How can we best chart children's growth in the paperless age? – The UK experience

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Abstract

Growth charts have played an integral part in the monitoring and assessment of children's health for the past fifty years, but their use is now under threat as paperless electronic systems become more widely used. While the obvious solution is to adopt electronic charting systems, this can prove challenging in practice. This article describes the key issues to consider in planning this transition and the charting options available, ranging from bespoke local systems to commercial package and a new initiative by the Royal College of Paediatrics and Child Health (RCPCH).

Growth is a defining feature of childhood and an important marker of health and wellbeing, assessed using growth monitoring. However, simply measuring a child tells us little about their growth, unless placed in the context of age and sex, and then compared to previous measurements. In practice, all this information can be accessibly summarised by plotting the child's measurements on a growth chart against age, on a graph which already shows the range of measurement for that sex plotted against age.

However, the paper growth chart, as used in clinical practice presents problems. Each child may have multiple measurement held in different centres and institutions in primary and secondary care, some plotted on charts and many not plotted at all. This dilutes the impact of growth monitoring in health, as measurements tend not to be reviewed as a whole, which may have important implications for the recognition of growth disorders as well for safeguarding.

The growth of unified electronic record systems would seem to provide a solution to this problem, except that paper charts are complicated to implement within electronic record systems, leading to reluctance on the part of EPR manufacturers to include them in systems that are largely designed for use in adults. Thus, the rapid shift towards paperless health records runs the risk of reducing rather than enhancing the efficacy of growth monitoring in the UK.

This article describes the history and use of growth charts, reviews limited international literature on this topic and describes the UK journey with moving childhood growth monitoring from paper to screen. It explains how digital charts work, what systems providing them should include, and how to go about incorporating them into electronic health records (EHR). In particular, it describes a single growth monitoring solution developed by the UK Royal College of Paediatrics and Child Health which is now available nationally.

History of growth charts

The concept of growth charts arose in the late 19th century, driven by Francis Galton's invention of centiles and Henry Bowditch's experiments with ways to display children's height growth by age.(1-3) In 1966 James Tanner and Reg Whitehouse published growth charts for British children, which became the official UK charts.(4) They established a design that has since been emulated worldwide: a grid of the measurement plotted against age, with seven smooth centile curves ranging from the 3rd to the 97th. Tanner also devised a mid-parental target height calculator, a system of pubertal staging, and ways to present growth during puberty.(5) In the UK the Tanner-Whitehouse charts became increasingly out of date, because of the secular trend to increasing height, and they were replaced by the British 1990 (or UK90) reference charts;(6) based on more recent data from multiple surveys, the UK90 reference extended the number of centiles to nine, equally spaced on the SD score (SDS) scale and ranging from the 0.4th to the 99.6th centile (7) (see Figure 1).

The curves on the Tanner-Whitehouse charts had been drawn by hand using a lead spline (a deformable metal ruler). In contrast, by the time the British 1990 reference was constructed, advances in statistical methodology allowed it to be modelled using the LMS method, with cubic spline curves to fit the centiles,(8) adjusting for the skewness in the distribution of weight and body mass index (BMI) and allowing measurements to be converted to SDS.(9)

In 2006 the World Health Organization (WHO) published its long-awaited growth standard for children aged 0-5 years, based on large samples of children selected for optimal growth and recruited from six countries.(10) After careful appraisal (11) the UK adopted the WHO standard for age 2 weeks to 4 years, reverting to the UK90 reference for age 4-19 years, and retaining the UK90 birth centiles by gestation (12) (see Figure 1). Two of the authors were members of the expert group commissioned by the Royal College of Paediatrics and Child Health (RCPCH) to design these new UK-WHO charts, their instructions, and to develop training materials(13) (see rcpch.ac.uk/resources/growth charts).

Going paperless

EGC systems appear to have been in use within EPRs in the United States for 20 years or more (14, 15). In 2007 the American Academy of Pediatrics published recommendations that all EPR systems serving children should include a facility to display serial growth data plotted on charts for height and weight, including gestational correction. A year earlier Rosenbloom had described the implementation and rollout between 2001-4 of a bespoke electronic growth chart (EGC) system in large children's hospital in Tennessee(15) which included all the features recommended the following year by the American Academy of Pediatricians (16) as well as providing z scores and calculating parent height percentiles and adjusting for skeletal age. Rosenbloom describes the process of rollout, via a mix of maximising availability on the system and in-service education for specific groups, and demonstrated that most of the data entry was done by nursing and technical staff, while charts were predominantly accessed by doctors and nurse practitioners (15). Rosenbloom has since described the use of data harvested from their EGC to create local reference data for Down syndrome and for Prader Willi (17, 18). By 2015 75% of large US pediatric centers already had a EGC facility and almost all the remainder were in the process of implementing one, although fewer (40%) were using z scores (19). Similarly, a survey of European primary care paediatricians in 2013 found that 61% of respondents reported using an EGC of some kind (20). Thus, UK appears to have been a relatively late adopter EGCs, with only one published account of a UK EGC found (21).

UK primary care has predominantly been using paperless EPR for at least 20 years, but at first these had no chart plotting functionality. Since then, at least one primary care EPR provider (EMIS) has introduced a chart-plotting facility, but this does not include BMI or any data beyond age 5 years. As more secondary care units seek to go paperless, those serving children face similar challenges, as they move away from paper records.

Child specialists, the main chart users, should be involved in the introduction of appropriate electronic substitutes for paper charts. Indeed, it is important that they resist relinquishing their paper notes until a proper digital solution has been provided. Arguing for the incorporation of digital charts may seem challenging, but a long-term business case can be made(21), at least partially based on savings in the cost of paper charts. The most challenging aspect (and greatest short-term cost) will be the process of securely and effectively linking the software to the EPR, but once linked this allows staff access to all the growth data available on a child and saves the time previously used to calculate age and plot the charts. The process eliminates chart plotting errors, but data entry errors are still a risk.

What makes a good digital growth chart?

There is a need for clear guidance about what paperless growth charts can and should provide. In the USA individuals (15) and organizations (16) have laid out the base requirements for these systems. The article aims to extend these, both to ensure their relevance for the UK and to incorporate aspects not explicitly stated in earlier guidance, so that those commissioning a software purchase or modification can ensure that it fully meets their needs. This guidance is laid out in detail in the appendix, while key aspects are described here.

First it is vital to ensure that any planned chart uses the correct growth reference (UK-WHO) and centile lines (the UK 9 line system(7)), and that it 'joins the dots' in the centiles using cubic interpolation to ensure smooth curves. Systems should also calculate body mass index (BMI) and convert all measurements to centiles and standard deviation scores automatically. The option to display growth data in the form of standard deviation scores (Z-scores or SDS) is then a flexible alternative to plotting in cm or kg units. This makes individual growth curves closer to linear, can display multiple measures at once (e.g. both height SDS and weight SDS), and also handles extreme measurements which might otherwise be off-scale on the chart (Figure 2).

The digital charts then need to be simple and intuitive to use. Charts repurposed in electronic format avoid many of the constraints of paper charts, so the entire basis of the chart can be re-thought; freed from the need to plot, the layout can be simplified by omitting the gridlines. Similarly, the necessarily arbitrary rules about gestational age correction can be simplified and automated (Figure 3). It has been standard practice to correct for prematurity up to age 2 years in babies born under 32 weeks gestation, and up to 1 year in those born from 32 to 36 weeks; above these ages, the difference between adjusted and unadjusted age is small and hard to plot accurately. However, when the correction is made automatically, it makes sense to continue it throughout childhood, to avoid the growth disjunction when it stops. It can also be extended to term babies, where growth in the early weeks also varies by gestation to some extent (12) This is the approach adopted by the RCPCH growth API (see below).

Paper charts usually split childhood into distinct age ranges, so that when a child's data extend from infancy into later childhood, multiple charts are needed. Electronic charts in contrast can match the axes to the age range of the available measurements, or alternatively use a standard format covering all childhood.

Finally, digital charts should include instructions on interpretation, both for clinicians and parents. These were recognised to be an essential element of the new UK-WHO paper charts(13), but at present this element tends not to be included in either off-the-shelf or bespoke electronic systems. Ideally instructions and guidance on interpretation of specific chart elements should be suppled contextually.

How digital growth charting could be better still

Rosenbloom noted in 2006 that introducing EGC led clinicians to expect more functionality than was possible for paper growth charts(15). The strength of electronic charting is that as our knowledge and experience grows, the functionality can be expanded. As well as growth, information on puberty progression could be presented using the simplified puberty phases defined on the RCPCH paper chart(22). In addition, there is the potential to include charts for other measures such as sitting height or skinfold thickness, and condition-specific charts for children with Down Syndrome(18)(23) or cerebral palsy (24) and other systems have already incorporated comparison to target height and mid-parental centile(15, 21, 25). The AAP also recommended including measures of growth velocity(16) but while there are existing norms for comparison, (26-28) it is not yet clear how to present them in a meaningful way on screen.

What digital charting software is available?

Some providers buy existing freestanding commercial software to be integrated with the EPR. The iGROW package is one such example, widely used in the UK, provided by the same firm that prints the UK-WHO charts. It presents its data floated over familiar looking charts using the RCPCH design principles, but does not currently provide instructions and only very limited interpretation. As with the API, there is an ongoing licensing cost.

Other trusts create their own bespoke local software(21), while others (e.g., EPIC, EMIS) use EPRs that already incorporate charting software. It is important to ensure that this bespoke software meets the standards described above and that they include guidance on the use and interpretation of the charts.

In practice many EPRs lack the capacity to affordably develop their own EGC and the complicated mathematics involved has deterred many electronic health record providers from providing this functionality. For these, the newly developed RCPCH Application Program Interface (API) may be the best option to provide the calculation of standard deviation scores and centiles,(8) An API is a *webservice* that responds to *requests* from a *client* and returns a result. The RCPCH growth API can process many millions of requests at a time, providing timely, accurate and validated centiles. Each request includes the raw data, which is not stored centrally, avoiding any privacy concerns. Whilst this removes the complexity involved in centile calculation, it does not provide a plotted chart, so in addition to the API, chart plotting software is required. Providers can use their own software, but the RCPCH project also provides dedicated charting software that incorporates many innovative features, e.g., the gestational age correction described above (Figure 3) and contextual interpretation and instructions. Organisations can install the RCPCH charting software to their EPR environment which then automatically renders the results. There is a long-term access fee payable, but even so the RCPCH package should be cheaper and more robust than organisations having to produce their own bespoke software.

Conclusion

Electronic charts when properly implemented provide major advantages over paper charts. A range of digital chart options are already available, but their implementation needs careful thought and coordination to ensure their full potential. The RCPCH API will be an important tool to ensure the quality of growth data calculation and set a standard for future chart design.

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Legends to figures

Figure 1: Example child plotted using RCPCH software; the authors can confirm that we have permission to reuse the image which was created by Simon Chapman

Figure 1

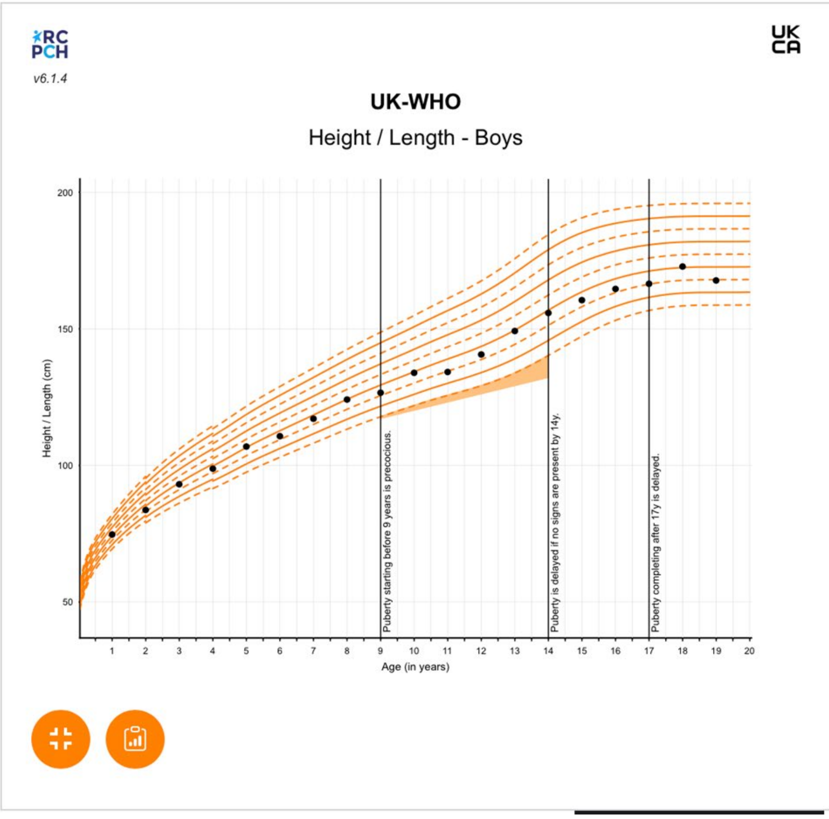


Figure 2: Example child plotted on Z score chart using RCPCH software; the authors can confirm that we have permission to reuse the image which was created by Simon Chapman

Figure 2

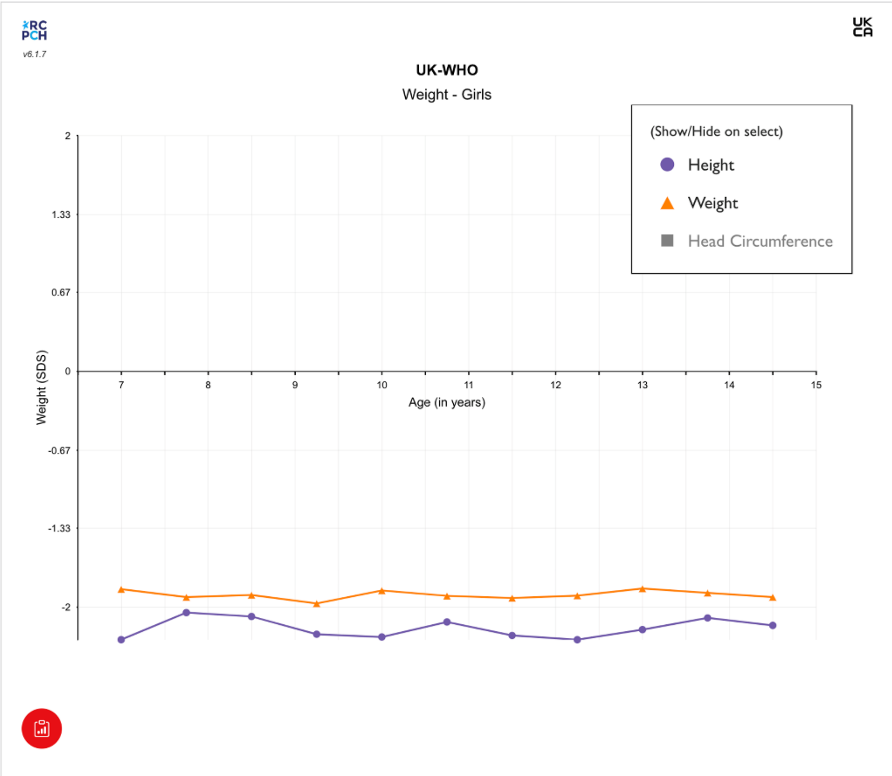
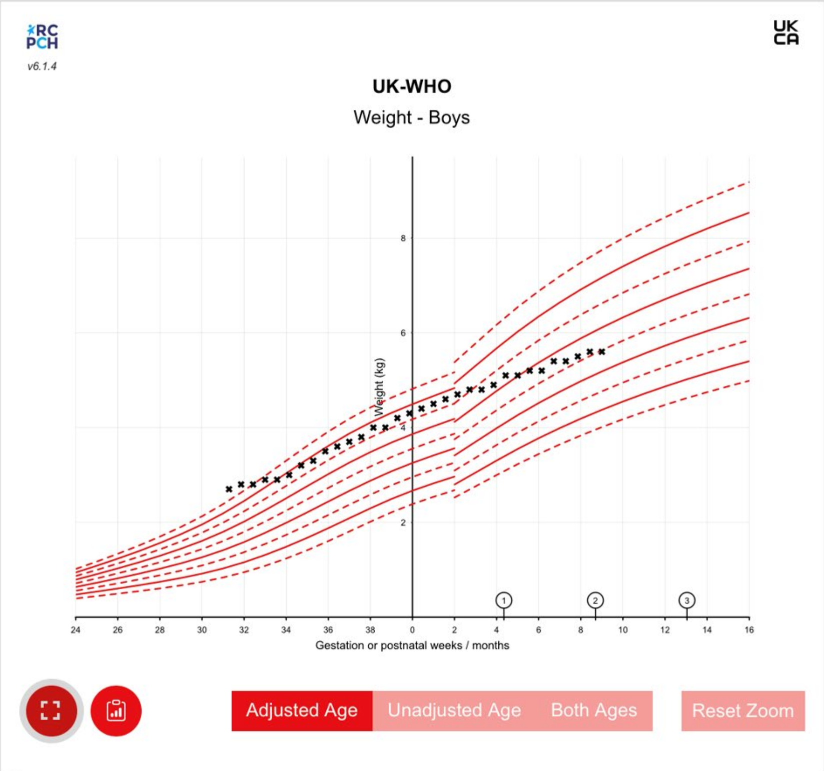


Figure 3: Example preterm infant plotted using RCPCH software; the authors can confirm that we have permission to reuse the image which was created by Simon Chapman

Figure 3


RCPCH
v6.1.4
UK CA
UK-WHO
Weight - Boys
Weight (kg)
Gestation or postnatal weeks / months
Adjusted Age
Unadjusted Age
Both Ages
Reset Zoom

Appendix: Features of an effective electronic Growth Chart system (EGCS) and its interaction with an Electronic Patient record (EPR)

Within the EPR

- Store measurements, the date collected, date of birth and gender.
- Allow the child's record to be loaded into the GCS at the push of a button.
- Open the growth software automatically when growth data entered.
- Store all the growth data, plus Z scores if calculated.
- Allow searching and sorting by patient and patient group.
- Enable data import/export for single children and for groups of children.

EGCS Communication with EPR

- Pass measurements, the date collected, date of birth and gender from EPR to EGC without the need for further data entry.
- EGC to write the calculated centiles and Z scores back to the clinical record.
- Error check measurements and flag erroneous values immediately.

EGCS data analysis

- Calculate exact age in days.
- For those born before 36 weeks, gestationally adjust all ages.
- Convert growth data into Z scores via an LMS lookup table for the UK-WHO growth reference from birth-20 years (or local equivalent) using interpolation.
- Flag measurements outwith the 0.4th and 99.6th centiles as abnormal.
- Flag measurements beyond +/- 6 SD as errors.

Information display

- Present entered data in table with date and calculated age, most recent measurements first.
- Present centile or Z score beside each measurement in table.

Chart presentation

- Present all measurements on a growth chart using the UK-WHO growth reference from birth-20 years (or local equivalent).
- Provide facility to toggle between height chart and weight chart or display together.
- Present BMI and head circumference charts.
- Allow the chart to be scaleable, i.e. zooming in or out, while maintaining visible axes.
- Offer a variety of age range displayed to optimise data view.
- Provide help facility to access instructions drawn from the RCPCH educational materials or local equivalent.
- Enable charts to be both printable and exportable to other software.

Chart plotting

- Provide separate preterm and infancy sections of charts.
- Show separate birth centile markings on Y axis at age 0.
- Omit centile lines between ages 0 and 2 weeks.
- Data points should not be joined by lines.
- Omit grid lines, which are only useful for manual plotting.

Z score plots

- Z score centile charts can be created with age on the X axis and Z score on the Y axis – this converts the centile curves to horizontal straight lines.

- All available measurements (weight, height, head, BMI) should be plotted as series on the same chart with consistent colour coding of the different series (e.g. weight could always be red and height blue etc).
- The data points could be joined by fine lines.
- The Y axis should cross the X axis at Z = 0 and have horizontal centile lines at intervals of 0.67 Z between -2.67 and 2.67.

Plotting preterm infants

- Make allowance for prematurity clear by plotting at actual (chronological) age as well as gestational age (age – number of weeks premature) with different coloured or shaped markers.
- On a Z score plot the gestationally adjusted Z score should be plotted against actual (chronological) age with a label on the plot specifying the number of weeks premature.