This document describes the application of the customised growth potential to assess fetal size and growth, using the Gestation Related Optimal Weight (GROW) software.

GROW – Customised Weight Centiles
- to calculate birthweight centiles individually or in bulk;

GROW – Customised Growth Charts
- to plot fundal height and estimated fetal weight.

Updated August 2009

1. Introduction

The customised growth chart concept was developed initially in Nottingham in the early 1990s [1]. While recognising the importance of growth for fetal well being, we became increasingly aware that existing charts were not useful for clinical assessment in a heterogeneous maternity population.

Over time, we have been able to test the concept of adjustable or customised assessment of growth and birthweight from many different perspectives. We are constantly seeking to improve and add to the database which allows application in different populations.

The project has been fortunate to benefit from a number of dedicated researchers, statisticians and programmers over the years, who are acknowledged in various publications referenced here. While the strengths of the method and its implementation are due to the efforts my collaborators, any weaknesses are entirely my own responsibility.

We hope that you find our software useful for the assessment of fetal growth and birth weight. We are continuing to seek to improve it, and comments and criticisms are always welcome, so please do not hesitate to get in touch.

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The software can be referenced as follows

Birthweight centiles:

Gardosi J, Francis A. Customised Weight Centile Calculator – GROW-Centile v.5.12/6.2 2009. Gestation Network, www.gestation.net (v. 5.12: individual; v 6.2: bulk centiles)

Antenatal growth charts:

Gardosi J, Francis A. Customised Antenatal Growth Chart - GROW-Chart v 7.5, 2009. Gestation Network, www.gestation.net

2. General Concepts

The software allows the generation of an individual or 'customised' standard by adjusting for physiological factors which are known to affect fetal growth. The pregnancy characteristics are entered to calculate the **Term Optimal Weight (TOW, Section 3)**. This is the weight which the baby is predicted to achieve in the absence of pathological influences. The calculation of TOW is centred on 40.0 weeks (280 days).

Through this point TOW, the proportionality curve is plotted to delineate how this weight is expected to be reached in a normal pregnancy (see section 5). This gives an individually adjusted **Gestation Related Optimal Weight (GROW)** curve. Around this optimal line, the normal variation can be calculated and limits such as the 10^{th} and 90^{th} centile lines drawn. Thus neonatal weights from previous pregnancies, as well as fundal height measurements or fetal weight estimations in the current pregnancy, can be seen in relation to individually adjusted optimal weight limits.

There are 3 underlying **principles for GROW-percentiles**:

1. Weights are assessed in reference to a standard which is **individually adjusted** for physiological pregnancy variables (maternal height, weight, parity and ethnic group); e.g. at 40 weeks, a 3000g baby is small for an average size mother but may be normal for a small mother.
2. The standard is **'optimised' to obtain the growth potential**, i.e. pathological variables such as smoking are excluded. This means that the expected term baby weight for a mother who smokes is calculated as if she was a non-smoker, so that if her baby's growth **is** affected, it is more likely to be detected.
3. Optimal weight is calculated using a **fetal** rather than a **neonatal** weight standard. Preterm neonatal weights are abnormal by definition, and have often been affected by fetal growth retardation preceding spontaneous or iatrogenic preterm delivery. Eg. at 32 weeks, a 1500g baby would fall within normal birth weight limits, but is small according to a 32 week fetal weight standard derived from normal term pregnancies.

3. Calculating the Optimal Weight

The main non-pathological factors affecting birth weight are **gestational age, maternal height, maternal weight at booking, parity and ethnic group.**[1] Coefficients to adjust for these were derived from a dataset of around 40,000 ultrasound dated deliveries. They allow calculation of an expected birth weight for each pregnancy, and the 'customised' percentile which a particular weight has achieved in relation to this expected endpoint. An alternative method to adjust for such variables is to calculate the individual birth weight ratio (IBR). [2 3 4]. IBR follows principle 1 above, i.e. adjusts for individual variation, but does not optimise (principle 2) or apply a fetal weight standard (principle 3).

> **NB:** In previous versions of the software, the adjustment for maternal weight was limited to within 'normal' BMI limits, defined as 20-30. However no such adjustment is made in current versions of the software, since evidence has shown that the association between SGA babies and perinatal mortality is stronger without such adjustment [5].

Other physiological variables such as **paternal height** have, unless extreme, a relatively minor effect [6] and may in any case not always be known with certainty. **Maternal age** appears to play no significant role once parity is controlled for.

Pathological factors such as **smoking, social deprivation, pre-eclampsia or diabetes** are also known to be related to birth weight but are not adjusted for. The purpose is to calculate the optimal weight, against which the actual weight can be assessed. Thus 'term optimal weight' (TOW) represents an ideal standard rather than the average for an unselected population. TOW is centred on day 280, the median length of pregnancy in our population.

4. Coefficients for adjusting the term optimal weight (TOW)

Coefficients are derived from suitable databases using a multiple regression model centred on a standard gestational age (280 days), the largest ethnic group, average maternal height and weight at booking, and first pregnancy (para 0). In addition, gender is listed as an 'average' i.e. sex-neutral. The regression model has a constant to which weight is added or subtracted for each of the variables, according to the formula

TOW = constant + htao + wtao + ethao + parao + sexao

where 'ao' are add-ons, respectively, for

ht = maternal height
wt = maternal weight at booking (first visit)
eth = ethnic origin
par = parity and
sex = sex of fetus/neonate, if known

The following table illustrates the application of coefficients, using a UK database [7] which has since been updated to include additional ethnic groups.

UK (Nottingham) coefficients

Name of coefficient	Contribution in grams
Constant	3455.6
Maternal height (*median 163 cm*) deviation for each cm	6.7
Maternal weight (*median 64 kg*) deviation:	
for each kg	9.173
for each kg^2	-0.151
for each kg^3	-0.001
Ethnic origin (*default European incl British Isles and those of European origin elsewhere. eg Australia, Canada, USA*)	
Indian	-149.4
Pakistani	-187.3
Bangladeshi	-79.3
Afro-Caribbean	-127.5
African (sub-Sahara)	-218.5
Middle East (inc North Africa)	-89.9
South East Asia (eg Thailand, Malaysia, Philippines)	+56.4
Parity at beginning of pregnancy (*default para 0*)	
Para 1	+101.9
Para 2	+133.7
Para 3	+140.2
Para 4 or more	+162.7
Sex of fetus/neonate (*default 'average' i.e. sex neutral*)	
Male	+48.9
Female	-48.9

We have coefficients from suitable databases from Australia, New Zealand and the United States (see Appendix - Section 10). Others are to be added soon .

5. Proportionality curve

Once the TOW (term optimal weight, predicted for 280 days gestation) is calculated, it is combined with a proportionality growth function to determine the optimal weight at all gestations. This function transforms the average weights at all gestations to a percent of term weight in that population. The proportionality principle can be used retrospectively (birthweight to fetal weight) or to project fetal weight to predict birth weight [7 8].

Reviews of published formulae for fetal weight gain suggest that most follow a similar pattern, or growth dynamic, although the endpoints (term weights) may vary [9 10]. Our standard formula is derived from Hadlock's fetal weight equation [11] which closely reflects normal fetal weight in other populations. The proportionality equation is :

$$\% \text{ weight} = 299.1 - 31.85\,GA + 1.094\,GA^2 - 0.01055\,GA^3$$

where GA = gestational age in weeks.

Thus for each individually predicted Term Optimal Weight (TOW), the formula is used to produce a Gestation Related Optimal Weight (GROW).

6. Normal range

The normal limits of weight for all gestations are calculated from the coefficient of variation (CV) of the TOW. It is derived from the SD and Mean (Constant) of the population through the regression model, and defined as:

$$CV\ (\%) = \frac{SD * 100}{Mean}$$

For the UK database, SD = 389, Constant = 3455. Thus, in this case CV = 11%

The centile limits are derived using Z scores. For example, the 90th and 10th centiles are represented by z = ± 1.28.

Therefore: $z * CV = \pm 1.28 * 11\% = \pm 14\%$;

Thus
90th centile = TOW + 14%
10th centile = TOW – 14%

E.g. the 10th to 90th centile range for a TOW of 3500g is 3500 ± 14%, i.e. range 3010-3990g.

The effect of using the CV is that the range designated as 'normal' becomes narrower for lower TOWs and wider for higher TOWs. Thus a small baby is allowed a smaller range of normal variation in absolute terms. The method compensates for the positive skewness of the distribution of birth weight.

The proportionality weight equation is fitted through the three term points: TOW, TOW+14% and TOW–14%. This defines the 50th, 90th and 10th centile lines respectively for the gestation period 24 to 42 weeks. This principle is used in the applications described in the following sections.

7. GROW - Customised Weight Centiles

The GROW Customised Weight Centile module allows a weight-for-gestational age centile to be determined for previous babies, and for estimated fetal weights and birth weight in the current pregnancy.

Centiles for previous pregnancies are calculated for the corresponding parity, i.e. the parity of the mother at the *beginning* of the respective pregnancy. However no adjustment is made for maternal weight if it was different in a previous pregnancy. The application can also be used for a fetal weight centile when the sex of the baby is not known.

Precise gestational age (at birth, or at the point of EFW measurement) needs to be entered. Gestational age can be calculated with the 'Gestational Age Calculator' - see section 9 below.

NB: When a particular data item is missing or unobtainable, e.g. maternal height, partial customisation can be undertaken by entering an estimate or population average - e.g. 165 cm.

The GROW Customised Centile Calculator comes also in spreadsheet format to allow calculation of centiles for whole databases.

8. GROW – Customised Growth Charts

The GROW Customised Growth Chart module allows the generation of antenatal charts After entering the pregnancy data through the 'Mother details', 'Baby details' and 'EDD' sub-routines, the chart is generated on screen and can be printed out in early pregnancy.

It shows

- a summary of the pregnancy details and the BMI calculated from maternal height and weight
- previous babies' birthweight centiles
- 10th, 50th and 90th centile lines for the current pregnancy
- on the x-axis, the EDD and the day and month for each week of gestation
- two y-axes:

  left axis: fundal height (FH, in cm),

  right axis: estimated fetal weight (EFW, in g)

The relationship between weight and fundal height is described by a formula derived from a study of 260 simultaneous EFW and FH measurements [12], showing a linear relationship in the third trimester

EFW (grams) = 226 * FH – 5012

Linked to weight, fundal height norms are therefore also customised according to pregnancy characteristics, thereby allowing for individual variation. Multivariate analysis of fundal height measurement in 325 pregnancies showed that maternal characteristics such as parity and weight were significantly associated with fundal height values in the third trimester [13].

The chart can be attached to the hand held maternity notes – (e.g. the Pregnancy Notes - *www.preg.info*) and used for fetal growth monitoring in the community, provided the pregnancy is considered low risk. From 24-26 weeks onwards, we recommend serial (2- 3 weekly) fundal height measurement with a non-elastic tape, preferably by the same care provider. The measurement should start from the variable point (the fundus) to the fixed point (upper border of the symphysis pubis), along the longitudinal axis of the uterus (which should *not* be corrected to the mid-line).

The FH should be plotted using an 'x' symbol. If slope through consecutive plots is not parallel to either of the predicted centile lines (90th, 50th, 10th) on the chart, and either of the centile lines are 'crossed', fetal biometry by ultrasound scan is recommended. It is important to assess liquor volume and measure fetal biometry parameters to calculate estimated fetal weight (EFW) This can then be plotted using an 'o' symbol. If the baby is small, further investigation such as Doppler flow assessment of the umbilical artery is recommended. Subsequent management will depend on these results and clinical considerations, and can include repeated ultrasound and Doppler, or return to serial FH measurements.

GROW-charts can be used for screening for intrauterine growth restriction (IUGR) and macrosomia. A controlled study of community growth screening suggests that serial plotting of fundal height on customised charts increases the detection rate of growth abnormalities while decreasing the rate of unnecessary referrals for further investigation. [14] A subsequent audit in the West Midlands has confirmed these findings [15]. Ultrasound EFWs plotted in normal pregnancies are more likely to stay within customised GROW limits than if general limits for the whole population are used - i.e. customisation of fetal weight reduces the false positive diagnosis of 'IUGR' [16]. The use of customised charts is recommended by RCOG guidelines [17].

9. Gestational Age Calculation

Accurate pregnancy dating is a central requirement for any weight centile assessment. The 'Calculate EDD' function within GROW has options for entering:

1 - the last menstrual period (LMP), to which 280 days are added to determine the expected date of delivery (EDD);

2 - scan measurements from which the EDD is calculated according to standard references for 1st trimester CRL[18] , or for 2nd trimester BPD [19] or HC [20];

We recommend that ultrasound dates should be used, where possible, *without* allowance for the LMP. There are considerable discrepancies between even 'certain' menstrual dates and scan dates [21] [22], and many analyses have suggested that ignoring menstrual history altogether improves the accuracy of pregnancy dates. [23] [24] [25]

10. Appendix: International coefficients

Coefficients for Australia [26] (Nepean Hospital, Sydney), New Zealand[27] (National Women's Hospital) and the United States [28] (NIH study with 15 centres) are given in the following three tables.

Each set of coefficients has been standardised to allow comparisons, to: maternal height 163cm; maternal weight 64kg; ethnic origin European; parity 0; sex neutral (see also Table 2 in Reference 26, and Table 3 in Reference 28).

Australian coefficients [26]

Database of 12,420 singleton live births without congenital anomalies, born at 37 weeks or longer. Births were routinely dated by ultrasound in the second trimester.

Name of coefficient	Contribution in grams
Constant	3463.6
Maternal height (*deviation from 163 cm*)	
for each cm	7.8
Maternal weight (*deviation from 64 kg*)	
for each kg	9.0
for each kg^2	-0.15
for each kg^3	-0.001
Ethnic origin (*default European*)	
Indian/Pakistani	-162.0
Middle-Eastern	-110.0
African	-297.4
Parity (*default para 0*) at beginning of pregnancy	
Para 1	+94.8
Para 2	+115.2
Para 3	+116.0
Para 4 or more	+99.2
Sex of fetus/neonate *(default 'average' i.e. sex neutral)*	
Male	+66.9
Female	-66.9

New Zealand coefficients [27]

Based on hospital births in Auckland between 1993 and 2000. Exclusions: multiple pregnancies, congenital abnormalities, stillbirths, preterm births; n=4,964

Name of coefficient	Contribution in grams
Constant	3464.4
Maternal height (*deviation from 163 cm*)	
for each cm	9.6
Maternal weight (*deviation from 64 kg*)	
for each kg	8.44
for each kg^2	-0.114
for each kg^3	-0.00065
Ethnic origin (*default European*)	
Indian	-149.5
Chinese	+100.9
Maori	-66.8
Samoan	+84.2
Tongan	+124.1
Parity (*default para 0*) at beginning of pregnancy	
Para 1	+101.6
Para 2	+101.8
Para 3	+123.3
Para 4 or more	+175.5
Sex of fetus/neonate *(default 'average' i.e. sex neutral)*	
Male	+57.7
Female	-57.7

United States (US) coefficients [28]

From a National Institutes of Health-sponsored study conducted at 15 centres, 1999 -2002.
N= 30,837 cases after exclusions

Name of coefficient	Contribution in grams
Constant	3453.4
Maternal height (*deviation from 163 cm*)	
for each cm	6.4
for each cm^3	-0.003
Maternal weight (*deviation from 64 kg*)	
for each kg	7.578
for each kg^2	-0.087
for each kg^3	-0.0005
Ethnic origin (*default European*)	
African American	-161.0
Hispanic	-38.6
Other	-140.8
Parity (*default para 0*) at beginning of pregnancy	
Para 1	+96.2
Para 2	+121.9
Para 3	+125.9
Para 4 or more	+122.7
Sex of fetus/neonate *(default 'average' i.e. sex neutral)*	
Male	+66.0
Female	-66.0

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