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Executive Summary

Adoption of electronic health record (EHR) systems in hospitals and physician practices is accelerating. Usability of EHRs has been identified as an important factor impacting patient safety, and recommendations for improvement have been provided. Pediatric patients have unique characteristics that translate into unique EHR usability challenges. It is not surprising, then, that the adoption of EHRs by pediatric care providers has lagged behind adoption for adult care providers. In this document, we highlight important user interactions that are especially salient for pediatric care and hence to the EHR user-centered design process. These interactions and associated usability recommendations were identified by consensus during a series of teleconferences with experts representing the disciplines of human factors engineering, usability, informatics, and pediatrics in ambulatory care and pediatric intensive care. In addition, extensive peer review was provided by experts in pediatric informatics, emergency medicine, neonatology, pediatrics, human factors engineering, usability engineering, and software development and implementation.

This report details recommendations to enhance EHR usability when supporting pediatric patient care and also identifies promising areas for EHR innovation. Finally, we illustrate unique pediatric considerations in the context of representative clinical scenarios which may be helpful for formative user-centered design approaches and summative usability evaluations.

1 Background: Usability and critical user interactions

Adoption of electronic health record (EHR) systems in hospitals and physician practices is accelerating.[1] At the same time, however, the lack of usability of EHRs has been identified as an important factor impacting patient safety,[2] and national guidelines have been released to evaluate, test, validate,[3] and document summative usability testing results.[4] In addition, recommendations have been made to improve the usefulness,[5,6,7,8] interoperability,[9] and ability to conduct research[10] of EHRs for pediatric patients.

Pediatric patients have unique characteristics that translate into higher complexity for providing care with both paper-based charts and EHRs. As such, EHRs have the potential to reduce complexity with advanced decision support features, and thus improve patient safety. Meeting this potential will likely require a specialized assessment of the unique challenges in providing pediatric care with EHRs, and in particular, unique usability issues associated with critical user interactions.[11,12,13] It is not surprising, then, that the adoption of EHRs by pediatric providers has lagged behind adoption for general population providers.[14] In this document, we highlight user interactions that are unique to or especially salient for pediatric care. As such, these interactions impact EHR usability in particular and user-centered design (UCD) in general.

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[1] Jha, A.K., Desroches, C.M., Campbell, E.G. et al., "Use of electronic health records in U.S. hospitals," The New England Journal of Medicine, 2009;360(16) :1628–1638.

[2] IOM**.** *Health IT and Patient Safety: Building Safer Systems for Better Care*. Washington, DC: The National Academies Press; 2012.

[3] (NISTIR 7804) *Technical Evaluation, Testing and Validation of the Usability of Electronic Health Records*

[4] (NISTIR 7742) Customized Common Industry Format Template for Electronic Health Record Usability Testing.

[5] Spooner, A. and Council on Clinical Information Technology. Special Requirements of Electronic Health Record Systems in Pediatrics. Pediatrics. 2007;119(3): 631-637.

[6] Shiffman et al. Information Technology for Children's Health and Health Care: Report on the Information Technology in Children's Health Care Expert Meeting, September 21-22, 2000. J Am Med Inform Assoc 2001;8:546-551.

[7] Grace, E., Kahn, J., Finley, S. Model Children's EHR Format. HIMSS 2011 Annual Conference. February 23, 2011.

[8] United States Pharmacopoeia. Error-Avoidance Recommendations for Medications Used in Pediatric Populations. Available at: http://www.usp.org/hqi/patientSafety/resources/pedRecommnds2003-01-22.html (Accessed March 22, 2011).

[9] Hinman, A.R., Davidson, A.J. Linking Children's Health Information Systems: Clinical Care, Public Health, Emergency Medical Systems, and Schools. Pediatrics 123 Supplement 2 January 1, 2009; S67 - S73.

[10] Stiles, P.G., Boothroyd, R.A., Robst, J., Ray, J.V. Ethically Using Administrative Data in Research Medicaid Administrators' Current Practices and Best Practice Recommendations. Administration & Society March 2011:43(2):171-192.

[11] Scanlon, M**.** C. Human factors and ergonomics in pediatrics. In: Carayon P, ed. Handbook of Human Factors and Ergonomics in Patient Safety: Lawrence Erlaum and Associates; 2006.

[12] Scanlon, M.C., Karsh, B., Densmore E**.** Human Factors and Pediatric Patient Safety. Pediatric Clinics of North America. 2006;53:1105-19.

[13] Spooner, A. and Council on Clinical Information Technology. Special Requirements of Electronic Health Record Systems in Pediatrics. Pediatrics. 2007:119(3):631-637.

[14] Nakamura, M.M., Ferris, T.G., DesRoches, C.M., Jha, A.K. Electronic health record adoption by children's hospitals in the United States. Arch Pediatr Adolesc Med. 2010 Dec;164(12):1145-51.

User-centered design (UCD) is an approach to designing systems; the approach is informed by scientific knowledge of how people think, act, and coordinate to accomplish their goals.[15] UCD design practices employ both formative and summative practices in order to achieve systematic discovery of useful functions grounded in an understanding of the work domain. Particularly for systems used in high-risk environments, where mistakes can result in fatalities, ensuring system usability is an important objective. Usability has traditionally been defined as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."[16] In healthcare settings implementing EHRs, an emerging consensus is that many of the critical risks for the care of pediatric patients associated with the use of the EHR are related not just to the system's user interfaces, but also to the system's functionality and workflow. Therefore, for the purposes of this document, we use a unified framework for defining EHR usability: "how useful, easy to use, and satisfying a system is for the intended users to accomplish goals in the work domain by performing certain sequences of tasks" (page 1).[17]

The focus of this document is not on all aspects of EHR usability, but rather on those that are part of *critical user interactions.* Critical user interactions are interactions between a user, such as a physician, nurse, pharmacist, caregiver, or patient, and the EHR, which can potentially lead to errors, workarounds, or adverse events that are associated with patient harm. Critical does not imply level of clinical care, such as critical care, but rather the highest-priority interactions to consider with respect to usability and patient safety in the context of his or her associated pediatric care. In other words, these are safety-critical interactions with the EHR. In safety-critical environments (hospitals, emergency departments, etc.), the importance of well-designed, usable interfaces is increased precisely because of the potential for catastrophic outcomes. The importance is further increased in the presence of time pressure,[18] as is the case in much of healthcare. Time pressure reduces a user's opportunity to detect signals in the face of noise and may also lead to inadvertent confirmation bias, so appropriate user interface design is all the more important in such environments.

Several usability-related concerns are not addressed in this report and considered outside the scope of this document. These include challenges associated with supporting collaborative work and shared situation awareness among interdisciplinary team members, transitions across care settings, interoperability between systems, integration with bar code point of care and other medical devices, quality improvement and research using data pulled from EHRs, integration with social media and handheld devices, and software designed exclusively for use by caregivers or nontraditional healthcare providers. The user interactions and associated recommendations described in this report were identified by consensus during a series of teleconferences. Participating experts represented the disciplines of human factors engineering,

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[15] Flach, J.M., Dominguez, C.O. Use-centered design: Integrating the user, instrument, and goal. Ergonomics in Design: The Quarterly of Human Factors Applications, July 1995;3(3):19-24.
[16] ISO/IEC. 9241-14 Ergonomic requirements for office work with visual display terminals (VDTs) - Part 14 Menu dialogues, ISO/IEC 9241-14: 1998 (E), 1998.
[17] Zhang, J., Walji, M. TURF: Toward a unified framework of EHR usability. Journal of Biomedical Informatics, 2011: 44 (6):1056-1067.
[18] Hancock, P.A., Szalma, J.L. Operator stress & display design. Ergonomics in Design. 2003;11(2):13-8.

usability, informatics, and pediatrics in ambulatory care and pediatric intensive care. In addition, extensive peer review was provided by experts in pediatric informatics, emergency medicine, neonatology, pediatrics, human factors engineering, usability engineering, and software development and implementation.

The notion of critical user interactions takes on special importance with pediatric patients. As is explained in the next section, pediatric patients are unique. Their uniqueness creates at least two important consequences with respect to EHR usability. First, the young and very young pediatric patients may be more physiologically vulnerable to even small mistakes or care delays. Second, pediatric patients have unique care challenges, which can create additional physical and/or mental demands on pediatric clinicians. Both of those observations reveal that user interactions with EHRs that might not be deemed critical in other environments become critical with pediatric patients. The unique pediatric factors are explained next.

2 Special considerations for pediatric patients

General Pediatric Considerations

Pediatric patients have been identified as a high-priority, high-risk population for patient safety due to differences in physical characteristics, developmental issues, and issues relating to the legal status of minor age children and complicated custody and guardianship situations.[19] Even within pediatric patients, there is much variability in clinical needs based upon 1) age group (prenatal, neonatal/infant, preschool child, school-age child, adolescent, and young adult); 2) health issues (health maintenance and preventive care [well child, including newborn care], critical and emergency care, chronic disease management, behavioral care); and 3) site and process of care (birth, delivery and neonatal/newborn care, inpatient care, primary ambulatory care, specialty care). Providing care in general, and medication management in particular, is more complex and has higher patient safety risks for pediatric patients for at least three reasons: 1) patient physiology, 2) the complex nature of common or routine tasks, and 3) patient limited communication ability.[20]

First, in terms of physiology, children undergo dramatic developmental changes from birth to adulthood. Disease states in children are dynamic and change over a continuum with age. Specific disease states, symptoms, exam findings, laboratory findings, and treatments vary with gestational age, actual age, weight, length, Body Surface Area, Body Mass Index, and other variables. In the first month alone, each organ system in the body (e.g., neurological, cardiac, pulmonary, hematologic, renal, hepatic, hematologic, and immune) transitions from fetal life to postnatal life; organ system changes happen in hours and days in the Neonatal Intensive Care Unit (NICU). The range of physical characteristics in pediatrics is much larger than for adults – for example, from a 500 gram premature infant to a 100 kilogram 12-year-old.

These unique pediatric characteristics influence the clinician's selection of: (a) factors to consider for appropriate care, (b) parameters on which to base decisions, (c) goals to attempt to achieve, and (d) tasks to implement that are required to achieve these goals. In turn, these characteristics and the clinician's preferred course of action influence how the user interface of an EHR must be designed to accommodate and support the cognitive and decision-making requirements of the clinician. This is why the unique aspects of pediatric care make selection and arrangement of information displays, definition of "normal" ranges and thresholds for alerts, among many other display and user interface considerations, more challenging to design and implement. In particular, for example, the norms which define "normal," "standard," and "wrong" dosages for pediatric patients change rapidly over time and the clinical parameters upon which "normal" pediatric doses are defined (age, Body Surface Area, and/or weight) also change with time. The user interface must be designed to flexibly and reliably accommodate the realities of

[19] Steering Committee on Quality Improvement and Management and Committee on Hospital Care. Principles of Pediatric Patient Safety: Reducing Harm Due to Medical Care. Pediatrics Vol. 127 No. 6 June 1, 2011 , pp. 1199 -1210.
[20] Hughes, RG,Edgerton, EA. (2005). First, Do No Harm: Reducing Pediatric Medication Errors. American Journal of Nursing*,* 105(5), 79-84**.**

the rapidly changing pediatric patient and relevant clinical parameters and settings. A one-size-fits-all user interface design will not accommodate the clinical needs of pediatric patients or support the cognitive and decision-making requirements of their care providers.

Ideally, the user interface will provide tools to support the configurability of the clinical parameters and setting that permits the clinician to modify those clinical parameters or settings over which they should have control (e.g., entering the body weight of the pediatric patient) while limiting or restricting access to other clinical parameters or settings (e.g., definition of "normal" dosages), which presumably should not be modified by a single care provider without careful consideration.

Second, there is immense complexity even for standard daily tasks such as ordering medications and vaccinations and administering breast milk that are not pertinent to adult patient care. The complexity stems from added burdens of calculations, individual tailoring, and patient identification not typically present in adult care. If designed properly, the EHR will provide the functions and features for advanced decision support in these areas.

Third, young and very young children may not be able to communicate at all or sufficiently to direct a clinician to important information, raise questions, correct errors, complain, or articulate symptoms. This may seem similar to the situation with very sick adults, but may be different in one important way. Very sick adults may at least have family and care providers that are able to help fill in gaps of information for current clinicians based on communications with the patient prior to them becoming sick. Clinicians caring for the young and especially very young may not be able to rely as much on past medical history or even family members, since the young and very young can no more communicate with their family than they can with clinicians. This lesser ability to communicate, like the aforementioned physical and physiological changes, translates into different EHR design needs to support care. If clinicians cannot rely as much on the patients, they may need to rely more on the EHR. Data that support clinical decision should be available, easily accessible, and customizable by groups of end users. All important information should be viewable with one click or "hover over" capability to minimize navigation burdens. Seeing more of what one might need is especially important for users who must rely more on the display and less on the patient.

Taken together, the unique physiology, task complexity, and patient communication abilities for pediatric patients create unique physical and cognitive burdens on care providers that must be accommodated by the design of EHRs. We suggest that flexible designs that accommodate the rapidly changing physiologic realities of these unique patients, pediatric-specific decision support, and well organized displays are high-level goals to help achieve more usable pediatric EHRs. Next we review specific pediatric considerations.

Specific Pediatric Considerations

The medication use process, specifically weight-based dosing, is more complex and difficult to standardize.[21] Additional complexities with medication orders include the use of alternative liquid, nasal, or partial-tablet formats, combinations of prescriptions. For example, Amoxicillin Clavulanate will typically be used in one or two dose forms for adults, whereas there are 13 different formulations from which a pediatric provider may choose. With low-weight patients, sophisticated rounding strategies and accurate weight measurements are particularly critical to avoid over-dosing or under-dosing.

Caregivers are another special consideration that must be factored. The role of pediatric caregivers is larger than with other populations, with the possible exception of the elderly. When caring for children, lay caregivers calculate and administer medications (e.g., breathing treatments to cystic fibrosis patients) instead of medical personnel in some hospitals, which creates the need to support nontraditional EHR users.

Risks for misidentification are different for pediatric patients, and generally higher. Although these risks are not new, many paper-based systems had evolved to have additional protections that are not available in most EHRs, such as filing charts of siblings together in the same location with handwritten cross-references to sibling chart numbers, which provided an intuitive indication for how many siblings were in a family.[22] Pediatric siblings are the only cohort of patients which share outpatient visits with a primary care provider on a routine basis, and usually have the same last name (although not always). In the case of multiple births, patients additionally share the same date of birth. In the case of newborns, many patients on the same unit will have the same birth date, and which is sometimes the same date as the current date. Newborn children are more likely to have identical birthdays in a labor and delivery unit than other parts of the hospital. As genetic information becomes more readily available and integrated into patient-centered care, it will be important to link updated information across patient records for patients who are genetically related, such as parents, children, and siblings.

[21] Caldwell, N, Power B. (2012). The pros and cons of electronic prescribing for children. Archives of Diseases in Childhood 2012;97 (2):124-128.
[22] Ross Koppel. Commentary on EMR Entry Error: Not so Benign. http://www.webmm.ahrq.gov/case.aspx?caseID=199.

There are sources of information that are unique to pediatric care. Growth charts are critically important and should be depicted in internationally accepted formats. There is a greater need to access information across multiple-birth patients, including the infant/child, parents, siblings, and other family members, particularly for genetic information and for information related to the labor and delivery process. High-risk patients, particularly low-birth-weight neonates, are often transferred to institutions that support higher levels of complex care, injecting further difficulty into information exchange. While a date of birth may seem quite straightforward in an adult EHR, a premature infant can have gestational age, postnatal age, and a date of birth. The phrase “days of life” is often used in neonatal ICUs (NICUs) and pediatric ICUs (PICUs) to prevent confusion.

Alerts for crossing normative thresholds are particularly challenging for the pediatric population, due to the need to do both age-based and weight-based tailoring with respect to medication doses and vaccination schedules. That is, what is perceived as “normal” changes rapidly, and so what is an appropriate alert changes too.

Finally, there is immense complexity even for standard daily tasks such as ordering medications and vaccinations and administering breast milk that are not pertinent to adult patient care. If designed properly, the EHR will provide the functions and features for advanced decision support in these areas.

3 A conceptual model of unique use-related risks of EHR systems for pediatric patients

Many of the critical risks for the care of pediatric patients associated with the use of the EHR are related not just to the system's user interfaces but also to the system's functionality and workflow. The Task, User, Representation, and Function (TURF) framework for EHR usability was developed by the National Center for Cognitive Informatics and Decision Making in Healthcare.[23] The TURF framework integrates user interfaces, functionality, and workflow into a coherent structure. A conceptual model of unique use-related risks of EHR systems that can be applied to the pediatric population is provided in Figure 1, building upon the TURF framework.

TURF outlines usability as how useful, usable, and satisfying a system is for the intended users to accomplish goals in the work domain by performing certain sequences of tasks. In this case, primary users are anticipated to include pediatricians, pediatric trainees (resident physicians and fellow physicians in pediatric training programs), physicians' assistants, registered nurses, licensed practical nurses, nurse practitioners, school-based health personnel, home nursing personnel, including for hospice care, and community-based pediatric health caregivers. Additional users include respiratory care providers, physical therapists, social workers, lactation consultants, religious support persons, lay caregivers, play therapists, and subspecialty consultants, including neurologists, radiologists, and others. Secondary users are anticipated to include parents and nontraditional caregivers, adolescent and young adult patients, administrators, quality improvement personnel, and public health officials monitoring outbreaks and immunizations.

In order for an EHR system to be useful, it should have functions that enable providers to meet the complex needs of their work domain, providing care to pediatric patients. Usefulness is to address the intrinsic complexity of the work domain, and it is determined by the functions of the system. "Usable" addresses the extrinsic difficulty of user interactions with the system, and it reflects the difficulty when a user uses a specific representation or user interface to perform a specific task. Extrinsic difficulty is mainly determined by the formats of representations and the workflows of tasks.

Figure 1 below shows how critical risks associated with pediatric EHR are mapped to the TURF model. The unique nature of pediatric care is captured as the intrinsic complexity that should be addressed by any pediatric EHR, as shown on the left of Figure 1. To avoid adverse events, the list of items under intrinsic complexity needs to be implemented and supported as core functions of the EHR. Critical risks associated with the extrinsic difficulty of the EHR need to be addressed by careful design of the representations (user interface) and tasks (task steps and workflow). When there is a mismatch between the intended workflow with an EHR and the actual workflow, risks for pediatric patients are higher. Functions, users, representations, and tasks are each linked to a set of root causes that can lead to adverse events. In Figure 1, examples of root causes for each category are provided. This list is for demonstration only; it is not exhaustive.

[23] Zhang, J., Walji, M. TURF: Toward a unified framework of EHR usability. Journal of Biomedical Informatics, 2011; 44 (6):1056-1067.

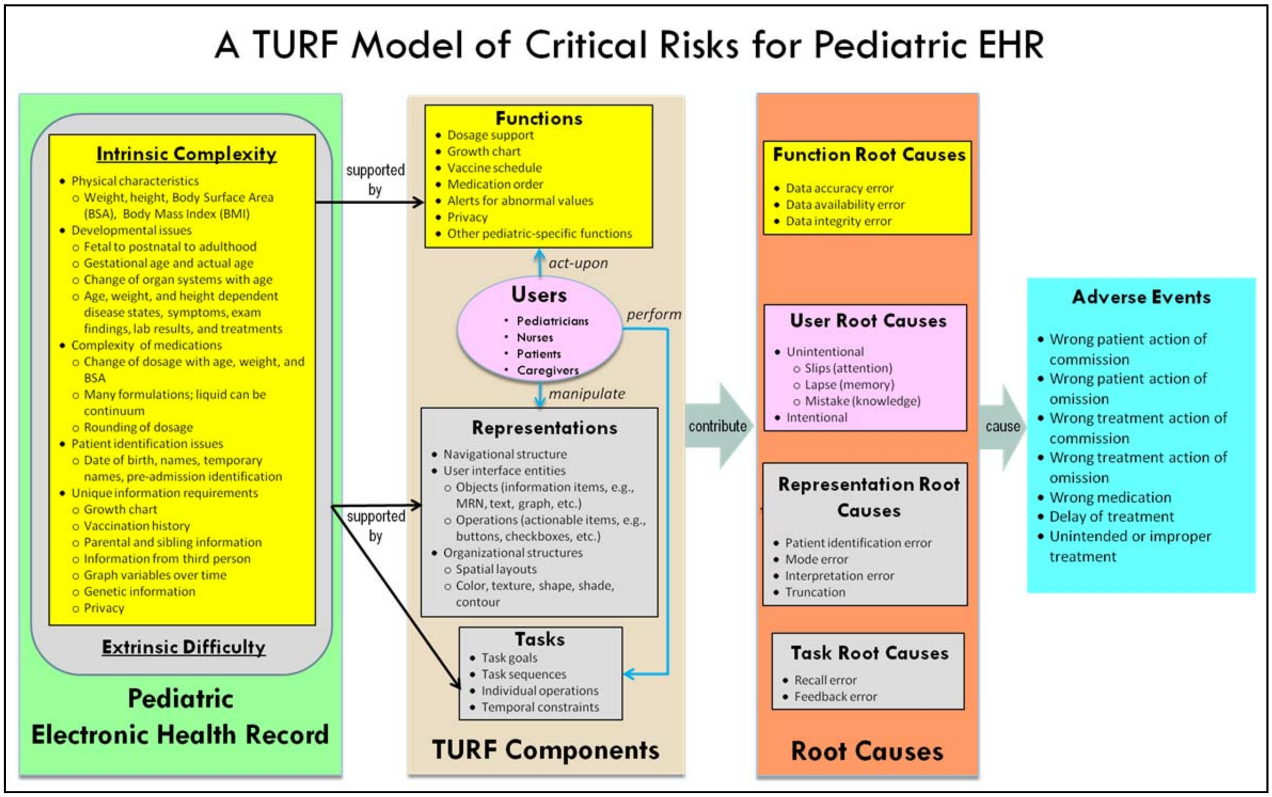

Figure 1. TURF model of unique use-related risks for pediatric patients
(based on the TURF framework from Zhang & Walji, 2011[24])

[24] Ibid.

4 Human factors guidance for critical user interactions with the EHR for pediatric patients

First, we provide high-level usability design goals and specific design considerations relevant to pediatric patients ("Detailed guidance for critical user interactions"). Next, Table 1 summarizes the human factors guidance provided in this section. Each recommendation is numbered and grouped by category of critical user interaction. Finally, we provide general themes across these recommendations.

High-Level Usability Design Goals. As explained in Section 2, we recommend that pediatric EHRs be flexible enough to accommodate rapid changes in patient physiology and related changes in relevant parameters and provide targeted decision support. EHR displays should reduce navigation burdens when complete views of critical graphs, tables, charts, or structured text are displayed without needing to scroll. Additional displays that present together data that are considered for a particular decision reduce the reliance on human memory when needing to access separate tabs or screens.[25] As is common when human factors design guidance is applied to special populations, when one designs to accommodate users with the greatest need for usable systems, generally everyone else benefits too. If a door is designed to accommodate the tallest among us, then everyone else can fit through. Similarly, many of our design recommendations for pediatric patients likely would benefit all patients. The specific recommendations below are consistent with these high-level goals.

[25] Koch, S.H., Weir, C., Haar, M., et al. Journal of the American Medical Informatics Association (2012). Intensive care unit nurses' information needs and recommendations for integrated displays to improve nurses' situation awareness. 2012 Mar 21
[Epub ahead of print].

Detailed guidance for critical user interactions:

I. Patient Identification. When assigning and/or verifying patient identification numbers and names, the risk profile for pediatric care differs from the adult care population. Human factors engineering has a long history of employing systematic methods to conduct ***risk assessments*** of the potential for human error in a given setting. Recognized methods include: Human Reliability Analysis (HRA), Probabilistic Risk Assessment (PRA), Accident Sequence Evaluation Program (ASEP), and Standardized Plant Analysis Risk (SPAR).[26] Some of these methods were used to assess the potential for "wrong patient" errors for adult populations in healthcare settings.[27] Based upon the unique risks for pediatric patients, we make the following recommendations to employ multiple means of identification criteria:

> *I-A. Use unique patient identification numbers that are not based upon social security numbers.* Most EHRs already follow this practice by using either unique patient identification (UPI) numbers or Globally Unique Identifiers (GUID). This is a prior recommendation for all patient populations due to a number of considerations.[28] Nevertheless, this recommendation is particularly important for newborn patients who have not yet received a social security number yet require care and documentation of care in the EHR. In addition, newborn infants sometimes have changes to last names in the first days of life (e.g., BG Jones for Baby Girl Jones changes to Sara Smith). In addition, it is recommended that identification numbers/medical record numbers not be sequential in order to reduce the risk of confusing multiple birth patients as well as newborns born on the same day in the same hospital. Utilization and maintenance of master patient indexes, particularly across multiple hospital organizations, could aid in reconciling temporary and permanent identifiers for newborn patients.[29]
>
> *I-B. Include photographs of newborns with primary caregivers for patient identification.* Photographs of newborn infants with their primary caregivers in the EHR would reduce the risks for wrong patient identification. At a minimum, warnings could be employed when patients with the same last name and same date of birth are in the same unit. For labor and delivery units, patients cannot be distinguished by birth date. In addition, particularly for cultures that have many common last names, unrelated patients can be located next to each other and have the same last name and same date of birth.
>
> *I-C. Include age, gender, and weight on constant-identification banner headers on all screens.* Based upon the unit's population, the following variables might be included: name, gender, weight, age, gestational age, post-conceptual age, and date of birth. For pediatric patients, it is common practice for family members with the same last name to be cared for by the same providers and/or same organizations during the same appointment. In order to prevent "wrong patient" errors, constant-identification banner headers should include gender, weight (in kilograms), and age as well as the units for

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[26] Lyons M, Adams S, Woloshynowych M, Vincent C. Human reliability analysis in healthcare: A review of techniques. International Journal of Risk & Safety in Medicine 16 (2004) 223–237.
[27] DeRosier J, Stalhandske E, Bagian JP, Nudell T. Using Health Care Failure Mode and Effect Analysis™: The VA National Center for Patient Safety's Prospective Risk Analysis System. The Joint Commission Journal on Quality Improvement Volume 27 Number 5:248-267, 2002.
[28] Hildebrand, Richard, James H. Bigelow, Basit Chaudhry, et al. "Identity Crisis: An Examination of the Costs and Benefits of a Unique Patient Identifier for the U.S. Health Care System." 2008. www.rand.org/pubs/monographs/MG753.html.
[29] www.himss.org/ASP/topics_privacy.asp.

age, which can range from “days of life” to “months” to “years” in scale. Note that for same age siblings due to multiple births, first name, medical record number, and unique medical events, such as birth time in minutes, can be the main distinguishing elements, and therefore should be easily accessible if not included on the banner header. Finally, there is information that is of little interest for pediatric care that can be distracting to users, such as information about smoking, drinking, and vaccinations that are only given to elderly patients.

I-D. Distinguish between newly generated and copied information. When taking care of multiple birth patients and patients in the same family, it is often important to have multiple charts open simultaneously in order to reduce reliance on human memory, reduce navigation burdens, and reduce the risks for missing or duplicate tasks that are the same for multiple patients. Nevertheless, having multiple charts open at the same time increases the risk for “wrong patient” errors where documentation is copied and pasted into the wrong chart. Providing the ability to track where information was copied from can aid in detecting these types of errors. For example, subtle background color can be used behind any text that is copied and as data is entered, the background becomes clear (normal) behind the written text. In addition, the source of the copied information can be displayed upon mouse rollover or other interaction to request the information. An additional protection against “wrong patient” errors in this context is to be able to return to the system configuration including automatically saved information that was being worked on when a user was automatically logged out when interrupted to do another task.

II Medications. When ordering medications for pediatric patients, there are unique factors that increase the risks for ***mode errors.*** Mode errors are actions performed in one mode that were intended for another mode.[30] A mode error example could be ordering a dose that would be appropriate for a weight in kilograms, but is incorrect for a weight in pounds, and vice versa. Mode errors have been reported due to confusion of prescribing a medication as the volume in milliliters (mL) rather than milligrams (mg). This common mode error results in tenfold iatrogenic overdoses in hospitalized young children receiving intravenous acetaminophen for pain relief.[31] Unique pediatric risks for mode errors are created by child-specific formats for calculating medication doses, including mg/kg/dose, mg/kg/day, mg/M^2, mg, ml, and dose intervals based on gestational and postnatal age. The last mode, "dose intervals," is particularly complex because it is temporally sensitive. For example, vancomycin has a recommended dosing interval of 18 hours for patients with a gestational age less than 30 weeks old and a postnatal age less than 15 days, but shifts to every 8 hours for a patient with gestational age from 37 to 44 weeks with a postnatal age of more than 8 days. In order to protect against unique risks with mode errors, the following recommendations are made:

II-A. Protect against mode errors for mg/kg dosing and ml dosing. For infant care, EHRs should support ordering expressed by volume of drug and by mass of a drug.[32] In the best case, EHRs would be designed to recognize inappropriate dosing based on the unit of measure it is displaying and the specific patient characteristics. In this way, if a clinician accidentally entered a value based on the wrong mode, the EHR could recognize it, prevent it, and warn the clinician. A weaker solution would be to highlight the distinction between these two modes (e.g., terms never truncated on the menu, mode risk items not placed near each other, units highlighted on the order form).

II-B. Flag that an intended dose is unusual. For example, when a 10 mg/kg dose is delivered with an every-18-hour (Q18) schedule, the attention of the user can be brought to the unusual dose regimen either through passive graphical or text displays of dose ranges or with alerts. A detailed discussion of alert design is beyond the scope of this report. Human factors alert design recommendations have been made for adult populations that are likely also relevant for pediatric patients.[33]

II-C. Support high-precision dosing for low-weight patients. Low-weight patients can experience toxicity if medications are rounded to the nearest digit.[34] In particular, medications with narrow therapeutic indices such as digoxin or insulin have a great potential for adverse consequences if dosed improperly. For example, for a 575-gram infant, kilogram units need to be accommodated to three decimal points. Therefore, a higher resolution for precision during medication dosing needs to be supported and encouraged with the interface design fields for patients below a particular weight for a particular medication. At a minimum, automated rounding based upon needs for adult

[30] Sarter, N.B., Woods, D.D. How in the world did we ever get into that mode? Mode error and awareness in supervisory control. Human Factors, 37(1):5–19.
[31] Cooper, W.O., Habel, L.A., Sox, C.M., et al. ADHD drugs and serious cardiovascular events in children and young adults. New England Journal of Medicine, 2011; 365:1896.
[32] Spooner, A. and Council on Clinical Information Technology. Special Requirements of Electronic Health Record Systems in Pediatrics. Pediatrics. 2007;119(3): 631-637.
[33] Handbook of Human Factors in Medical Device Design Boca Raton, FL: CRC Press, 2010.
[34] Johnson, K.B., Lee, C.K., Spooner, S.A., Davison, C.L., Helmke, J.S., Weinberg, S.T. Automated dose-rounding recommendations for pediatric medications. Pediatrics. 2011 Aug;128(2):e422-8.

patients which cannot be overridden should not be permitted for low-weight patients. This is particularly true for neonatal infants (e.g., 0.016 mg digoxin is the accurate dose needed). Note that this issue also exists for body weight. The weight of infants who weigh less than one kilogram should not be rounded up to one kilogram.

II-D. Do not permit automated defaults to adult doses. Some EHRs employ defaults for standard doses in the event of what appears to be an erroneous dose entry since it is much lower than the adult normal dose. This practice is extremely risky for low-weight patients, particularly if no warning is provided to the provider of the change. For pediatric patients, errors due to “automation surprises”[35] where the system makes unexpected, automated changes to medication orders can have higher patient safety impacts than for adult populations.

II-E. Support custom formulations for liquid medications. With pediatric patient care, a common task is ordering medication in liquid form. Custom formulations, such as “mg/ml,” should be available as an option.

II-F. Support documentation of incomplete medication information. With pediatric patient care, it is not uncommon for medications to be prescribed by other providers and for caregivers to have incomplete information about the medication. For example, if a parent describes that the patient is on “some antibiotic,” that information needs to be captured even if the medication is not ordered in the EHR. For example, if a medication is ordered to address arrhythmia, a disorder of the heart rate or rhythm, it needs to be verified that the ordered medication does not negatively interact with the specific antibiotic. Similarly, if a caregiver reports that a patient is allergic to “an over-the-counter fever medicine.” there should be a way to document that information without having to select a specific one.

II-G. Reduce displayed options for medication orders. Medication prescribing for children is a more complex process than for adult patients, particularly in intensive care.[36] With most paper-based ordering systems, medications are ordered by physicians without the specificity used in pharmacies. When pharmacy-specific information is displayed to physicians, there can be 17 choices for a common medication, creating complexity that can lead to erroneous selection of medications. For medications for children, medications are often given together or with complex dosing regimens, thereby increasing the number of potential options for ordering. Fewer and simpler options are recommended, which would then require support for nurses or pharmacists to correctly translate the order into the level of detail required during the dispensing process.

II-H. Display where the ordered dose (in mg or mg/kg or mg/kg/day) is with relation to the recommended dose range. One protection against mode errors is to display the expected dose range for a selected amount, particularly in order to prevent errors on the scale of ten times the amount. A stronger protection would be afforded by using

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[35] Sarter, N.B., Woods, D.D. Pilot Interaction with Cockpit Automation:
Operational Experiences with the Flight Management System. International Journal of Aviation Psychology, 1992;2(4): 303-321.

[36] van Rosse, F., Maat, B., Rademaker, C.M., van Vught, A.J., Egberts, A.C., Bollen, C.W. The effect of computerized physician order entry on medication prescription errors and clinical outcome in pediatric and intensive care: a systematic review. Pediatrics. 2009 Apr;123(4):1184-90.

“guardrails” technology which alerts when medication orders are outside pre-specified ranges. This type of technology would require a low rate of false alarms and pediatric-specific information in order to be usable.

II-I. Display “input masks” for data entry to clarify type of data. A technique to standardize data entry is to control the format that is allowed, including the format and number of digits allowed, with input masks (e.g., 0.0 mL for volume-based dosing of preschool-age children and 0.00 mL for volume-based dosing of neonates).

II-J. Avoid truncation of medication names and dosages in menus. Users should be able to view the full name of the medication and dose without having to select the item to see the full text. The full text should be viewable without additional interactions. When display space is too limited, at a minimum, rollover interactions that show the full text when the user moves their mouse or other input device over the items are recommended rather than requiring an item to be actively selected to view all of the information.

III Alerts. For pediatric patients, there is much specialized expertise that is taken into account when determining a “normal” range for medications, lab results, and other variables. In theory, clinical decision support systems can be extremely useful in aiding especially novice providers with an order that falls outside the normal range. On the other hand, even for adult patient populations, warnings about potential drug interactions are overridden about 90 percent of the time,[37] primarily due to very high false alarm rates and associated ***“alert fatigue.”***[38] Other types of alarms have similar override rates, including in a pediatric intensive care unit.[39] Recommendations to improve effectiveness of alerts, reminders, and warnings are:

> *III-A. Support flexibility in unit-based settings for alarms, warnings, and alerts based upon weight and age.* Specialized units focusing on pediatric care including pediatric intensive care units, pediatric emergency departments, labor and delivery, and pediatric outpatient clinics need to be able to adapt threshold settings appropriate for their patient demographics, particularly with respect to weight and age. A committee is recommended to be responsible for determining these settings for groups rather than for individuals in collaboration with staff members, including pharmacists, physicians, nurses, and administrators, and with periodic updates to thresholds and underlying logic.
>
> *III-B. Ensure that adult-based thresholds do not replace pediatric-specific thresholds following a system-wide crash.* Pediatric-specific thresholds can be designed to apply wherever indicated and maintained locally by units that specialize in pediatric care. In the event that local adaptations are used rather than embedded in the system settings that are used upon start-up of a system, an important consideration is how to recover after a system-wide shutdown, planned or unplanned. Although reasonable for systems providing care to adult patients to put in place system-wide generic default settings for alarms after a system crash, this practice could be dangerous for pediatric patients, particularly if providers are not alerted to the changes in default range settings. For this situation, no system defaults are preferable to defaults for adult populations.
>
> *III-C. Do not permit “hard stops” for changes to medication orders. “*Hard stop” alerts are pop-up alerts which block the ability for clinicians to complete an intended action with potentially serious consequences. Instead, alerts that permit users to override a recommendation in exceptional situations are recommended. Even when warnings are effective in preventing dangerous drug combinations such as the anti-clotting drug warfarin and certain antibiotics that can produce hazardous effects in combination, somewhat rare but critical situations where exceptions need to be made will be critically delayed.[40] Therefore, alerts with override features are recommended rather than “hard stops.”
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> *III-D. Cap the dose at the standard adult dose and allow override with justification.* When an order is entered for a child less than 14 years of age that exceeds the standard adult

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[37] Isaac, T., Weissman, J.S., Davis, R.B., Massagli, M., Cyrulik, A., Sands, D.Z., Weingart, S.N. Overrides of Medication Alerts in Ambulatory Care. Archives of Internal Medicine. 2009;169(3):305-311.

[38] Van der Sijs, H., Aarts, J., Vulto, A., Berg, M. Overriding of drug safety alerts in computerized physician order entry. Journal of the American Medical Informatics Association. 2006; 13(2):138-47.

[39] Lawless, S.T. Crying Wolf: false alarms in a pediatric intensive care unit, Critical Care Medicine. 1994:22;981-5.

[40] Strom, B., M.D., M.P.H. ,Schinnar, R, et. al. Unintended Effects of a Computerized Physician Order Entry Nearly Hard-Stop Alert to Prevent a Drug Interaction. Archives of Internal Medicine. 2010;170(17):1578-1583.

dose, provide a real-time alert that the adult dose has been exceeded. Alerts should not be “hard stops” in that they should be allowed to be overridden with a justification, particularly for obese adolescent patients.

III-E. Display normal ranges for medication doses and lab values based upon weight and age information. Even in cases when EHRs do not have normal ranges for medications based upon weight and age information available, the systems could support ways for organizations to incorporate this additional information and display it.

III-F. Display together parameters that are continuously monitored to facilitate rapid interventions. It is particularly important to rapidly intervene for premature infants based upon a defined set of pre-identified parameters that are displayed together on a single screen. Parameters to support monitoring of respiratory distress, hypoglycemia, nutrition, muscle tone, circulation, and perfusion are particularly important.[41] Navigating to other areas of the EHR for real-time monitoring is inefficient and may lead to delays and potential errors. A common example is accessing glucose levels in a labs report screen, plus the feeding schedule on a different screen, with additional information about timing documented in nurses' notes on yet another screen.

[41] http://clinicaltrials.gov/ct2/show/NCT01478711.

IV Growth chart. For patients between the ages of 0 and 24 months, the World Health Organization (WHO) international growth standard is a critical tool for nearly every pediatric diagnosis. The Centers for Disease Control (CDC) growth chart is recommended for patients older than 2 years old.[42] Training for pediatricians is standardized for these representations for quick and effective clinical care. When nonstandard representations are used, there is a risk of creating the ***"representation effect."*** This human factors phenomenon refers to the fact that expertise when using cognitive artifacts is contextualized such that the specialized knowledge is difficult to apply when information is not represented in the way in which professionals were trained to use it.[43] Therefore, to best support cognitive strategies based upon clinical expertise, the following recommendations are made:

IV-A. Change measurement units (e.g., lb vs. kg) only when initiated by the user. For infants, it is somewhat common to use the English pound measurement system for data collection and then convert to the metric system when ordering medications. In order to reduce mode error risks from working in different measurement systems, displays should not automatically default to a different measurement system. In addition, displaying units of measure along with data values reduces risks for confusion about the current measurement system and scale.

IV-B. Support accurate conversion from pounds to kilograms. A frequent task is converting weights for children from pounds to kilograms, and vice versa for communicating with caregivers, and can be supported by the EHR to increase the usefulness of the system.

IV-C. Ensure visibility of chart data and axes. Axes should be clearly labeled and the values for plotted data should be easily visible. Plotted data points should not overlap or otherwise obscure information about other data points. Vertical (age) axes should be in 1-month increments (rather than 2-3 month increments for the first year of life). A useful feature would be providing additional information when "hovering" over a plotted data point, such as a percentile. For some functions, it is also useful to have this information for parts of the graph that are not plotted, such as for determining a target body weight for a particular length.

IV-D. Display units accurately in standard notation. Standard "shorthand" notation for units such as "kg" for kilogram or "lb" for pounds should be employed. Age information needs to be clearly denoted as whether it is the current age or age at the time of the last visit.

IV-E. Support selection of particular weight data value to display. Although an important function of growth charts is to see trends, there are situations in which an exact weight data are needed, such as when dosing medications. Therefore, retrieving the exact number plotted on a graph quickly is an important feature.

IV-F. Display age-based percentiles for weight, height, head circumference, and BMI data. Percentiles are critically important indicators for tracking whether growth trajectories are stable or changing. Changes in percentiles in weight and height (length or stature) can be a signal of poor health. Extreme ends of percentiles might be

[42] http://www.cdc.gov/growthcharts/clinical_charts.htm.
[43] Woods, D. D., Roth, E. M. Cognitive engineering: Human problem solving with tools. Human Factors, 1988;30(4): 415-430.

considered healthy as long as the percentile values remain relatively constant over time. Therefore, displaying this information as a temporal trend over hours, days, weeks, or years is highly useful; the timeline scale is context-dependent.

IV-G. Single-click navigation to access growth chart display. Growth charts should be easily accessible with little navigational burden to access the chart (e.g., one click on an easily recognizable icon or menu item).

IV-H. Single-click interaction to view complete growth chart. The most frequently used growth charts should be easily viewed in their entirety with little navigational burden (e.g., no scrolling to view the entire chart).

IV-I. Display height and weight on the same chart. Pediatricians are trained to visualize growth charts that display height and weight on the same chart; the visual representation points quickly to various types of growth abnormalities that have diagnostic importance. The CDC and the WHO growth standard charts are available online.

IV-J. Support custom views with custom time ranges. For some diagnostic tasks, it is important to look closely at a narrow point in time, such as ages 3 to 6 months. Similarly, it is helpful to look at an enlarged segment of a chart when there are many points plotted on a chart. Therefore, supporting the ability to focus on specific time periods or otherwise expand a portion of the chart is a useful feature.

IV-K. Support corrections to plotted data. There are a number of reasons why plotted data may be inaccurate and need to be corrected in order to aid decision making. One common reason is when a premature infant's chronological age is evaluated based upon a younger age group. One technique is to "move back" data points by a time period (e.g., two months) in order to assess growth given the premature birth. Data quality issues might also arise based upon where measurements were taken, how the data were collected, and errors in data entry.

V Vaccinations. Delivering vaccinations is a scheduling task, which has been a much-researched task in human factors engineering.[44] The scheduling task complexity is greatly increased when there is interdependency among tasks, otherwise known as ***task coupling***.[45] Recommended vaccination schedules from the Centers for Disease Control are available for children from 0 to 6 years old and 7 to 18 years old.[46] In situations where multiple care providers coordinate ordering and administering vaccinations, vaccinations are received at more than one organization (e.g., child attending college), vaccinations are missed or children did not follow a typical schedule (such as children adopted from other countries), modifying the schedule is an extremely challenging cognitive task. To reduce errors in vaccine tracking and ordering processes, the following recommendations are made:

V-A. Allow ordering vaccination via reminder. Reminders that suggest ordering a vaccine can facilitate the process by allowing direct ordering via the reminder's dialog box, rather than requiring navigation to an area dedicated for orders or vaccinations.

V-B. Allow data entry for vaccinations given at other institutions. In the event that systems are not completely integrated across institutions, at a minimum, it should be possible to document vaccinations given at other institutions. Displaying the origin of the information upon demand would be extremely useful, particularly when there are discrepancies. For example, a child attending a university might receive a vaccination at the student clinic, and this should be able to be documented by the primary care provider at home. The same goes for children who switch providers because of a move. This ability would reduce the risk of double vaccinations. Similarly, printouts of vaccination records should incorporate data from all institutions where vaccinations were given.

V-C. Support display and tracking of components of combination vaccines. In the event that vaccinations are administered in combination format rather than individually, the system should support tracking what has been administered and when. Ideally, there would be support for evaluating whether vaccination intervals satisfy requirements for both regular schedules and catch-up schedules. Vaccination scheduling requirements can be partially based on whether a vaccine is live (activated) as opposed to inactivated, so EHRs supporting tracking and alerting based on that information would be useful. For example, two live vaccinations could be administered the same day.

V-D. Display the days on which prior vaccinations were given and support alerts for recommended minimum/ideal/maximum intervals between vaccinations. Information about recommended intervals between vaccinations is publicly available and infrequently changes.[47] A useful feature would be to support scheduling when to give vaccines when the recommended schedules were not previously followed for any number of reasons, including waiting until school to receive vaccinations and adoptions from other countries with different schedules.

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[44] Emmett, J., Lodree, E., Geigerb, C., Jiangc, X. Taxonomy for integrating scheduling theory and human factors: Review and research opportunities. International Journal of Industrial Ergonomics, January 2009;39(1): 39-51.
[45] Snoo, C., Wezel, W. Coordination and task interdependence during schedule adaptation. Human Factors and Ergonomics in Manufacturing & Service Industries. Online 12 Dec 2011.
[46] http://www.cdc.gov/vaccines/recs/schedules/.
[47] Gardner, P., Pickering, L.K., Orenstein, W.A., Gershon, A.A., Nichol, K.L. Guidelines for Quality Standards for Immunization. CID 2002:35 (1 September 2002): 503-511.

V-E. Allow sorting of vaccination data by multiple fields. Information about vaccinations is used to support a variety of clinical decisions. Sorting displayed information alphabetically, by time, by component, and in a shot record format should all be supported.

VI Labs. For pediatric patients, the definition of ***"normal ranges"*** is extremely complex and based upon data that are often only relevant for pediatric patients, such as body surface area. In addition, the definitions of "normal" ranges vary based upon the source of the definition. Therefore, to increase the chances of accurately depicting findings against useful "normal" ranges and support effective communications among the relevant personnel, the following are recommended:

> *VI-A. Support communications to change inaccurate normal ranges.* It is recommended that one contact person be designated to receive requests to change inaccurate normal ranges for medications and labs. Requests for change are recommended to be facilitated by EHR features, which automatically direct the request for change to the designated person.
>
> *VI-B. Enable seeing where normal ranges originated from.* For example, normal ranges in pediatrics could be based on adult normal, pediatric normal, weight-based normal, age-based normal, or body surface area normal, depending on which entity generated the ranges.
>
> *VI-C. Enable integrated view of test results from different sources.* EHRs provide the ability in principle to improve reliability and efficiency of the management of electronic test results, such as lab results. In adult patient care, one survey found that 83 percent of responding physicians reviewing at least one test result in the previous two months reported "they wished that they had known about earlier."[48] For the care of pediatric patients, concerns have been raised that electronic results management systems were not designed explicitly for use in pediatric purposes and thus might pose a threat to patient safety. In particular, there can be delays in diagnosis, missed diagnoses, and delays in the receipt of appropriate care.[49] In one study, a primary barrier to adoption was found to be lack of inclusion of all ordered tests in the system.[50] When labs are received from multiple locations, there should be a way to track trends over time despite originating from different institutions. For example, International Normalized Ratio (INR) levels from a blood test need to be tracked carefully over time for patients who have had cardiac valves replaced and are thus treated with Coumadin. When integrating information, it will be important to identify differences in measurement units (e.g., molar vs. concentration values) and normative ranges.

[48] Poon, E.G., Gandhi, T.K., Sequist, T.D., Murff, H.J., Karson, A.S., Bates, D.W. "I wish I had seen this test result earlier!": dissatisfaction with test result management systems in primary care. Archives of Internal Medicine. 2004;164(20):2223–2228.
[49] Wahls, T.L., Cram, P.M. The frequency of missed test results and associated treatment delays in a highly computerized health system. BMC Family Practice. 2007;8:32.
[50] Ferris, T.G., Johnson, S.A., Co, J.P., Backus, M., Perrin, J., Bates, D.W., Poon, E.G. Electronic results management in pediatric ambulatory care: qualitative assessment. Pediatrics. 2009 Jan;123 Suppl 2:S85-91.

VII Newborn care. Newborn infants require special considerations as a category where many of the standard assumptions for adult patients do not apply. In particular, more and unique information is needed for much quicker decision-making cycles by highly specialized physician, nursing, and other care providers. Particularly for premature infant care, it is appropriate to have distinct workflows and information displays since the care needs are sufficiently distinct to warrant ***unique support for high-stakes tasks***. It is possible that the recommendations made below will not be sufficient to truly meet the unique needs of this vulnerable population, and that specialized products might be required for safe and effective systems. In the situation where newborn care is supported by existing EHRs, the recommendations are:

> *VII-A. Enable efficient creation of newborn records.* Newborns should be able to receive urgent care immediately upon birth regardless of whether there is an EHR-based requirement for services such as providing blood for a transfusion. For example, there could be an efficient means for creating a new record for a newborn that automatically pulls relevant data from the mother's record that is accomplished with a single selection of a menu item or push of a button.
>
> *VII-B. Support updating information that is initially inaccurate or unknown.* Information is often not immediately available in the NICU or labor and delivery, such as last names, sex, and weight.
>
> *VII-C. Support the use of gestational age and corrected age for patient care (in addition to chronologic age)*. Care decisions are often made based upon nonstandard age formats in the NICU and for care of premature infants.
>
> *VII-D. Support efficient processes for administration of breast milk, including labeling and matching mother to baby to milk.* Inefficient processes for verifying matches between mothers, babies, and milk can be frustrating and time-consuming, particularly in the NICU where it is a frequent and potentially error-prone activity.
>
> *VII-E. Support connecting prenatal data (e.g., fetal imaging procedure) with post-birth data.* Prenatal data is often available in the EHR chart for the parent, but it would be helpful to explicitly link these data with the child's EHR chart. Of particular importance is information about maternal infections, blood type, and pregnancy complications, including substance abuse.
>
> *VIIF. Support efficient documentation of blood type.* Newborns can receive more appropriate blood transfusions than O negative blood if the information can be efficiently entered based upon information obtained during birth.
>
> *VII-G. Support the use of alternative weights for dosing.* Newborn weights can vary dramatically in the first days of life. In some cases, birth weight or "dry weight" (weight before surgery) is used to dose medications rather than current weight, referred to as a "dosing weight." For example, when weight is automatically populated in medication ordering, the wrong weight could result in ineffective or toxic amounts. This is exacerbated when equipment such as an "arm board," a board to which the arm is taped in order to deliver medications intravenously, is included in the weight measure.
>
> *VII-H. Support conversion from Days of Life (DOL) to Days Old (DO) during care transitions.* Some healthcare organizations use "Days of Life" and some use "Days Old" to denote the age of a newborn infant. During transitions of authority and responsibility

across organizations, it is critically important to be accurate with this information. Since all EHRs can be expected to have accurate birthdate and current date information, it should be possible to allow hospitals to use either convention and support this conversion from one system to the other.

VIII. Display weights in grams and ages in days, weeks, or months under thresholds. For newborns, the appropriate unit is often different given the young age and low weight. Under 3 kilograms, it may be preferable to display weights in grams. During patient rounds and other verbal communications between neonatologists, grams are often used, and supporting this convention, as well as supporting accurate conversions to kilograms for dosing, may reduce conversion errors. Under thirty days, it is preferable to view age in days, weeks, and months. In addition to better support decision making and communications with caregivers, having an age such as “0.005 years old” could lead to erroneous assessments.

VIII Privacy. Ensuring patient privacy and allowing sufficient support for communications to provide effective care is challenging for any patient. For pediatric patients, there are special considerations due to the unique nature of the ***transfer of care responsibility*** based upon age and maturity from the parent or nontraditional caregiver to the child for responsibility for care, particularly with respect to mental health and sexual information. The following recommendations are made:

VIII-A. Support documenting consent agreements for nontraditional parents. It is important to support privacy for nontraditional caregiving arrangements such as children in foster or custodial care, adults who are not parents, adoptive parents, and guardians.

VIII-B. Support "break the glass" privacy law violations for urgent care situations. In urgent care scenarios, it might be necessary to access critical health information that is available in an EHR yet restricted for privacy or security purposes. In the event this is needed, the system should support access as long as documentation is made by the user logging the event, who accessed the information, and the reason for getting access.

VIII-C. Make easily visible what information can be viewed, printed, and transferred with different levels of privacy or security. Many levels of confidentiality for different notes can make it difficult for users to understand what privileges are provided with each level, particularly if the distinctions are not well-defined in the online help documentation. For example, systems can have confidential notes, sticky notes, private notes, and internal notes, each of which has different definitions regarding access for viewing and transferring to other systems. Access issues are particularly complicated for adolescent patients based on age, assent status, and nontraditional caregiving arrangements.

IX Radiology. Radiology is a particularly important specialty in pediatric care. Knowing which test to order is an important decision because the risk associated with exposure to radioactivity is particularly high for infant patients whose cell division is very active and whose cumulative exposure over a lifetime is just beginning. For adult patient populations, consultations between a physician and a radiologist about which test is appropriate to order are important communications. For pediatric patients, the stakes are much higher. Sedation, intubation, and radiation for pediatric patients are much higher-risk activities than for adult patients. Having multiple scans due to inaccurate selection of correct procedures from ***physician-radiologist communications*** conducted only through EHR orders and poor ***usability*** of the interface can have many negative clinical implications for pediatric patients. Therefore, the following recommendations are made:

> *IX-A. Support physician-radiologist communications to clarify which scan variation to order for high-stakes sedation and intubation procedures.* A useful feature would be supporting real-time communications between an ordering physician and a radiologist about which procedure to order in order to reduce delays in care and redundant procedures. In order to ensure that the correct test has been ordered, a narrative including a diagnostic, short history and indication for the reason for the test is needed. It is also important to include information about who can be contacted in real time in order to answer a radiologist's questions. In addition, this support could meet The Joint Commission's (TJC) recommendation to "Create and implement processes that enable radiologists to provide guidance to and dialogue with referring physicians regarding the appropriate use of diagnostic imaging using the American College of Radiology's Appropriateness Criteria."[51] For example, this communication could avert an erroneous order of "chest CT" when a "chest and abdomen CT" is needed. In the event that real-time communications cannot be supported, support could be provided for quality improvement reports to facilitate quality improvement by interdisciplinary teams of physicians and radiologists.
>
> *IX-B. Support alerts for contraindicated procedures.* There is often information electronically available from the chart that, in theory, could inform alerts about procedures potentially being contraindicated during the ordering process. In the event that the current level of technology cannot support this with an acceptable rate of false alarms, reports could be printed to support manual review by assigned personnel prior to the date of a procedure.
>
> *IX-C. Monitor cumulative radiation exposure over time.* A listing in one location of all radiology tests, done at any location, for each patient would help to monitor and reduce exposure to ionizing radiation. Over the past two decades, the U.S. population's total exposure to ionizing radiation has nearly doubled.[52] For newborn patients, it is possible that new sources of radiation will emerge in future decades, further raising the cumulative exposure over a lifetime. High cumulative radiation exposures create cancer and other undesirable consequences. As such, The Joint Commission has recommended that dose information be captured in the patient's EHR.[53] Once the dose information is captured, a highly useful feature would be a cumulative plot of radiation

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[51] Recommendation 2. http://www.jointcommission.org/assets/1/18/SEA_471.PDF.
[52] National Council on Radiation Protection and Measurements: Ionizing radiation exposure of the population of the United States (2009). NCRP Report No. 160, Bethesda, Md.:142-146.
[53] Recommendation 19. http://www.jointcommission.org/assets/1/18/SEA_471.PDF.

exposure over time for physicians, nurses, radiologists, and ideally caregivers and patients.

Summary of Human Factors Themes in Recommendations

In addition to the detailed recommendations described above, there are several overall recommendations that apply across multiple categories to enhance usability in general. These are:

- Facilitate smart rounding of the dose of the medication based on actual formulation of drugs. For example, digoxin is 50 mcg/mL, 10 mcg/kg/day. For a baby with a low weight, an order of 0.4553 mL is too specific, but the ability to order 0.46 mL and not 0.5 mL is important to avoid toxicity. Systems must take into account the correct amount of arithmetic precision needed in values.
- *Avoid truncation of displayed information.* This includes medication names for ordering medications, units for displayed data, names of vaccinations, and information for points plotted so closely together that the information was obscured.
- *Support notations on data.* Much of the numeric information used by pediatric clinicians is influenced by data quality issues. Being able to notate “fussy” on a blood pressure medication reading, information such as “6-week preemie” on growth chart data, and “needs booster shot at next visit” for vaccinations would be extremely helpful. In addition, it is very important to know where information originated from, particularly when there are unusual data values or discrepancies to resolve.
- *Support local display options for age and weight.* Age and weight do not have the same meaning, units, or ranges for pediatric patients as for adult populations. In addition, there are multiple variations on these measures. Having the ability to locally select display options (e.g., g vs. kg, Days of Life [DOL] vs. Days Old [DO], dosing weight vs. current weight) would be useful.
- *Support the use of customized forms, charts, graphs, and reports.* There are many specialized tasks that some pediatric providers perform routinely that are supported by specialized forms, graphs, charts, and other tools. In general, these tools require graphing and analyzing quantitative data where the interpretation is based on other dynamic factors. For example, if a patient has a dilated aortic root, their dimensions are tracked based on Z-score, which is a measure of standard deviation from the mean based on the Body Surface Area. When an adult has an aortic root being tracked, you simply follow the absolute value of the dimension (e.g., 4 cm, 4.1 cm, 4.2 cm). For pediatric patients, the variables that are tracked change with age, weight, height, and other factors. Another example is tracking INR data to see what the dose of an anti-coagulation should be. With paper-based records, physicians typically made flowsheets and graphs that were pasted into the chart. With electronic records, most EHRs currently lack flexibility to provide support for data entry, graphing, or documentation of paper graphs.
- *Support optimizing alerts.* Alerts are particularly important in pediatrics given the extreme complexity of providing care, particularly for vaccination scheduling and medication ordering. On the other hand, designing threshold settings for alerts is particularly challenging in pediatrics given high variability and the need for specialized information that may change quickly over time. Being able to optimize the alert settings locally, particularly for particular units and levels of experience, would be highly useful. In general, in pediatrics, the variability is so high that it is strongly recommended that all alerts can be overridden at the discretion of the provider.

Table 1. Critical user interactions and human factors recommendations

Critical User Interactions	Human Factors Recommendations
Patient identification	IA. Use unique patient identification numbers that are not based upon social security numbers. IB. Include photographs of newborns with primary caregivers for patient identification. IC. Include age, gender, and weight on constant-identification banner headers on all screens. ID. Distinguish between newly generated and copied information.
Medications	IIA. Protect against mode errors for mg/kg dosing and ml dosing. IIB. Flag that an intended dose is unusual. IIC. Support high-precision dosing for low-weight patients. IID. Do not permit automated defaults to adult doses. IIE. Support custom formulations for liquid medications. IIF. Support documentation of incomplete medication information. IIG. Reduce displayed options for medication orders. IIH. Display the recommended dose range for the selected mg/kg dose. III. Display "input masks" for data entry to clarify type of data. IIJ. Avoid truncation of medication names and dosages in menus.
Alerts	IIIA. Support flexibility in unit-based settings for alerts, reminders, and warnings based upon weight, height, Body Surface Area, Body Mass Index, and age. IIIB. Do not permit replacing pediatric-specific thresholds with default adult-based thresholds following a system-wide crash. IIIC. Do not permit "hard stops" for changes to medication orders. IIID. Cap the dose at the standard adult dose and allow override with justification. IIIE. Display normal ranges for medication doses and lab values based upon weight, height, Body Surface Area, Body Mass Index, and age information. IIIF. Display together parameters that are continuously monitored to rapidly intervene.
Growth chart	IVA. Do not permit changes to measurement systems (e.g., lb vs. kg) unless initiated by the user. IVB. Support accurate conversion from pounds to kilograms. IVC. Ensure visibility of chart data and axes. IVD. Display units accurately in standard notation. IVE. Support selection of particular weight data value to display. IVF. Display age-based percentiles for weight, height, head circumference, and BMI data. IVG. Provide single-click navigation to access growth chart display (e.g., one click on easily recognizable icon). IVH. Provide single-click interaction to view complete growth chart (e.g., no scrolling). IVI. Display height and weight on same chart. IVJ. Support custom views with custom time ranges (e.g., 3 months to 6 months). IVK. Support corrections to plotted data.
Vaccinations	VA. Allow ordering vaccination via reminder. VB. Allow data entry for vaccinations given at other institutions. VC. Support display and tracking of components of combination vaccines. VD. Display the days prior vaccinations were given and support alerts for recommended minimum/ideal/maximum intervals between vaccinations. VE. Allow sorting of vaccination data by multiple fields.

Table 1 (Cont). Critical user interactions and human factors recommendations

Critical User Interactions	Human Factors Recommendations
Labs	VIA. Support communications to change inaccurate normal ranges. VIB. Enable seeing where normal ranges originated from (adult normal, pediatric normal, weight-based normal, age-based normal, body surface area normal). VIC. Enable integrated view of lab results from different sources.
Newborn care	VIIA. Enable efficient creation of newborn records. VIIB. Support updating information that is initially inaccurate or unknown (e.g., last names, sex, weight). VIIC. Support the use of gestational age and corrected age for patient care (in addition to chronologic age). VIID. Support efficient processes for administration of breast milk, including labeling and matching mother to baby to milk VIIE. Support connecting prenatal data (e.g., fetal imaging procedure) with post-birth data. VIIF. Support efficient documentation of blood type. VIIG. Support the use of alternative weights for dosing. VIIH. Support conversion from Days of Life (DOL) to Days Old (DO) during care transitions. VIII. Display weights in grams and ages in days, weeks, or months under thresholds.
Privacy	VIIIA. Support documenting consent agreements for nontraditional parents (children in foster or custodial care, adults who are not parents, adoptive parents, and guardians). VIIIB. Support “break the glass” privacy law violations for urgent care situations. VIIIC. Make easily visible the rules that describe what information can be viewed , printed, and transferred with different levels/types of security on notes and all text in the chart.
Radiology	IXA. Support physician-radiologist communications to clarify which scan variation to order for high-stakes sedation and intubation procedures. IXB. Support alerts for contraindicated procedures. IXC. Monitor cumulative radiation exposure over time.

5 Opportunities for innovation

In addition to the recommendations provided in Table 1, potential opportunities for future innovation were identified. In particular, developers interested in developing specialized “child modules” for pediatric patient care that can be used in conjunction with established EHR systems might consider the following areas that we believe would be viewed as useful features:

- “Normal” dose ranges, lab, and vital sign values for pediatric patients. Complex factors are used in each of these calculations. For example, vital signs and blood pressure ranges depend on height and age but not weight, whereas dosing is based on weight.
- Support seeing all variations on a medication order (e.g., amoxicillin) or procedure (e.g., CT scan) without clicking on them, and view which ones have most frequently been selected.
- Support selecting the necessary billing codes and generating the associated documentation to receive the appropriate financial reimbursement from third parties (e.g., insurance companies).
- Support innovations in “smart alerts,” including expertise-based adjustments and escalations of who receives alerts based on values and combinations of variables with Boolean logic.
- Provide smart vaccine support, such as verifying vaccine combinations, catch-up doses, and missed doses.
- Support locally adding charts for specific conditions (e.g., Down syndrome). The growth chart is not the only chart that is useful for pediatric patient care.
- Support tracking and graphing medical data, where the interpretation is based on other dynamic factors. For example, if a patient has a dilated aortic root, their dimensions are tracked based on Z-score, which is a measure of standard deviation from the mean based on the Body Surface Area. When an adult has an aortic root being tracked, you simply follow the absolute value of the dimension (e.g., 4 cm, 4.1 cm, 4.2 cm). For children, the variables that are tracked change with age, weight, height, and other factors. With paper-based records, physicians typically made flowsheets and graphs that were pasted into the chart. With electronic records, most EHRs currently lack flexibility to do this strategy.
- Support role-based access control for sensitive portions of the note. As responsibility for care is transferred from parents to children, there is an increased need to protect sensitive portions of the note from parents, such as psychology notes and suicide flags. Provide support for communications to add medications to the formulary, reduce false alarms for alerts, reminders, and warnings, and address sources of inaccurate data. It is recommended that one contact person be designated to receive requests to change inaccurate settings or undesirable settings. Requests for change are recommended to be facilitated by EHR features, which automatically direct the request for change to the designated person.
- Provide support for identifying areas for quality improvement by displaying clinical data for cohorts of patients against benchmarks. A useful feature, particularly for quality improvement or administrative personnel, is to have reports and dashboard displays to see how patient care measures relate to national benchmarks. Pediatric subspecialties are continuously advancing local, state, and hopefully eventually national standards for care and associated measures, few of which are currently captured with existing or future requirements for quality improvement measures for adult patients. For example,

all infants with a fever within the last 28 days treated in the hospital might want to be reviewed for quality improvement or research purposes.

- Drug dictionaries with pediatric-specific dose ranges and alerts that include single-dose, daily-dose, and cumulative-dose decision support, including lifetime cumulative dose for chemotherapies.[54]
- Support physician-radiologist communications to clarify which scan variation to order for high-stakes sedation and intubation procedures. A useful feature would be supporting real-time communications between an ordering physician and a radiologist about which procedure to order in order to reduce delays in care and redundant procedures. In addition, it is important to track the frequency of radiology procedures to assess the cumulative patient safety risk.
- Support warnings for contraindicated procedures. There is often information electronically available from the chart that could inform the system notifying the user that a procedure is contraindicated during the ordering process. For pediatric patients, procedures often are more challenging than for adult patients due to small sizes and resistance to staying still during intubation and other critical activities. On the other hand, some procedures occur more often, such as lumbar punctures for young infants since they have a higher risk of meningitis and do not reliably show signs of meningeal irritation. Patients with increased intracranial pressure (ICUP) are contraindicated for receiving a lumbar puncture.
- Accommodate critical information exchange for patient facility transfers (particularly for premature neonates). Extremely sick premature neonates will frequently be transferred to receive care at institutions with the most specialized knowledge to provide care. Having an efficient way to get an overview of critical information is critical to meet the needs of these patients. In most cases, no social security number will yet be available for these patients; therefore, additional support for accurate identification is needed.
- Display the origin of medication, lab, and procedure information. Knowledge of where information originates is critical to determining what information to consider when there are discrepancies. As EHRs begin to incorporate more information originating from other systems designed for other purposes, such as insurance companies, billing services, and personal health records, this ability will be even more important.

[54] Kim, G.R., Lehmann, C.U., Council on Clinical Information Technology. Pediatric Aspects of Inpatient Health Information Technology Systems. Pediatrics. December 1, 2008;122(6):e1287 -e1296.

6 Conclusion

Usability of EHR systems has been identified as an important factor in patient safety. The adoption of EHRs by providers specializing in pediatric patient care has lagged behind adoption for general population providers. Pediatric patient care has unique features and some aspects of care are more complex and have higher stakes. In this document, we highlighted unique user interactions important for providing pediatric care with the support of an EHR and provided guidance from the human factors literature to increase usability. Of particular importance in the provided recommendations are:

- Display information in menu items and on charts/graphs without truncating critical information, including doses and measurement units;
- Support one-click access to the growth chart in the standard display format;
- Eliminate automated changes to adult doses for medication orders; and
- Protect against ordering medications in the wrong units, which could result in tenfold or higher dosing errors.

Appendix A Representative clinical scenarios

In the appendix, we illustrate some of the unique considerations for pediatric patients in the context of representative, fictional clinical scenarios. Developers may find these scenarios helpful for the purpose of assessing unique risks for pediatric patients, such as through formative user-centered design approaches or summative usability evaluations. Human factors elements are highlighted in call-out boxes on the right.

Scenario A: Newborn with sepsis treated by Emergency Department physician

A six-day old infant is brought to the Emergency Department (ED) by his mother who reports that he has a fever. At triage, he is very irritable, has a rectal temperature of 39C, and a bulging anterior fontanel. By ED protocol, he is brought to a treatment room immediately to be seen by a physician. The infant's history is significant for being the A twin of a term pregnancy delivered by a scheduled C-section. The B twin is reported to be well at home with the father. The physician's assessment is that the infant may have sepsis/meningitis and requires a workup. On examination, the physician hears crackles and assesses that a chest x-ray is indicated.

Increased risk for wrong patient error: Same parents, last name, sex, birth date, age, and gestational age

The mother does not know the medical record number, so the registrar in the ED asks for the social security number, but it has not been issued yet. The registrar successfully finds the mother's file that includes a note with medical record numbers for both children. The physician successfully pulls up the chart. The physician clicks the "sepsis bundle" quick order on the interface. The system orders standard adult doses for these medications, which are far too large, as well as an inappropriate procedure for placing a central line, so he cancels the set of orders.

Increased risk for wrong patient error: Delay in obtaining social security number

Automation surprise: Unexpected default to standard adult dose

The physician then calls up a feature that supports weight-based dosing. He estimates that the patient weighs 8 pounds and types 8 in the weight box entry and switches the default system from kilograms to pounds by clicking the radio button next to the number. The physician does not realize that the system records the weight as 8 kg. The alert that the weight falls outside the normal values is located on the "face sheet" page, not on the page where the dose is entered. The ordered dose is not what the nurse expects, and she realizes that the system treated the entry as if it were kilograms, not pounds (because the software does not store units with the data and assumes kilograms for any weight-based data entry). The nurse informs the physician that the weight is incorrect.

Automation surprise: Unexpected change in measurement system for weight results in inaccurate data

The nurse then informs him that the exact weight is 4.1 kg (9.0 pounds). The physician remembers that the appropriate dose for the antibiotic is 10 mg/kg/dose, and calculates in his head that the appropriate dose is 41 mg. He types in the order for a brand name antibiotic for that dose. When he reviews the medication order, he sees that the system has created an additional order for the standard adult dose of 2000 mg as well as in the

Complexity: Potential for mode error, calculation mistakes, during medication ordering *generic form rather than the brand name form of the medication. He cancels the adult dose and confirms the pediatric dose.*

Automation surprise: Unexpected change to generic form of medication

The doctor needs broad antimicrobial coverage and wants to start a second antibiotic. The physician then enters an order for the second medication. The dose and frequency of administration for this medication are dependent on the gestational age of the patient, the actual age, the weight, and the renal function. This medication is administered by IV, so the options available for ordering are reported in ml, but the information about the concentrations that indicate what the dose is in mg/kg are truncated on the display. In some of the EHR systems that the doctor uses, this medication is ordered in mg/kg/day, and in some mg/kg/dose, so the doctor needs to double check how the information is being displayed. He clicks on each of the options, and then cancels the orders until he finds the correct concentration. He calculates the amount of medication needed in his head and orders it. When he reviews the order, the system has automatically rounded the dose amount to the nearest regular dose, which is too high and would be potentially harmful to the child if administered. He cancels the order and manually enters the correct amount.

Mode error: High potential for selecting the wrong dose due to complexity, truncation of critical information, and inconsistent conventions

Automation surprise: Unexpected consequences of rounding a dose for low-weight patients

The physician then returns to assess the patient, and informs the mother that antibiotics have been ordered. He learns that the patient's twin is at home with the father and asks again what the patient's first name is. When he looks at the record, he realizes that he had ordered the medications for the wrong sibling. He informs the mother that since this is an emergency situation, he will not correct the mistake now, but that he will add this information to the progress note so that people in the future will be aware that it was the other sibling that had sepsis. He writes in his note that there was an error in patient identification and that the sepsis treatment was administered to the other child, including the temporary ID number and the mother's name for referencing purposes.

Workflow mismatch: Difficult to change inaccuracies in documentation after the event

The physician attends to another patient with critical issues. He then orders a CT scan for the infant in the electronic health record. There are 24 available options for CT scans taking into account the potential implications of size-based parameters, sedation techniques, and body size. Choosing the appropriate test would be very difficult for a less experienced physician without consulting with a radiologist.

Specialized expertise: Would benefit from consulting with radiologists or decision support for which CT scan to order

Scenario B: Premature twins cared for by NICU interdisciplinary team

The unit clerk in the neonatal intensive care unit (NICU) receives a phone call asking for transport of two premature (30 weeks gestational age) twin girls, both with significant critical care needs. The NICU attending physician, Dr. Patel, accepts the patient and is in communication with the air transport team and the attending care team at the transferring community hospital. While on the phone with the transferring ICU team, Dr. Patel is taking handwritten notes. Dr. Patel needs to order critical medications/drips and emergency diagnostic imaging in anticipation of the arrival of the transport team and the twins. A full set of general admission orders is also needed.

Because the patients have not been admitted yet, Dr. Patel is unable to use the EHR to write orders for the patients, so he notifies the unit clerk of the impending admissions and uses paper. Dr. Patel creates the names of Smith Baby A and Smith Baby B in keeping with NICU protocol and randomly chooses two admitting bed numbers in the NICU for their admission. Dr. Patel randomly chooses the bed numbers because he knows that the pharmacy will not process the medication orders without a bed assignment (Dr Patel's attempt at a workaround). Dr. Patel submits the paper orders to the unit clerk who proceeds to call the pharmacy.

Workaround: Provider attempts to select beds with other patients already in them in order to write time-critical orders.

The two bed numbers that Dr. Patel selected were already occupied with other patients, and thus the names associated with the orders did not match the names available to the pharmacists about patients in beds (the form was called the bed assignment roster). The pharmacist refused to verify the medication orders. Similarly, diagnostic imaging refused to schedule the procedure, and called the NICU unit clerk with the message "call us back when the babies arrive and you have bed assignments."

Dr. Patel then was informed by the charge nurse that the standard workaround was to use "virtual bed numbers" for urgent care situations prior to bed assignments. The charge nurse in the unit called the pharmacy and provided the two virtual bed numbers to the pharmacist tech who answered the phone and asked the admissions clerk to admit the incoming twins to the virtual beds. The pharmacy then began to process the orders for Smith Baby A and Smith Baby B. The presence of the virtual bed numbers also allowed the admissions clerk to formally "admit" the patients, even though they had not physically arrived yet. The admissions clerk typed the age in as 30 weeks, since it did not make sense to her to type 0 in as the age. Admitting the patients then allowed two new electronic records to be created, one for Baby A and one for Baby B.

Learnability: Nonroutine process of 'virtual bed numbers' is used to allow timely care in exceptional circumstances, not intuitive for first-time users.

The twins arrived shortly thereafter via airlift from the community hospital. The fragments of the patient's charts that arrived with them as printouts listed the babies as Baby 1, Smith and Baby 2, Smith. It was now after midnight, so technically this was now the second day in chronological age for the twins.

Smith baby A/Baby 1, Smith and Smith Baby B/Baby 2, Smith were delivered via C-section at 30 weeks gestation, and therefore were premature (preemies). The mother was a 20-year-old woman in her first pregnancy that developed preeclampsia. The transferring community hospital (out of state) was not part of the same hospital system as the NICU/admitting hospital. Because the babies did not have social security numbers yet, the transferring hospital had used a unique medical record number (MRN) for each of the babies. The admitting NICU did not recognize the transferring MRNs, so two new identification numbers were created based on the NICU protocol. Data from the transferring hospital was therefore linked to babies with different names and different unique identifiers than what had been created in the admitting hospital system. Both babies were eventually assigned to open (non-virtual) beds in the NICU, requiring a change in the bed assignments in the system. Any paper-based orders and incoming data were manually transcribed into the EHR in the NICU system by the bedside nurse using the new bed assignments and the new identifiers. The baby names were changed to Smith Baby A and Smith Baby B. (Note that John Smith, an unrelated patient, was also in the NICU at this time.)

Patient identification: Challenges with nonstandardized identifiers increases the potential for patient identification errors based on mismatch of babies, beds, and identifiers.

Smith Baby A weighed 3 lbs. 12 oz. Smith Baby B weighed 3 lbs. 15 oz. Smith Baby A presented with gastroschisis, a birth defect in which an infant's intestines stick out of the body through a defect on one side of the umbilical cord, and was intubated. Smith baby A's intestines appeared to be poorly perfused, indicating concerns about blood flow, and oral secretions were positive for meconium, indicating the potential for airway blockages. Both babies had Patent ductus arteriosis (PDA), a congenital disorder in the heart that causes shortness of breath. Smith Baby A's PDA was small and asymptomatic, Smith Baby B's was not. Smith Baby B was receiving oxygen therapy via a nasal cannula tube.

Data availability: Poor interoperability creates the potential for medication errors, delays in care, and redundant workflow.

Baby A was transported to the Operating Room (OR) within three hours of arrival. The system in the OR was not integrated with the NICU's EHR. The medications ordered and filled by the pharmacy were delivered to the NICU, although Smith Baby A was now in the OR. Other orders had to be temporarily suspended or modified while the patient was in the OR. Smith Baby B's PDA was hemodynamically significant and also was receiving supplemental oxygen to correct hypoxia, also known as oxygen depletion. An order was written for indomethacin for Smith Baby B.

Baby A returned from the OR to the NICU. Both Dr. Patel (the original admitting physician) and the original charge nurse had handed off responsibility for care at the shift change to new providers, Dr. Ware and the new charge nurse. The day shift personnel assumed responsibility for care and began rounding on all patients, including the two patients. Seven personnel (1 attending physician, 2 fellow physicians, 3 resident physicians, and a rounding nurse) comprised the rounding team. Four of the team members pushed computers on wheels (COWs), two had iPads, and one was using a bedside tray table with a laptop on it. The resident physicians took turns using one of the COWs to open the next patient's chart since the process of authenticating into the system and opening a chart took approximately 4 minutes. This approach made the rounding process somewhat more efficient. At the end of the rounds, the attending physician, Dr. Ware, opened each chart of the 30 neonates in the unit to review and sign off on the plan of care. She used two side-by-side computers to alleviate the delay between opening one patient's chart at a time.

Workarounds: Lengthy response time requires workarounds to meet urgent care needs. Workarounds tend to circumvent built-in safety features.

Scenario C: Teenager treated for knee pain by family physician

A 16-year-old male patient goes to a family practice physician for knee pain after falling during basketball practice as a same-day ill-child urgent outpatient appointment. His past medical history is significant for requiring a pacemaker for heart block caused by neonatal lupus, which is a rare temporary autoimmune disorder due to receiving positive maternal autoantibodies from the mother while in utero.

His mother has signed a release, and he is being seen by the doctor without any parent present at the visit. While at the visit, the patient discusses concerns about personal matters. The pediatrician assures him that the conversation will remain private. The physician selects the option "secure note" on the interface in order to protect the information. (Unfortunately, the correct option was "confidential note" for this purpose, not the selected option or the other available options of sticky note, private note, or internal note, none of which are defined in the online help system documentation.)

Shared access to protected data: Difficult to see what information is accessible to whom

After physically examining the knee, there is a concern about a torn anterior cruciate ligament (ACL). The pediatrician consults an orthopedic surgeon, who recommends a Magnetic Resonance Imaging (MRI) test to make a picture of the knee to definitively determine whether the ACL has been torn. The physician orders an MRI from available options, without realizing that the order will not provide the correct billing (Current Procedural Terminology - CPT) code for full reimbursement from the insurance company. The correct test was available in the menu options, but looked nearly identical based on the description.

Alert: No alert for contraindication for MRI with a pacemaker

The mother asks for a printout of the findings from the physical examination to be taken to the surgeon's office. The physician selects "print to PDF" with the option for a "redacted note with no addendum" for the note on the date of the outpatient visit and emails the file through a secure patient portal. The mother is surprised to see the private information documented in the note and discusses the matter with the patient, who feels a loss of trust in his relationship with the physician.

On the day of the MRI, the test is cancelled because the nurse realizes the patient has a pacemaker, which they consider a contraindication for MRI. The patient schedules a new appointment three days later with his family physician in order to determine an appropriate treatment plan.

Scenario D: Infant treated for recurrent ear pain by pediatrician

A 30-month-old female patient has been having recurrent ear infections. There is nothing significant in the prior medical history, and she was well during her 2-year annual examination. She has had 4 visits in the last 6 months for recurrent otitis media (OM), which is inflammation of the middle ear; sinusitis, which is inflammation of the sinuses; and bronchiolitis, which is swelling and mucus buildup in the lungs. However, she just started day care, along with her 4-year-old brother, and many of the children in the daycare have been ill with similar symptoms.

During the fifth same-day ill-child visit for the same problem, the pediatrician notices that one of the vaccinations was ordered but then canceled, and recommends to the parents that the child receive the vaccination immediately, which they consent for, and it is given. (She later realizes that the vaccination order was canceled because it was previously given.)

Visibility of critical information: Difficult to quickly see what vaccinations were previously given and on what day

At the 3-year-old annual well-child visit, the mother requests for the patient to be seen by a specialist for all of the infections. In carefully reviewing the growth chart, the pediatrician realizes that the child has not grown well in the last 6 months, and has gone from the 75th percentile to the 25th percentile in both height and weight. She apologizes to the mother because the team had missed the poor growth for several months. It would have been unusual to miss the trend with the previous paper-based growth charts, but the doctor suspects the error to be more common with the electronic growth embedded in the EHR, because it requires 8 mouse clicks to view, and an additional 3 mouse clicks to look at height and weight in the internationally standard format promoted by the Centers for Disease Control.

Navigation: Difficult to access growth chart display on format that has been trained on

In addition, she realizes that the child received two doses of the same vaccine due to confusion about what had already been given when. She apologizes for having given a duplicate dose of the vaccine and determines an adjusted vaccination schedule for future vaccines which are based upon a desired time window after receiving an earlier vaccine. She carefully documents this schedule in a note and writes a post-it note that the vaccination schedule has been changed and the date of the electronic note to read with the new schedule on the paper copy of the chart that is kept in the secretarial suite.

Coupled variables during scheduling task: Deviating from a routine vaccination schedule is a complex cognitive task requiring remembering changes to plans months later.