Application of Information Technology

Implementing Pediatric Growth Charts into an Electronic Health Record System

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Abstract

Electronic health record (EHR) systems are increasingly being adopted in pediatric practices; however, requirements for integrated growth charts are poorly described and are not standardized in current systems. The authors integrated growth chart functionality into an EHR system being developed and installed in a multispecialty pediatric clinic in an academic medical center. During a three-year observation period, rates of electronically documented values for weight, stature, and head circumference increased from fewer than ten total per weekday, up to 488 weight values, 293 stature values, and 74 head circumference values (p < 0.001 for each measure). By the end of the observation period, users accessed the growth charts an average 175 times per weekday, compared to 127 patient visits per weekday to the sites that most closely monitored pediatric growth. Because EHR systems and integrated growth charts can manipulate data, perform calculations, and adapt to user preferences and patient characteristics, users may expect greater functionality from electronic growth charts than from paper-based growth charts.


Electronic health record (EHR) systems are increasingly being adopted by all categories of health care providers,12 including those caring for children. Goals of EHR systems include improving the availability, clarity, and accuracy of patient information, enhancing clinical efficiency, and reducing errors.3–8 Pediatrics, which includes a strong focus on caring for children growing and developing in a family context, may have functional requirements for EHR systems distinct from those necessary in other medical specialties.9,10 Because a central component of pediatric care is the assessment of growth as a measure of patients’ nutritional and general health status,11 EHR systems supporting pediatrics should assist in growth monitoring.9

To inform users and system developers, the American Academy of Pediatrics (AAP) Task Force on Medical Informatics recently outlined special requirements for electronic medical record systems in pediatrics.9 The Task Force’s report includes a comprehensive listing of desirable pediatric EHR system attributes, including details about managing growth data. Outlined growth-related functionality included the ability to record height, weight, and head circumferences; to plot these data against population-based curves such as those published by the U.S. Centers for Disease Control and Prevention (CDC) and the National Center for Health Statistics (NCHS)12,13; to adjust the normative curves based on patient age, gender, and possibly other demographic or diagnostic features14–17; to calculate body mass index (BMI) and population-based percentiles; and, to integrate into a busy clinical practice.

A major challenge for software developers is to translate high-level functional requirements, such as those outlined above, into readily adoptable clinical systems. We have developed and deployed automated electronic growth charts via an EHR system in wide use at Vanderbilt University Medical Center (VUMC). The growth charts incorporated many of the functional requirements outlined by the AAP as well as others requested by EHR system users. Health care providers in several pediatric clinics voluntarily adopted the electronic growth charts. To advance the discussion about EHR growth chart characteristics and to inform potential developers and users of automated growth charts, we report our design, implementation, and usage experiences.

Methods

Setting

The VUMC includes the Vanderbilt Children’s Hospital (VCH), a 196-bed academic inpatient tertiary care facility with large local and regional primary referral bases. The VUMC and VCH annually care for over 86,000 pediatric patients through more than 11,000 inpatient and 231,500
outpatient encounters. The VUMC also offers graduate medical education and residency training in 53 subspecialty areas to more than 650 house officers and fellows every year. At the VCH, the following clinics were identified as those that monitored pediatric growth most closely and used growth charts as part of their routine workflows: primary care pediatrics, endocrinology, gastroenterology, neurology, and specialty clinics for patients with Down syndrome and spina bifida. In these clinics, most direct patient care is provided by attending physicians and nurse practitioners, although housestaff and medical students may also spend time on academic rotations there. Since 1994, the VUMC has also developed and implemented a number of patient care information systems, including a clinical data repository, an EHR system now available through the Internet, and a computerized provider order entry (CPOE) system available throughout the medical center.

**Growth Chart Design**

The automated growth charts were developed to use reference parameters and Z-score values for weight, height, and head circumference, such as those published by NCHS on the CDC Web site. Based on the patient’s age, the EHR system displays the appropriate reference growth chart (i.e., charts for 0–36 months for patients in that age range, and 2–20 years for patients older than three years). The charts replicate the standard coloring scheme (i.e., pink for girls, blue for boys) and display normative curves representing the 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th percentiles for each growth parameter. The system automatically plots individual patient weight, height, and head circumference measurements on the relevant charts. It also can plot data points linked together with lines or as discrete dots, with or without the date of measurement, according to user preference.

The automated growth charts were designed to be easily viewed in multiple places in the EHR system (e.g., from within a patient’s record, a clinic schedule, or a hospital census) and for users to interact with the charts in a number of ways. For discrete data points, users can display the value, date, percentile, and standard deviation score and the patient’s age on the date that the measurement was made with a mouse click. By selecting two data points, users can trigger the system to calculate and display a growth velocity for the interval between the two points. Users may add, delete, or modify points in the growth chart as necessary. Quick links available at the top of the charts also allow users to superimpose on the growth charts parental height percentiles with a calculated mid-parental height point and to plot stature against skeletal age measurements in addition to chronologic age. Users may choose from three growth data displays: the basic growth charts described above; simple charts that do not include normative percentile lines and gender-based background colors but do permit zooming in and out; and a tabular display that includes columns with percentile and BMI calculations. An example growth chart is presented in Figure 1. Growth charts and growth data tables may also be printed for parents, referring health care providers, or to document the need for or efficacy of treatments to third-party payers.

**Implementation Process**

An institutionally developed CPOE system (1994-1995) had been in wide use throughout the VUMC and VCH since 1997. With a goal of replacing paper-based processes, an institutionally developed EHR system was formally installed through all VUMC clinics (except Ophthalmology) between September 2001 and June 2004. The EHR system was designed to be used by physicians, housestaff, nurse practitioners, nurses, and other ancillary staff for management of patient data, including clinical documentation, review of notes, testing results, lists of problems, medications and allergies, and clinical messaging among health care providers. The electronic growth charts were initially developed and integrated into the EHR system at the end of January 2002, before the subsequent formal EHR system rollout to the pediatric clinics in September 2002. Based on system-user feedback, the growth chart functionality was expanded to include additional features in July 2003.

The electronic growth charts were designed to allow them to reuse anthropomorphic data collected through routine workflows and documented into the EHR system. As part of standard intake processes at the VUMC, growth measurements were obtained in most pediatric outpatient settings. In general pediatric clinics, for example, weight and stature are recorded for all children, and head circumference for children younger than 36 months of age. To encourage clinic staff to enter anthropomorphic measurements directly into the EHR system, most VUMC clinics installed computer workstations in each patient room. In addition, developers created a simple computerized intake form that allowed staff (such as nurses or patient care technicians) easily to select a scheduled patient and then document the patient’s vital signs, anthropomorphic measurements, medications and allergies, and problem list information, all directly into the EHR system. For clinics that monitor growth closely, patient intake processes were modified to include documentation by staff of patient anthropomorphic measurements directly into the specialized intake form rather than on paper. Once entered into the system, anthropomorphic measurements were immediately available to other users and applications, including integrated electronic growth charts and clinical documentation tools. The EHR system also stored weight, stature, and head circumference measurements entered into the CPOE system and historical values entered as needed by system users.

The EHR system modeled growth charts by using the data tables and equations presented by the NHCS on the CDC Web site. The data tables on the CDC Web site include age- and gender-specific values that correspond with the 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th percentiles for weight, height, and head circumference. From these values, the EHR system generated a connected plot for each percentile curve, with age along the x-axis and the anthropomorphic measurement values along the y-axis. In addition, the CDC data tables include constants for the Box-Cox transformation power (L), the median (M), and the standard deviation (S) for anthropomorphic measurements by categories of age and gender. Using the appropriate constants with the equation provided by the CDC (i.e., $Z = \frac{1}{2}\left([X/M]^L - 1\right)/[LS])$, the standard deviation score (Z) can be calculated from any given patient measurement (X). The EHR system plotted specific patient values on the growth curves and could be triggered to display the value for Z and the calculated percentile for each point (Fig. 1). The growth velocity could be calculated from any two growth
Figure 1. Height growth chart for a hypothetical nearly nine-year-old boy who has experienced a growth delay. Note that the subject’s height is below the third percentile for a chronologic age of 8.75 years, while the height is between the 25th and 50th percentiles for his physiologic age (measured by a hand radiograph for bone age and indicated on the growth chart with an X). At the upper right margin of the chart, the child’s adult parental heights are displayed based on their percentiles of adult height for gender (Fa, Mo, with percentile values extrapolated from the CDC height for age tables), and a mid-parental height (MPH) percentile is presented. A table showing the growth data from two user-selected points, including their percentiles, standard deviation scores, and the growth velocity between them, is superimposed.
points by normalizing the difference between the two values to a one-year period (e.g., a height gain of 2 cm in four months would normalize to a height velocity of 6 cm per year).

While the EHR system rollout to the pediatric clinics was driven and organized by the clinic administration and by “clinical champions,” there was no specific rollout or training on the EHR system-based growth charts. To ensure that users knew about and could access the electronic growth charts, links were placed to them from multiple places within the graphical user interface of the EHR system. In addition, the electronic growth charts were demonstrated at weekly support meetings and to staff and physicians from clinics requesting information. System users received minimal training on the growth charts as part of their overall one-hour EHR-system training classes.

Usage Statistics
Growth chart usage was defined as a mouse-click on a link that would cause the EHR system to display a growth chart and was independent of whether a user entered anthropomorphic measurements into the system. Upon receiving Institutional Review Board approval, we screened EHR system logs for growth chart usage and administrative databases for visit rates to the VCH and to the VUMC pediatric clinics that monitored growth most closely. Because the data sources stored system-usage and patient visit information differently, we were unable directly to calculate percentages of patient visits in which the growth charts were used. We calculated summary usage statistics and performed comparative analyses using the Wilcoxon rank-sum test for nonparametric distributions and tested for trends using time series analyses that incorporated moving average and autoregressive terms as well as structural components correcting for patient volume, gender, and age. All patients aged 0 to 21 years receiving care at the VUMC were included in the analyses. All analyses were performed using Stata SE, version 8.0 (Stata Corporation, College Station, TX).

Observations
During the three-year observation period, covering July 2001 through June 2004, the VUMC cared for 143,672 patients aged 0 to 21 years old. These patients contributed 755,802 outpatient clinic visits (20,994 per month), 95,066 emergency department visits (2,641 per month), and 35,244 admissions to the VCH (979 per month). Of the visits to outpatient clinics, an average of 2,771 per month were to the clinics that monitored pediatric growth most closely.

System users, including patient care technicians, nurses, students, physicians, and nurse practitioners, entered a total 176,290 weight values on 56,589 pediatric patients (a mean of 3.1 per patient); 112,096 stature values on 44,211 pediatric patients (2.5 per patient); and 27,717 head circumference values on 10,960 pediatric patients (2.5 per patient). As would be expected, prior to electronic growth chart implementation...
in February 2002, there were fewer than ten values per weekday for weight, stature, and head circumference entered into the EHR system for pediatric patients. Immediately following formal EHR implementation in the pediatric clinics, the daily rate that measurements were entered into the EHR system increased to 257 weight values, 225 stature values, and 52 head circumference values (p < 0.001 for each measure). These results are shown in Figure 2. When corrected for patient volume, the rates of weight, stature, and head circumference values entered into the EHR system continued to increase during the remainder of the observation period; by the end of the period, there were 488 weight values, 293 stature values, and 74 head circumference values entered per weekday (p < 0.001 for trend for each measure). In addition, users entered a total of 178 bone age measurements and 621 pairs of parental heights into the EHR system between July 2003 and June 2004. System users accessed the electronic growth charts a total of 128,022 times between January 29, 2002, when the charts were first introduced, and June 30, 2004. Among growth chart accessions, 81% were by physicians and nurse practitioners, 14% by nurses and patient care technicians, and 5% by students, ancillary personnel, nutritionists, pharmacists, and others. When corrected for patient volume, growth chart usage increased to 194 accessions per day during the period in which the EHR system was being implemented in pediatric clinics (p < 0.001) and then dropped to 116 accessions per day after the formal implementation in the pediatric clinics was completed (p < 0.001). By the end of the observation period, system users accessed the EHR growth charts on average 175 times per weekday (compared to 127 patient visits per weekday to the clinics that most closely monitored pediatric growth, above, and the 488 weight values entered per weekday institution-wide). During the period that they could request that the EHR growth charts display the details of individual data points (i.e., from March 1, 2004, through the end of the observation period), users requested details 8,443 times.

**Discussion**

We found that pediatric providers readily adopted electronic growth charts when the charts were integrated into an EHR system. The EHR growth charts described in this article were designed to translate the AAP's functional requirements and other features requested by users into a tool that could be readily accessed by providers during their normal workflow. To accomplish this, the charts used available anthropomorphic measurements that were routinely entered into the EHR system, were easily accessible to EHR system users, displayed reference population-based curves, and allowed the underlying data to be reused for calculating growth velocities, percentiles, and growth targets. Many of the values were also available to other EHR component systems; for example, percentiles calculated for the growth charts could also be imported automatically into clinical documents such as progress notes. This combined functionality allowed pediatric providers easily to adopt the EHR growth charts and may have helped them to accept the EHR system.

We found that because EHR systems can manipulate clinical data, perform calculations, and adapt to user preferences and patient characteristics, users expected greater functionality than from paper-based records, such as an ability to calculate percentiles, growth velocities, and predicted growth. Systems having greater functionality may be more efficient and more readily adopted by health care providers, but may also be more expensive to develop and more complicated to use. Despite the increased costs, enhanced functionality may help offset the time that clinicians invest in using EHR systems by automating other tasks (e.g., BMI and growth velocity calculations) and by making growth data more readily available to other systems (e.g., weight percentiles can be used to assist in blood pressure interpretations in a decision support system and can be inserted into the physical examination section of an EHR-assisted clinical documentation tool).

**Table 1** Desiderata for Management and Representation of Pediatric Growth in an EHR System*

<table>
<thead>
<tr>
<th>Workflow</th>
<th>Use routinely gathered growth measurements†</th>
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<tbody>
<tr>
<td></td>
<td>Automatically generate growth charts†</td>
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<td></td>
<td>Growth charts accessible from standard EHR system components†</td>
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<td></td>
<td>Growth data and calculations reusable for other tasks (e.g., decision support, documentation)‡</td>
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<tr>
<td>Growth data</td>
<td>Capture weight, height or length, head circumference†</td>
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<tr>
<td></td>
<td>Calculate body mass index and growth velocity†</td>
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<tr>
<td></td>
<td>Calculate percentiles and standard deviations based on population norms‡</td>
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<td></td>
<td>Capture data using different units of measurement (e.g., grams, kilograms, pounds)†</td>
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<td></td>
<td>Capture context of measurement (e.g., lying or standing, ventilated, receiving growth hormone)</td>
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<td>Support automated data capture from measurement devices (e.g., digital scales)</td>
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<td>Presentation</td>
<td>Display growth data on standardized charts as the default view†</td>
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<td>Display against standard population-based normal curves†</td>
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<tr>
<td></td>
<td>Display normal curves based on age, gender, and other demographic characteristics‡</td>
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<td></td>
<td>Display using graphical and tabular formats†</td>
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<td></td>
<td>Display predictive growth curves or growth targets‡</td>
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<td></td>
<td>Display time and date of birth for infants‡</td>
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<tr>
<td>Functionality</td>
<td>Calculate mid-parental height by gender-specific parent height percentiles†</td>
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<td></td>
<td>Display bone age measurements with actual age measurements†</td>
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<td></td>
<td>Display development stages (e.g., Tanner stages) with actual age measurements</td>
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<td>Derive and display the median age at which a given growth point is achieved</td>
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<td>Allow adding, deleting, and editing of growth points†</td>
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<td></td>
<td>Enable varying the scale's level of detail (i.e., zoom in or out)</td>
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<td></td>
<td>Support printing and faxing†</td>
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<tr>
<td></td>
<td>Support user preferences (i.e., connected points, superimposed values, table or graphical chart)‡</td>
</tr>
</tbody>
</table>

EHR = electronic health record.

†Functionality included in the EHR-based growth charts described in this article, as initially developed.
‡Functionality added to subsequent versions of the EHR-based growth charts based on system-user feedback.
growth disorders, such as pediatric endocrinology. In these settings, automated growth charting may improve the diagnostic accuracy and follow-up of complex medical conditions involving growth, such as growth hormone deficiency, hypothyroidism, congenital adrenal hyperplasia, and disorders of puberty. Automated growth charts may improve the precision and accuracy of plotted anthropomorphic measurements and of commonly monitored derived values, such as height velocity, standard deviation score (i.e., Z-score), height for skeletal age and chronologic age, and height compared to mid-parental height. Improved growth charts may enhance subspecialists’ ability to monitor response to expensive growth-altering therapies (e.g., growth hormone replacement) and to justify the ordering of complex and expensive diagnostic tests (e.g., pituitary function testing). Such charts may also reduce the workflow required to support dose adjustments and payer authorization for growth-related therapies (e.g., growth hormone therapy often requires annual or semiannual re-authorizations) common to these subspecialty practices.

Lessons Learned
Based on our experiences, we have learned that implementing basic pediatric growth charts into EHR systems is relatively straightforward from a technical standpoint and may enhance adoption of such systems by pediatricians. However, users of EHR system–based growth charts may expect such charts to have greater functionality than the paper-based growth charts they replace, including having the ability to reuse previously documented measurements and to calculate derived values such as percentiles and growth velocities. Our experiences demonstrate that it is possible to take high-level functional requirements made by clinical subspecialty organizations and specific functional needs outlined by users and iteratively develop EHR system components to meet them. This approach may serve as a model for developers customizing EHR systems to achieve the necessary functionality to be useful in pediatric practices.

In addition, and informed by our experiences with EHR system users and from discussions with members of the AAP Council on Clinical Information Technology and members of the Health Level-7 Pediatric Data Special Interest Group, we have compiled a list of desiderata for EHR system–based growth charts, reported in Table 1. While the growth chart functionality outlined by these desiderata may be desired for EHR systems supporting pediatric practice, necessary growth chart functions may vary depending on user subspecialty and patient diagnosis. These desiderata should serve as a framework for system developers, clinical users, and evaluators as they consider the functionality of growth charts implemented in EHR systems.

Limitations
The current report has limitations that merit discussion. First, it is possible that the success of the EHR growth charts at our institution was partially the result of the clinical workflow. Both before and after the EHR system rollout, nursing staff generally have had the burden of documenting weight, height, and head circumference measurements; it is possible that in settings in which the primary health care provider documents these measurements, usage of the automated growth charts would be less efficient than paper-based charts. Second, this report includes no evaluation of the effect of the EHR system–based growth charts on clinical efficiency, patient outcomes, or user satisfaction, all which may have been affected when compared to using paper-based growth charts. Third, due to data limitations, we were unable to determine actual rates of growth chart usage per patient encounter and could not identify which features were especially desirable to users. Nonetheless, the usage rates presented in this report suggest that the charts were well adopted; with 127 encounters per weekday in pediatrics clinics that monitor growth most closely, there were 175 growth chart accessions per weekday institution-wide. Fourth, this report describes automated growth charts deployed in an academic tertiary institution, where information requirements and workflow considerations may be different from those in other settings.

References