Advances in Growth Chart Design and Use: The UK Experience

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Abstract

As part of the process of adopting the WHO standard in the United Kingdom, the Royal College of Paediatrics and Child Health (RCPCH) was commissioned by the UK Department of Health to design new UK-WHO growth charts. The working group for this project combined expertise ranging from statistics and graphic design to qualitative research, as well as paediatrics, nursing and dietetics. New charts for children under 4 years were published in 2009 and are now widely used in the UK and beyond (www.growthcharts.rcpch.ac.uk). This paper will describe what we have learned in general about the process of designing charts and how these principles were applied to the design of a novel chart designed specifically for sick and premature infants. A successful design first requires clarity about the exact purpose of the chart and who will use it. The layout of the chart can then be varied in many ways to fit that use and ensure users are not misled. Users need consistent and well-evidenced rules for chart use. Drafting the instructions serves as a powerful test of the validity and clarity of the design. However, charts need also to be formally evaluated, as expert views will not reflect those of the average user. The Neonatal and Infant Close Monitoring (NICM) chart included various novel design features, including date boxes for gestational age adjustment and low SD lines to help assess very small infants. It was evaluated at three stages using plotting exercises and each phase led to substantial design changes. Growth charts are conceptually very complex, with the capacity to mislead as well as inform and should always be formally evaluated before implementation.

Background

Growth charts are used almost universally and are essential for child health surveillance and early detection of growth abnormalities. They are vital to diagnostic decisions and judgments, but chart design also frames perceptions of normality and thus drives screening activity. The World Health Organization (WHO) growth charts, being based on healthy breastfed children, define for the first time how all
children aged 0–5 years should grow, whatever their ethnic origin. Whilst this has led to much thought about the data underlying growth charts, the design and layout of the charts themselves has been much less studied.

The limited research that has been done in this area has demonstrated on the whole that parents and health professionals understand charts poorly [1–3]. In 2008, the United Kingdom Royal College of Paediatrics and Child Health (RCPCH) was commissioned by the English Department of Health to design new preschool charts implementing the new WHO Standard in the UK. This was an opportunity to take a fresh look at the use of growth charts in the UK. The preschool charts were published in Spring 2009 and are free to download along with supporting educational materials (www.growthcharts.RCPCH.ac.uk). Since then the Working Group has been developing school-age charts, to be published in May 2012. The process of designing these charts has taught us a great deal, which could inform other countries going through similar processes.

What Makes a Good Growth Chart?
Successful chart design requires the combination of careful planning a consultation and graphic design skills (table 1). Our working groups included the full range of clinicians using the charts, including nurses and dieticians, as well as experts in design and evaluation.

Who Is the Chart for?
Firstly, it has to be clear exactly what the intended use of the charts is. Which health professionals will mainly use this chart? What skills and experience will they need? It also needs to be clear whether the main use will be for population screening or for the diagnosis and monitoring of sick children and exactly what age range will be covered. It is also important to decide who the chart should not be used for, so that rare conditions do not dominate design decisions. For example, when designing the main preschool chart, we had to produce a design describing normal growth between birth and the age of 4 years that would be useful in screening and monitoring a rather than managing disease [4]. A design suitable for children born at term could not meet the needs of those monitoring the growth of extremely preterm infants, so a separate chart for children born before 32 completed weeks of gestation was produced (see below).

Layout
Only once the proposed use is clear can a design be developed. The layout of charts can be varied in many ways and this will strongly influence one’s perception and understanding of the chart. For example, an early focus group with parents demonstrated that they interpret a bold 50th centile as meaning that all children should follow that centile closely [5], leading us to de-emphasise the 50th centile in our designs (fig. 1). Choosing the appropriate major centile or SD lines to be used is also important. If a national growth chart has the 5th percentile as its lowest
centile, it labels 1 in 20 healthy children as potentially abnormal. The UK nine centile format [6] provides more extreme centiles, which are valuable for screening purposes, but for sick children even lower SD lines may also be helpful (fig. 2). It is helpful to depict more than one anthropometric measure per page to allow appreciation of body proportions. This avoids wasted chart space, but it is important to avoid overlap between the extremes of adjoining measures: for example, obese children’s weights being plotted within the height centiles. The age range and scale can then be manipulated to maximise the useable plotting area and avoid curves that are too steep; gradients of between 30 and 45% seem to be most easy to plot and interpret. While it may be tempting to smooth transitions between different data sets, this can be highly misleading. For example, previous UK charts smoothed the transition between gestation, specific birth and infancy data, but this

**Fig. 1.** The arrow drawn back method of gestational correction to be used from term onwards for moderately preterm infants, 32–36 completed weeks gestation. The method avoids the need for calculation and ensures that the age adjustment is evident to subsequent chart users.

**Table 1.** What makes a good growth chart?

<table>
<thead>
<tr>
<th>Be clear about the purpose and the main users of the chart</th>
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<tr>
<td><strong>Design</strong></td>
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<tr>
<td>Should fully (and only) reflect meaning and proposed use</td>
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<td>Prioritise simplicity of use</td>
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<tr>
<td>Avoid need for calculations wherever possible</td>
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<td><strong>Instructions</strong></td>
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<tr>
<td>Start drafting early and use them to drive the design process</td>
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<td>Should describe rules for use which are</td>
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<td>Well evidenced</td>
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<td>Acceptable to main stakeholders</td>
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<tr>
<td>Consistent with national and professional guidelines</td>
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<tr>
<td>Clear, explicit and internally consistent</td>
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<tr>
<td>Most important rules should be on chart itself</td>
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<td>Supply supporting educational materials</td>
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failed to characterise the normal slowing of weight gain after birth, making them inaccurate in the neonatal period [7]. Finally, the design needs to incorporate sufficient contrast and clear labelling to aid readability and photocopying.

Charts need to be as simple as possible for use by busy healthcare staff, particularly when under pressure. In the evaluation and educational phases for the UK-WHO charts, we learnt that it was advisable to avoid all calculation if possible, as few staff use calculators and computational mistakes are common. We have now designed a number of chart features that obviate the need for calculation and that staff find useful: a BMI lookup [8], a predicted height scale [9] and date boxes (see below). Charts that may appear simple to the expert enthusiast, can be confusing to non-expert staff, so formal testing and consultation is essential. In designing the UK-WHO charts, a mixture of discussion and formal testing with plotting exercises was used [10]. The aids described above were much improved as result, but others design ideas were abandoned altogether.

Instructions
Drafting the instructions for the UK-WHO charts proved extremely challenging, but the process strongly informed the chart design, as the process of describing how to use chart features aided recognition of inconsistencies and uncertainties. Instructions need to cover measuring, plotting, terminology and interpretation, but not clinical protocols, which will depend upon the setting and the type of staff using the chart. These need to be well evidenced, rather than relying on consensus from within what may be a quite narrow group. We drew on existing publications, but also undertook new analyses and collected our own evidence via specially convened focus groups [10].

Not all aspects could be informed by hard evidence, but it became evident during the evaluation that staff appreciated clarity and consistency and were looking for rules rather than generalities. An example of this was the question of adjustment for preterm gestation. It was clear in the evaluation groups that staff found this confusing and were inconsistent in applying it [10]. The working group thus identified a consistent and simple approach – the ‘arrow drawn back’ method (fig. 1). These rules must also be acceptable to the main professional groups using the charts and be consistent with national and professional guidelines, something that requires consultation and negotiation.

Throughout this process the instructions need to be edited and proof read repeatedly to achieve clarity and consistency. We went through many drafts that were continually improved.

In practice, the instructions will never be read in full and many users will not read them at all. Thus, we placed the key information on the chart itself, for example using speech bubbles to highlight novel features and placing the definition of prematurity and the adjustment method on the preterm chart section. These were major chart changes so they required formal dissemination, so it is important to simultaneously produce good quality supporting educational materials that are widely available.
Designing the Neonatal and Infant Close Monitoring Chart

We describe here the planning and design of this novel chart as a worked example of how evaluation informs the design process. The Neonatal and Infant Close Monitoring (NICM) chart was designed initially just for children born before 32 completed weeks of gestation, but it became evident that it would also be useful for any neonate or infant requiring close monitoring, hence its final title 'The Neonatal and Infant Close Monitoring Chart'.

The Design Team
The design process was led by a community paediatrician (C.M.W.) a neonatal paediatrician (A.W.) and a statistician (T.J.C.), advised by an expert group of neonatal paediatricians, a neonatal dietician and an infant feeding advisor. The graphic design work was undertaken by a specialist printing firm (Harlow Printing) in consultation with the RCPCH team.

Source Data
The source data for the chart were the same as the for the main UK-WHO charts: a combination of cross-sectional birthweight, length and head circumference data for British babies born between 23 and 42 weeks of gestation [11] reanalysed to fit the curve through to 42 weeks of gestation [12]. After 2 weeks of corrected age (or 42 weeks of postmenstrual age) the source data came from the WHO Multicentre Growth Reference Study [13].

Novel Features of the NICM Chart
Most previous charts have been designed to describe the patterns of growth of healthy average children, although in practice their most important use is often for assessing children at the extremes of the normal range. In designing a chart for extremely preterm infants, we therefore sought to include design features that would make it easier to assess children who may be much smaller than normal and require frequent monitoring.

Large Scale and Low Reading
The aim was to provide a chart with plenty of room to plot children over short time intervals, so the age axis was stretched between estimated date of delivery (EDD) plus 2 weeks to 6 months. In order to maximise the plotting area within the curves, the length grid was moved to the top of the page with head circumference in the middle. As well as the 9 major centiles used on other UK charts [6] extra lines for –3, –4 and –5 SD (z-score) were added. These are a different colour and weight from the major centiles to ensure that they are recognised to be well below the range of measures observed in healthy children.
Date Box Method of Gestational Adjustment

Use of the ‘arrow drawn back’ method (fig. 2) poses significant problems when applied to gestational correction in extremely preterm babies. In consequence, it was recognised that the NICM chart would require an inbuilt system for plotting against postmenstrual and corrected age. However, early evaluation demonstrated that adjustment (or ‘correction’) of age for the degree of prematurity was laborious and difficult. Even very experienced users made significant mistakes, particularly at later ages (table 2). Members of the working group used a variety of methods, but the most robust method identified was the use of date boxes (fig. 2). This novel feature requires users to enter dates along the bottom of the chart, starting either from...
Table 2. Stages of evaluation of the NICM chart and impact on design

<table>
<thead>
<tr>
<th>Setting/characteristics of respondents</th>
<th>Results of plotting exercise</th>
<th>Comments&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Design changes following field testing</th>
</tr>
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<tbody>
<tr>
<td>Testing within working group. 9 neonatologists, 71 plots at 14 ages</td>
<td>Most (91%) preterm plots accurate 14% plots birth–6 months &gt;1 week wrong 57% plots 6–24 months &gt;1 week wrong</td>
<td>Slow to plot, gestational age calculation laborious</td>
<td>Date boxes added to design up to age 6 months. Arrow drawn back method recommended 6–12 months</td>
</tr>
<tr>
<td>Plotting workshops in 3 neonatal units. 41 participants (38 paediatricians) 348 plots; 14 (34%) &gt;10 years' experience. 38 (95%) plotting charts ≥ once per week</td>
<td>23% (9) misdated date box nearest to birth Most (97%) preterm plots accurate to within 1 week 10% plots birth–6 months &gt;1 week wrong 33% plots 6–24 months &gt;1 week wrong, 9% &gt;1 month wrong.</td>
<td>85% (28) commented positively about the date box system. Only 46% commented positively about the arrow drawn back method and only 31% (11) used it. 52% (17) rated the new charts as better, 15% (5) worse than their previous charts</td>
<td>Date boxes on the 2 weeks to 6 months page changed from monthly to fortnightly. Date boxes added to last page (6–24 months). Arrow drawn back method&lt;sup&gt;1&lt;/sup&gt; discouraged Universal calendar added to the chart</td>
</tr>
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<td>Questionnaires completed by delegates at RCPCH annual meeting. 22 paediatricians, 138 plots; 15 (71%) &gt;10 years' experience. 20 (95%) plotting charts ≥ once per week.</td>
<td>6% (1) misdated date box nearest to birth All preterm and 0–6 months plots accurate to within 1 week 15% (7) plots 6–24 months &gt;1 week wrong, 4% &gt;1 month wrong, all by respondents who had misdated date boxes.</td>
<td>73% (16) commented positively about the date box system. 70% (14) commented positively about the new calendar. 85% (16) rated the new charts as better and 5% (1) worse</td>
<td>Length and head curves swapped to make more space for head as used more than length Date box instructions refined</td>
</tr>
<tr>
<td>Plotting workshops comparing old and new, 6 age points plotted on each chart version; 24 participants (14 paediatricians, 10 dieticians) 54% (12) &gt;10 years' experience. 92% (22) plotting charts ≥ once per week.</td>
<td>On new charts 10% (2) misdated date box nearest to birth, but all within 1 week. All preterm plots accurate to within 1 week. No difference between old and new chart types before 6 months, but between 6 and 24 months, on new chart only 5% plots (2) plots were 1 week or more wrong, compared to 30% (10) on old chart (p &lt; 0.01)</td>
<td>85% (11) commented positively about the date box system 92% (11) commented positively about the new calendar 100% (12) rated the new charts as better</td>
<td>Transition from dates boxes on 23–42 week page to 2–26 week page made clearer Labelling of date boxes improved Calendar instructions simplified</td>
</tr>
</tbody>
</table>

<sup>1</sup>Percentages are of those who wrote comments.
estimated date of delivery (EDD) if known, or using birth date and the gestational age at birth. Once date boxes have been populated, all measurements can be entered accurately and quickly against the date of measurement. This system avoids the need for repeated age calculation, achieving accuracy and clarity of gestational correction. The concept seemed hard for some to grasp initially, but proved popular once used in practice in the plotting workshops. Adding the date boxes reduced the proportion of errors overall and further improvement was seen once a generic calendar was added to the chart. It was also evident that completing the date boxes beyond the EDD was time consuming, making it only worthwhile for long-term monitoring rather than short-term individual plots.

Field Testing
As the design progressed it was tested repeatedly, with amendments after each phase. First members of the working group did some plotting, then the first formal testing was undertaken in plotting workshops conducted in three neonatal units. These involved an introductory talk followed by a plotting exercise, after which both workbooks and charts were handed in for analysis. After further changes, a more refined version of the chart was tested through self-completion questionnaires administered to delegates attending the RCPCH annual meeting in April 2009. Final changes were then made and a prototype chart published. Three further plotting workshops then compared the prototype NICM chart with the previously used neonatal chart and further evaluation was undertaken during training. A few more subtle problems with chart layout and instructions were identified and the final design was published in April 2011. Details of the findings at each phase and the impact this had on the design are shown in table 2.

Conclusions
Clinical tools and equipment require careful design and growth charts are no exception. It is essential to be clear who will be using them and for what purpose, in order to achieve a design that works well. Evaluation helped us to appreciate how effectively growth charts can mislead as well as inform. As with any tool, correct and consistent instructions for use are essential. These should be written at an early stage, as the process of drafting them may itself yield design insights. We conclude that new growth charts should be always formally evaluated before introduction to clinical practice.

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**References**


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