This document covers the principles behind Gestation Adjusted Optimal Weight (GROW) for the following applications

GROW-CC (customised centiles)
- for calculating weight centiles individually or in a spreadsheet;

GROW-AC (antenatal charts)
- for antenatal plotting of fundal height and estimated fetal weight

1. Introduction

GROW has arisen out of a collaboration in Nottingham the early 1990s. While recognising the importance of growth for fetal well being, we became increasingly aware that our existing charts were not useful for clinical assessment in our heterogeneous maternity population.

Over time, we have been able to develop and 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 many dedicated researchers, statisticians and programmers over the years, who are acknowledged in various publications referenced here. While the strengths of the method are due to the efforts of 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, 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. GROW Customised Centile Calculator – GROW-CCC software v 5.1, 2006. Gestation Network, www.gestation.net

Gardosi J, Francis A. GROW Customised Centile Spreadsheet – GROW-CCS: Software v 5.1, 2006. Gestation Network, www.gestation.net

Antenatal growth charts:
Gardosi J, Francis A. Customised Antenatal Growth Charts - GROW-CAC software v 7.1, 2006. Gestation Network, www.gestation.net

Antenatal growth charts:
GROW-CAC software v 7.1, 2006. Gestation Network, www.gestation.net

2. General Concepts

This 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)**. 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. 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. E.g. 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 in our population 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). The results of both methods are highly correlated (R>0.99) and are each better correlated with growth retardation than raw birth weight percentiles [2 3 4]

The coefficients for adjusting birth weight percentiles have been upgraded to include additional ethnic categories, using a comprehensive, population based, well dated database from a single unit (Queen's Medical Centre, Nottingham, UK). Details are given in the next documentation section ('**Coefficients for model**'). The analysis has shown that differences between 1st and 2nd generation migrants and those between UK and non-UK 'Europeans' are negligible.

The **'booking weight'** refers to the main visit in the first half of pregnancy, i.e. up to say 20 weeks. Pre-pregnancy weight may be better but is often not known. Our coefficient for maternal weight is derived from the hospital booking visit which in the 1990s was usually at 16-19 weeks.

The program includes a subroutine which determines the **body mass index** [BMI = Weight / (Height2)]. If BMI is below the 10th centile for our population (=19.96), the maternal weight is adjusted upwards so that BMI is = 10th centile before the TOW is calculated, and a warning appears on the GROW chart to alert the clinician of possible maternal malnutrition. A corresponding downward adjustment of maternal weight is made if BMI > 90th (29.9), and a warning appears on the chart that BMI is high.

Other physiological variables such as **paternal height** have, unless extreme, a relatively minor effect [5] 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 para=0. In addition, gender is listed as an average or 'neuter', 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

Currently, we have coefficients from suitable databases from the UK, Sweden and New Zealand. Soon to be added: Australia, Spain, Israel.

The following illustrates the application of coefficients, using the UK database REF. These come from 10 year data of routine scan-dated pregnancies booked and delivered at Queen's Medical Centre, Nottingham, and represent a general, unselected maternity population.

	Grams
Constant:	3455.6
Maternal height (median 163 cm)	
For each cm from median:	+/- 6.7

Maternal weight (median 64 kg)
For each kg from median +/- 9.1733 * wt + (-0.151wt^2) + (-0.001wt ^{3})

Ethnic origin (default: European)
incl British Isles and those of European origin elsewhere - e.g. Australia, Canada, US)

Indian	-149.4
Pakistani	-187.3
Bangladeshi	-79.3
Afro-Caribbean	-129.9
African (sub Sahara)	-218.5
Middle-East incl. North Africa	-89.9
Far East Asia -e.g. Japan, Korea, China	-0.3
South East Asia - e.g. 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: not known = 'neuter')

Male	+ 48.9
Female	- 48.9

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) REF or to project fetal weight to predict birth weight [6 7] .

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 [8 9]. Our standard formula is derived from Hadlock's fetal weight equation [10] which closely reflects normal fetal weight in other populations. The proportionality equation is :

% weight = 298.8 - 31.85 GA + 1.094 GA^2 -0.01055 GA^3

where GA = gestational age in weeks.

(Note: The constant has been changed from the originally published 299.1 [6] to 298.8, to take account of rounding errors in coefficients, to ensure that weight = 100% when GA=40)

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:

$$CV\ (\%) = SD * 100 / Mean$$

The CV is derived from the SD and Mean (Constant) of the population through the regression model. For the UK database (see section ….above), SD = 389, Constant = 3455 i.e. CV = 11%

The centile limits are derived using Z scores. For example, the 90th and 10th centiles represent z = +/- 1.28. Therefore Z * CV = +/-1.28 * 11 = 14%;

Thus 90th centile = TOW + 14%

10th centile = TOW – 14%

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

The effect of using the CV is that the range designated as 'normal' becomes narrower for lower TOWs and larger 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 50yh, 90th and 10th centile lines for the gestation period 24 to 42 weeks. This principle is used in the applications described in the following sections.

7. GROW-CC: Customised Centiles

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

Birth weight centiles for previous pregnancies are calculated for the corresponding parity. 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 measuring EFW) needs to be entered. GA can be calculated with the Gestational Age Calculator' - see below, 7. software on *www.gestation.net/EDD*.

When a particular data item is missing and unobtainable – e.g. maternal height – partial customising of the normal limits can be undertaken by entering an estimate or a population average - e.g. 165 cm.

GROW-CC comes also in a spreadsheet format (GROW CCS) to calculate centiles for databases.

8. Gestational Age Calculation

A central requirement to any weight centile assessment is the knowledge of accurate pregnancy dates. The 'Calculate EDD' function has options for :

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

2- entering scan measurements from which the EDD is calculated according to standard references for 1st trimester CRL[11] or 2nd trimester BPD [12] or HC [13];

We recommend that, where possible, ultrasound dates should be used, without 'allowing' for the LMP. There are considerable discrepancies between even 'certain' menstrual dates and scan dates [14] [15] and many analyses have suggested that ignoring menstrual history altogether improves dating accuracy. [16] [17] [18]

9. GROW-FG: Fetal Growth

The GROW Fetal Growth module allows the generation of customised antenatal growth 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
- 10^{th} 50^{th} and 90^{th} centile lines for the current pregnancy
- on the x axis, the EDD and the day and month for each completed week of gestation
- two y - axes – left: fundal height (FH), right: estimated fetal weight (EFW)

The relationship between weight and fundal height is described by a formula derived from a study of 260 simultaneous EFW and FH measurements [19], showing a linear relationship in the third trimester

EFW (grams) = 226 * FH – 5012
where FH = fundal height in cm.

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 [20].

The chart can be attached to the pregnancy notes (see *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) 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', and if the line through consecutive plots is not parallel to either of the predicted centile lines (90th, 50th, 10th) on the chart and centile lines are 'crossed', fetal biometry by ultrasound scan is recommended. It is important to assess liquor volume, and

the fetal biometry parameters needed to calculate the estimated fetal weight (EFW) This can be plotted manually, using an 'o'. If the baby is small, further investigation by Doppler flow assessment of the umbilical artery is recommended. Subsequent management will depend on these results and clinical considerations, and can include continued ultrasound / 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. [21] A subsequent audit in the West Midlands has confirmed these findings [22]. Ultrasound estimated fetal weights plotted in normal pregnancies are more likely to stay within the customised limits defined by the GROW curves than if general limits for the whole population are used - i.e. 'customising' fetal weight limits reduces the false positive diagnosis of 'IUGR' [23]. The use of customised charts is recommended in RCOG guidelines [24]

10. References

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