,545	1,833	2,088	2,350	2,610	2,858	3,134
35	18,011	1,790	2,082	2,341	2,610	2,879	3,140	3,434
36	36,320	2,036	2,324	2,584	2,856	3,132	3,400	3,706
37	77,022	2,280	2,558	2,815	3,089	3,368	3,641	3,948
38	164,252	2,511	2,775	3,026	3,298	3,577	3,848	4,148
39	284,035	2,695	2,952	3,202	3,476	3,757	4,029	4,325
40	334,872	2,829	3,085	3,337	3,618	3,907	4,186	4,486
41	185,060	2,934	3,193	3,450	3,738	4,037	4,323	4,632
42	22,731	2,942	3,219	3,489	3,789	4,099	4,397	4,722
43	1,237	2,731	3,059	3,363	3,687	4,019	4,346	4,718
n = number of datasets, %ile = percentile								

Table 3: Percentile values for birth weight for gestational age (22 to 43 weeks) of females – based on the complete dataset.

		Birth weight percentile – Female newborns						
		Complete dataset						
		Birth weight (g)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
22	128	402	446	486	530	582	646	747
23	389	436	487	534	586	645	712	804
24	529	467	529	589	654	726	802	899
25	655	492	572	650	735	825	917	1,026
26	751	508	613	713	823	937	1,049	1,173
27	999	526	659	786	924	1,065	1,200	1,346
28	1,193	567	726	879	1,046	1,215	1,375	1,547
29	1,429	650	829	1,001	1,189	1,380	1,561	1,755
30	1,745	769	965	1,153	1,357	1,563	1,759	1,969
31	2,160	902	1,119	1,325	1,547	1,772	1,986	2,218
32	3,178	1,049	1,288	1,513	1,754	1,998	2,232	2,489
33	4,484	1,234	1,491	1,729	1,983	2,241	2,489	2,766
34	7,809	1,459	1,729	1,977	2,240	2,507	2,768	3,061
35	14,724	1,697	1,975	2,230	2,500	2,776	3,047	3,357
36	29,818	1,937	2,213	2,467	2,737	3,014	3,287	3,601
37	65,202	2,178	2,444	2,693	2,960	3,235	3,507	3,816
38	147,342	2,409	2,659	2,898	3,160	3,431	3,697	3,995
39	269,939	2,590	2,830	3,066	3,328	3,600	3,865	4,159
40	333,335	2,721	2,959	3,197	3,463	3,742	4,012	4,307
41	182,142	2,819	3,060	3,303	3,577	3,864	4,141	4,439
42	21,179	2,806	3,063	3,323	3,615	3,918	4,207	4,515
43	1,058	2,602	2,897	3,189	3,513	3,845	4,155	4,479
n = number of datasets, %ile = percentile								

Table 4: Baseline characteristics of newborns (Head circumference and body length) – based on the complete dataset.

Maternal group	Number of infants			Number of preterm infants		Duration of pregnancy (weeks)	Age of the mother (years)
	all	male	female	male n (%)	female n (%)		
all	2,225,348	1,144,383	1,080,965	79,256 (6.9)	64,403 (6.0)	39.6 ± 1.8	28.9 ± 5.0
> 177 cm / > 79 kg	35,069	18,150	16,919	962 (5.3)	767 (4.5)	39.8 ± 1.7	29.2 ± 4.6
> 177 cm / 71 – 79 kg	29,737	15,370	14,367	755 (4.9)	626 (4.4)	39.8 ± 1.6	29.6 ± 4.4
> 177 cm / < 71 kg	38,600	19,804	18,796	1,236 (6.2)	935 (5.0)	39.6 ± 1.7	29.1 ± 4.6
173 – < 177 cm / > 73 kg	93,895	48,566	45,329	2,749 (5.7)	2,188 (4.8)	39.8 ± 1.7	29.1 ± 4.7
173 – < 177 cm / 66 – 73 kg	78,146	40,392	37,754	2,280 (5.6)	1,810 (4.8)	39.7 ± 1.7	29.3 ± 4.6
173 – < 177 cm / < 66 kg	87,819	44,875	42,944	2,880 (6.4)	2,379 (5.5)	39.6 ± 1.7	28.6 ± 4.8
168 – < 173 cm / > 70 kg	221,950	114,333	107,617	7,007 (6.1)	5,754 (5.3)	39.7 ± 1.8	29.4 ± 4.9
168 – < 173 cm / 63 – 70 kg	207,341	106,912	100,429	6,412 (6.0)	5,147 (5.1)	39.6 ± 1.7	29.4 ± 4.8
168 – < 173 cm / < 63 kg	235,494	121,225	114,269	8,543 (7.0)	6,841 (6.0)	39.5 ± 1.8	28.8 ± 4.8
163 – < 168 cm / > 66 kg	222,066	114,623	107,443	7,679 (6.7)	6,114 (5.7)	39.6 ± 1.8	29.2 ± 5.1
163 – < 168 cm / 60 – 66 kg	178,707	91,956	86,751	6,100 (6.6)	5,018 (5.8)	39.6 ± 1.8	29.0 ± 5.0
163 – < 168 cm / < 60 kg	223,976	114,394	109,582	8,933 (7.8)	7,245 (6.6)	39.4 ± 1.8	28.3 ± 5.1
158 – < 163 cm / > 63 kg	145,216	74,746	70,470	5,503 (7.4)	4,617 (6.6)	39.5 ± 1.9	29.2 ± 5.3
158 – < 163 cm / 57 – 63 kg	119,725	61,662	58,063	4,599 (7.5)	3,614 (6.2)	39.5 ± 1.8	28.7 ± 5.2
158 – < 163 cm / < 57 kg	152,599	78,020	74,579	6,571 (8.4)	5,403 (7.2)	39.3 ± 1.8	28.0 ± 5.2
< 158 cm / > 59 kg	57,253	29,498	27,755	2,537 (8.6)	2,084 (7.5)	39.4 ± 1.9	29.0 ± 5.5
< 158 cm / 53 – 59 kg	45,228	23,118	22,110	1,942 (8.4)	1,619 (7.3)	39.4 ± 1.9	28.3 ± 5.4
< 158 cm / < 53 kg	52,527	26,739	25,788	2,568 (9.6)	2,242 (8.7)	39.2 ± 1.9	27.5 ± 5.3

Table 5: Percentile values for the head circumference for sex and gestational age (25 to 43 weeks, males).

Males		Head circumference (cm)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
25	459	20.9	21.9	22.7	23.7	24.7	25.7	26.9
26	584	21.6	22.7	23.7	24.6	25.7	26.7	28.0
27	727	22.3	23.6	24.6	25.6	26.7	27.8	29.2
28	1,023	23.0	24.4	25.5	26.6	27.7	28.8	30.3
29	1,313	23.8	25.3	26.4	27.5	28.6	29.8	31.3
30	1,644	24.8	26.2	27.4	28.5	29.6	30.7	32.3
31	2,269	25.8	27.2	28.3	29.4	30.5	31.7	33.1
32	3,227	26.8	28.1	29.3	30.3	31.4	32.5	33.8
33	5,164	27.8	29.1	30.2	31.3	32.4	33.4	34.6
34	9,008	28.9	30.2	31.2	32.3	33.3	34.3	35.3
35	17,379	30.0	31.1	32.1	33.2	34.1	35.1	36.0
36	35,709	30.9	31.9	32.9	33.9	34.8	35.7	36.6
37	76,410	31.6	32.6	33.5	34.4	35.4	36.2	37.1
38	163,487	32.3	33.1	34.0	34.9	35.8	36.6	37.5
39	283,021	32.7	33.5	34.4	35.2	36.1	36.9	37.7
40	333,676	33.1	33.9	34.7	35.6	36.4	37.2	38.0
41	184,294	33.4	34.3	35.1	36.0	36.8	37.6	38.4
42	22,614	33.5	34.4	35.3	36.2	37.1	37.8	38.7
43	459	33.2	34.1	35.0	36.0	36.8	37.6	38.5
n = number of datasets, %ile = percentile								

Table 6: Percentile values for the head circumference for sex and gestational age (25 to 43 weeks, females).

Females		Head circumference (cm)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
25	390	20.7	21.5	22.3	23.3	24.4	25.8	27.8
26	449	21.2	22.2	23.1	24.1	25.2	26.5	28.4
27	633	21.9	23.0	24.0	25.1	26.2	27.5	29.2
28	845	22.5	23.9	24.9	26.0	27.1	28.4	30.0
29	1,096	23.3	24.7	25.8	26.9	28.0	29.2	30.8
30	1,333	24.3	25.7	26.8	27.9	29.0	30.2	31.7
31	1,756	25.2	26.6	27.7	28.8	30.0	31.1	32.6
32	2,714	26.1	27.5	28.6	29.7	30.9	32.0	33.3
33	3,983	27.2	28.5	29.6	30.7	31.8	32.9	34.1
34	7,197	28.4	29.6	30.7	31.7	32.8	33.8	34.9
35	14,173	29.5	30.6	31.6	32.6	33.6	34.5	35.6
36	29,330	30.4	31.4	32.3	33.3	34.3	35.1	36.1
37	64,659	31.1	32.1	32.9	33.8	34.8	35.6	36.5
38	146,656	31.7	32.6	33.4	34.3	35.1	35.9	36.8
39	269,026	32.2	33.0	33.7	34.6	35.4	36.2	37.0
40	332,246	32.5	33.3	34.1	34.9	35.7	36.5	37.3
41	181,439	32.8	33.6	34.4	35.2	36.0	36.8	37.6
42	21,092	32.9	33.8	34.6	35.4	36.3	37.0	37.8
43	436	32.4	33.3	34.2	35.1	36.0	36.7	37.5
n = number of datasets, %ile = percentile								

Table 7: Percentile values for the birth length for sex and gestational age (25 to 43 weeks, males)

Males		Body length (cm)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
25	605	27.8	30.0	31.8	33.4	35.0	36.5	38.3
26	715	28.3	30.9	32.9	34.7	36.4	38.0	40.0
27	873	28.9	31.9	34.0	36.0	37.8	39.6	41.7
28	1,187	29.9	33.0	35.3	37.4	39.3	41.2	43.4
29	1,480	31.4	34.5	36.8	38.9	40.9	42.7	44.9
30	1,809	33.3	36.1	38.3	40.4	42.3	44.1	46.1
31	2,475	35.1	37.8	39.9	41.9	43.8	45.5	47.4
32	3,446	36.8	39.3	41.4	43.4	45.2	46.8	48.6
33	5,433	38.5	41.0	43.0	44.9	46.6	48.2	49.8
34	9,299	40.5	42.8	44.6	46.4	48.1	49.6	51.1
35	17,652	42.4	44.5	46.2	47.9	49.5	50.9	52.5
36	36,005	44.1	46.0	47.5	49.1	50.7	52.1	53.6
37	76,762	45.6	47.2	48.7	50.2	51.7	53.1	54.6
38	163,941	46.8	48.3	49.6	51.1	52.6	54.0	55.5
39	283,637	47.7	49.1	50.4	51.9	53.3	54.8	56.3
40	334,400	48.4	49.7	51.0	52.5	54.0	55.5	57.0
41	184,737	48.8	50.2	51.6	53.1	54.6	56.1	57.7
42	22,670	48.9	50.4	51.8	53.4	55.0	56.5	58.1
43	459	48.2	49.9	51.4	53.1	54.7	56.2	57.8
n = number of datasets, %ile = percentile								

Table 8: Percentile values for the birth length for sex and gestational age (25 to 43 weeks, females)

Females		Body length (cm)						
Gestational age (weeks)	n	3rd %ile	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	97th %ile
25	520	26.9	29.2	31.0	32.6	34.3	36.0	38.0
26	579	27.6	30.2	32.1	34.0	35.7	37.5	39.8
27	773	28.5	31.3	33.4	35.3	37.2	39.1	41.5
28	978	29.5	32.5	34.7	36.7	38.7	40.6	42.9
29	1,207	31.0	33.9	36.1	38.2	40.2	42.0	44.2
30	1,481	32.6	35.4	37.6	39.7	41.7	43.6	45.6
31	1,913	34.2	36.9	39.1	41.2	43.2	45.0	47.0
32	2,896	36.0	38.5	40.6	42.7	44.6	46.3	48.2
33	4,171	37.8	40.2	42.2	44.1	46.0	47.6	49.3
34	7,454	39.8	42.0	43.9	45.7	47.5	49.0	50.7
35	14,401	41.7	43.8	45.5	47.3	48.9	50.4	52.0
36	29,579	43.4	45.3	46.9	48.4	50.0	51.4	53.0
37	64,938	44.9	46.5	48.0	49.5	51.0	52.3	53.9
38	147,084	46.1	47.6	48.9	50.3	51.8	53.2	54.7
39	269,632	47.0	48.4	49.7	51.1	52.5	53.9	55.4
40	332,964	47.7	49.0	50.3	51.7	53.1	54.5	56.1
41	181,903	48.2	49.5	50.8	52.2	53.7	55.1	56.7
42	21,141	48.2	49.6	50.9	52.4	54.0	55.4	57.0
43	436	47.4	48.9	50.4	52.0	53.6	55.2	56.8
n = number of datasets, %ile = percentile								

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Dissertation selbständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe.

Die Dissertation ist bisher keiner anderen Fakultät, keiner anderen wissenschaftlichen Einrichtung vorgelegt worden.

Ich erkläre, dass ich bisher kein Promotionsverfahren erfolglos beendet habe und dass eine Aberkennung eines bereits erworbenen Doktorgrades nicht vorliegt.

Bochum, 15.07.2022

Ort, Datum

L. Meyer-Kahrweg

Unterschrift

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