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Use of Integrated Clinical Decision Support Tools to Manage Parenteral Nutrition Ordering: Experience From an Academic Medical Center

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Abstract

Parenteral nutrition (PN) is a complex therapy with numerous opportunities for error during the prescribing, preparation, and administration processes. Advances in technology, such as computerized provider order entry (CPOE), electronic health records (EHRs), and clinical decision support (CDS) have helped decrease the risks associated with PN therapy. These technologies can be utilized to guide prescribing, provide automated safety checks, and increase overall safety and accuracy in PN ordering, compounding, and administration. In recent years, increased awareness of the risks associated with PN therapy, in particular issues with ordering and transcription, have magnified the need for improved support of PN ordering within currently available systems. Additionally, drug shortages continue to impact key components of PN admixtures, further increasing the risks associated with this complex therapy. These concerns and risks present an opportunity for the development of new functionality, as well as improvements in and innovative utilization of available technology within systems supporting the PN use process. This discussion will highlight the risks associated with PN, examine the role of drug shortages on the safety of this therapy, describe the application of available technology to manage shortages, and report the experience of using commercially available CDS tools at one academic medical center. It will also include a discussion of the transition from paper orders to CPOE/EHR-based orders for PN and the transition from one commercially available electronic system to another at this particular institution. (*Nutr Clin Pract.* 2021;36:418–426)

Keywords

clinical decision support systems; drug shortages; electronic health records; medical order entry systems; nutrition support; parenteral nutrition

Introduction

The parenteral nutrition (PN) use process, including PN prescription/communication of the order, order review/verification, preparation/compounding, and administration, is complex with high levels of inherent risk at every step in the process.[1] Advancements in technology and integration into patient care (eg, computerized provider order entry [CPOE], electronic health records [EHRs], clinical decision support [CDS], automated compounding devices [ACDs], "smart" infusion pumps) may improve safety and

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reduce medication-related errors.[2-5] However, there are still gaps and opportunities for improvement within EHRs, as many institutions have not been able to fully adopt or optimize technology and CDS in the PN use process.[5,6] This lack of adaption and optimization decreases the capacity of healthcare systems to realize the full safety benefits of these systems and could continue to allow for PN-related errors, in which transcription, dosing, and component compatibility errors can have a significant impact on patient safety and morbidity.[1,7] In recent years, increased awareness of PN risks and safety concerns has led to the development of consensus recommendations from the American Society for Parenteral and Enteral Nutrition (ASPEN), as well as several other documents and resources focused on improving safety in the PN use process.[1,5,8-10] Concurrently, advances in technology have provided additional opportunities to minimize potential PN-related errors. EHRs can better integrate and utilize CDS alerting features, improve PN order sets/templates, and directly interface with ACDs and other systems, which can increase efficiency and eliminate the need for manual transcription. These advances can improve accuracy, decrease the number of orders that require clarification,[11,12] and help eliminate errors during the ordering process.[13,14]

Studies have shown that the use of PN-specific software can reduce errors, with some studies showing reductions as high as 89%.[3] One study published by MacKay et al in 2016 highlights the benefit of developing a CPOE system that is completely compliant with the ASPEN guidelines for PN. Within their institution, analysis of data from 7 years of CPOE development and implementation showed lower error rates compared with national averages and the elimination of all errors related to transcription.[4] Standardization of available PN admixtures can also reduce error rates, which was shown at Johns Hopkins All Children's Hospital when they standardized PN admixtures for neonatal and pediatric patients in an attempt to improve PN safety.[2] The standardization of PN admixtures and the incorporation of such admixtures into the EHR significantly decreased the PN ordering error rate from a baseline of 22% to 3.2% over the first quarter of the study period.[2]

Despite literature demonstrating the benefits of technology and standardization, wide variations in practice persist. Published surveys have highlighted inconsistent practices and frequent adverse events related to PN ordering. A survey conducted by ASPEN and published by Seres et al in 2006 found that existing practices were inconsistent with published guidelines and that there were wide variations in the ordering and administration of lipid injectable emulsions (ILEs) and electrolytes. Approximately 45% of respondents reported adverse events requiring intervention directly related to PN, and, consistent with other institutional surveys at that time, only 54% of respondents reported using standardized order forms.[15,16] Most errors described were related to incorrect order interpretation, information transfer errors, or procedural inaccuracies. A 2009 publication by Sacks and colleagues found that the majority of errors in a 471-bed academic teaching hospital occurred during the transcription and administration processes, resulting in a total error rate of 15.6 errors per 1000 PN orders.[7] The large number of errors found during the transcription stage was likely related to the practice of all PN orders being handwritten by members of the nutrition support team at the time this study was conducted.

A follow-up survey of ASPEN members regarding EHRs, published by Vanek in 2012, revealed a marked variation in the perceived quality and effectiveness of commercially available EHR systems, with the top-rated vendor receiving an overall score of 90.3% and the lowest-rated vendor receiving a score of 57.8%. Although 67% of survey respondents used an ACD to prepare PN, 81% had no interface between the ACD and the CPOE system.[17] A second follow-up survey conducted by ASPEN in 2014 and published by Vanek et al in 2016 found no improvement in perceived EHR quality and effectiveness. In fact, the percentage of favorable responses regarding PN ordering decreased significantly. The use of an ACD increased to 71% in 2014, but the use of an electronic interface between the CPOE system and the ACD remained low at 28%.[6]

EHR functionality and interoperability are key components in the safe delivery of PN therapy.[18] ASPEN, the Academy of Nutrition and Dietetics (AND), and the American Society of Health-System Pharmacists (ASHP) recently published a consensus statement encouraging improvements in the functionality of EHRs to ensure safe and optimal delivery of PN. The document describes key challenges encountered when using EHRs for PN and is a call to action for clinicians and vendors to optimize electronic PN ordering and workflow.[5] Technology should support standardized processes for the ordering of PN, the implementation of a verification process, appropriate compounding that meets current standards of care, proper dispensing of the completed product, and safe administration.[19]

The thoughtful design and implementation of electronic PN ordering and associated CDS has been shown to improve the accuracy, safety, and efficiency of this complex process, but this can only be achieved with a significant investment in both initial and ongoing technical support.[20] Continuous maintenance of these systems is required in order to incorporate new medications, new products, fluctuating drug shortages, and new evidence regarding compatibility and safety.[21] ASPEN provides recommendations to assist organizations in maximizing the clinical benefit of PN therapy while minimizing the potential for adverse events.[1] CPOE optimization should involve the use of "hard-stop" (override not allowed) and "soft-stop" (override allowed)

alerts, development of order sets, compatibility and solubility checks, and automated calculations.[22] CPOE systems can also greatly impact the accuracy and efficiency at which PN orders can be filled by standardizing repetitive tasks and simplifying complex tasks.[23] Programs should have the ability to ensure that labels match the electronic order entry form to limit error in the verification and administration processes, as well as the ability to prevent multiple orders from being entered or for orders to be entered more than 24 hours in advance. [24] Unfortunately, the ability to support PN ordering and dispensing varies widely among EHR vendors.

This paper will describe the development and implementation of PN ordering within a commercially available vendor CPOE system at our institution, a large academic health system comprising three hospitals with 1000 licensed beds. It will also describe the use of integrated CDS to improve safety and manage the rapidly changing availability of different PN components at the point of order entry. The health system implemented Sunrise Clinical Manager (version 4.5; Allscripts, Chicago, IL, USA) between 2006 and 2008 and then transitioned to Epic (version 2012; Epic Systems, Verona, WI, USA) in June 2014. The data presented in this paper are derived from the five full years (2009–2013) during which PN was ordered through Allscripts at our institution. This project was reviewed by the Institutional Review Board of the University of Michigan and determined to be a project not regulated.

CPOE Build at Our Institution

Standardized order forms and processes for PN were in place at our institution well before the implementation of CPOE; however, these standardized forms and processes were not fully compliant with ASPEN recommendations. Three different templates were used: neonatal PN (<10 kg), pediatric PN (10–30 kg), and adult PN (>30 kg). These forms were developed to have weight group–specific amino acid and multivitamin products, ordering of electrolytes using salts (rather than ion-based ordering), weight-based dosing of all ingredients for neonates, and total daily dosing of all ingredients for pediatrics and adults. For adult patients, the macronutrients and electrolytes were initially ordered in amounts per liter on the paper forms and then converted to amounts per day prior to the transition to electronic ordering. The original paper order forms included a standard day 1 PN formula for each patient group and a place to order a customized formula; the back of the form contained guidance on the minimum and maximum amounts of additives, infusion suggestions, and laboratory monitoring orders and guidelines. A prescriber could select the standard formulation, a starting volume, and a plan to advance toward goal, or they could create a custom PN by filling in a specific value for the particular ingredient being customized. PN compounding was outsourced to an external compounding pharmacy vendor during this time, and paper PN orders were manually transcribed into the external vendor's electronic system for additional review and compounding.

Major challenges associated with the use of paper PN orders included the requirement of manual transcription into the external vendor's software and the lack of automated calculations and CDS, which required manual calculations and assessment of dosing and concentrations for safety and compatibility. When our institution transitioned to electronic ordering, the PN order sets used on the paper forms were built into the CPOE system. This allowed for several improvements in the process, including allowing our institution to align its PN ordering practices with most of the existing ASPEN PN Safe Practices[25] and aligning with many of the recommendations that would eventually be included in the ASPEN PN Safety Consensus Recommendations.[1]

Automated calculations and CDS were built into the PN order sets. Examples at our institution included the following:

- Calculations of total daily amounts of individual ingredients (eg, total electrolyte content based on individual amounts from various salt forms and electrolytes inherent in some amino acid formulations, total daily dose based on a weight-based order)
- Individual ingredients ordered in amount per day or amount per kg per day, and electrolytes ordered by salt (vs ion) were displayed in an order summary with total amounts per day of individual components and individual electrolytes/ions (calculated automatically)
- Additional calculations based on amounts ordered (eg, dextrose infusion rate [in mg/kg/min], conversion to amount per kg per day, relative percentage of calories from each macronutrient)
- Minimum and maximum doses and concentrations were set for various components related to safety (eg, maximum total sodium concentration of 154 mEq/L, maximum osmolarity of 900 mOsm/L for peripheral PN order), efficacy (eg, set a standard/suggested dose), and compatibility (eg, minimum and maximum macronutrient concentrations, estimate of calcium-phosphate compatibility)
- Ability to block individual components or fields or set a dose limit (eg, in the event of a medication shortage and/or for safety)
- PN cycle infusion rate schedules were built for many different volumes and infusion/cycle times, and infusion instructions would automatically populate in the order based on the ordered volume and cycle time (manual calculation only required if a cycle volume or time was not one of the prebuilt combinations)

Many soft-stop and hard-stop alerts were also built into the system. Specific examples at our institution included the following:

- Alerting when a prescriber selected an order template that did not match the patient population (eg, selecting the Adult PN Order Set [>30 kg] on an infant weighing <10 kg)
- Requiring certain fields to be completed before the order could be entered (eg, patient weight, specific components)
- Requiring prescriber to acknowledge that a patient met predefined criteria (eg, for peripheral PN)
- Alerting when any minimum or maximum concentrations or amounts were exceeded

Examples of other ordering enhancements at our institution included the following:

- Allowed for all components in the current PN order to be carried forward when reordering PN, eliminating the need to reenter or transcribe information from the previous day's order
- Included a section for "Notes," which allowed communication of updates and changes directly in the order set (eg, when a product was not available due to a shortage, updates to the order sets)
- Ability to set hours when PN orders were available to prescribe and block access to orders after a set cutoff time (to allow for adequate time to review and verify orders, transmit orders to the external compounding pharmacy, and compound and deliver orders and to avoid situations in which a prescriber could order PN "in advance") and not allow modifications to existing/currently infusing PN orders
- Allowed for electronic transmission of orders to the external compounding pharmacy, eliminating the need for manual transcription
- Formatted the PN order set so that the sequence of ingredients matched the sequence on the PN label to facilitate ease and accuracy of nursing double check that PN label matches PN order prior to administration (eg, nurse review/verification of the PN label vs the original prescription order)

Despite the significant improvements, there were still challenges and limitations to manage. For 2-in-1 PN administration, ILE was a separate order, and there was not a way to "link" this to the primary PN order (the prescriber was prompted to enter the amount of ILE ordered in the main PN order before completing the rest of the order). When advancing PN therapy to goal (specifically macronutrients and volume), there was no way to specifically alert if micronutrients were not advanced accordingly; an alert was only generated if a minimum or maximum dose or concentration was exceeded. If a prescriber ordered a PN cycle that was not one of the prebuilt volumes or times, then it required manual calculation and verification. Despite these and other limitations, it was a significant advance and improvement in safety and the overall PN use process at our institution.

Preimplementation and postimplementation studies of CPOE systems in overall medical care (not related to the use of PN) have shown significant reductions in medication turnaround times, radiology procedure completion times, and laboratory result–reporting times.[26] These benefits are accompanied by significant costs in the form of large time and resource requirements for the deployment of CPOE systems. Commercially available CPOE systems provide a set of basic PN configuration tools, graphical user interface PN-related templates, and CDS that has the potential to be modified to meet organizational preferences and requirements. The extent to which PN configuration can be modified and the technical resources and expertise required to do so vary significantly across vendor systems.

CDS can include compatibility and dose-checking functionality (eg, calcium-phosphate solubility, electrolyte limits, osmolarity limit for peripheral PNs), embedded calculators to determine PN volume requirement or rate titration for cyclic PNs, and order-form or order-set features to help guide the provider in making appropriate selections during ordering. A few examples of order-entry guidance include dynamic display of electrolyte and nutrition totals on the order (eg, g and g/kg/d of protein; caloric contributions of protein, carbohydrate, and lipid), pre-defaulted amounts for day 1 of PN, and dynamic visibility of various order-entry fields based upon what has been entered thus far. For example, an order may have a radio button for standard trace elements or individualized trace elements (ie, separate fields for zinc, selenium, copper, manganese, and chromium). If the latter is selected, a series of new fields appear with default doses for the corresponding individualized trace elements, and the standard trace elements radio button is dithered out to prevent duplicate entry.

Establishing functional requirements for PN ordering at our institution demanded a sizeable investment of effort and time. The initial PN design was developed by a group of stakeholders representing every clinical discipline involved in the PN process. This original stakeholder group included physicians, pharmacists, dietitians, nurses, laboratory professionals, and clinical system analysts/informaticists, with specific patient populations (pediatrics, neonatology) represented in the group. The goal was to incorporate as much of the existing standardized practice into the CPOE system as possible. Throughout development, the visual layout of the CPOE order forms was guided by the existing PN labels, whereas the order-set structure and content was guided by the existing paper PN order forms. The CDS rules and logic were programmed to enforce the dose and concentration limits in existing protocols, therefore helping to enhance the safety of PN prescribing.

Table 1. Quantity and Types of Parenteral Nutrition Orders in Allscripts.

PN Orders	2009	2010	2011	2012	2013
Parenteral nutrition <10 kg	8390	8496	8301	8271	8948
Parenteral nutrition 10–30 kg	1221	1402	1551	1238	1674
Parenteral nutrition >30 kg	8801	9084	9412	8048	8545
Totals	18,412	18,982	19,264	17,557	19,167
Per day averages by type					
Parenteral nutrition <10 kg	23.0	23.3	22.7	22.7	24.5
Parenteral nutrition 10–30 kg	3.3	3.8	4.2	3.4	4.6
Parenteral nutrition >30 kg	24.1	24.9	25.8	22.0	23.4
Average total parenteral nutrition orders per day	50.4	52.0	52.8	48.1	52.5

The initial CPOE build in Allscripts required approximately 500 hours of time from a dedicated analyst/programmer/pharmacist. It was an iterative process involving repeated cycles of demonstration, feedback, and revision that lasted several months. The first step was the creation of custom data items to capture and display component amounts, units of measure, infusion and cycling instructions, and calculated concentrations and volumes. These data items were then added to custom order forms, the order forms were assigned to the orders, and the orders were placed into order sets. Three types of PN order templates were initially built, which allowed for 12 different types of PN to be ordered: PN < 10 kg (neonatal), PN 10–30 kg (pediatric), and PN > 30 kg (adult). Each of these forms allowed for ordering of central or peripheral concentrations and the corresponding latex-free orders. Once the field for central or peripheral concentration was selected, a medical logic module (MLM) applied the appropriate concentration limits to the order.

Four MLMs provided calculations and CDS. MLMs are small programs written in Arden syntax that can read data from and write data into the EHR. The MLMs supporting PN ordering were "form-called" MLMs, meaning that the programs were only executed during PN order entry. The MLMs were able to control the appearance of the order-entry forms, read data from the order-entry forms, and write data back to the order-entry forms. They were also able to display an alert to the ordering clinician if the PN formula exceeded dose or concentration limits. One MLM contained logic for the pediatric and adult PN orders, one contained logic for the neonatal PN orders, one contained logic for ILE in the adult hospital, and one contained logic for ILE in the pediatric hospital. The neonatal MLM was programmed to calculate daily fluid requirements, and the two ILE MLMs supported dispensing differences between the pediatric and adult hospitals. Our institution spent significant time designing, vetting, and testing the PN build in Allscripts and achieved a robust and end user–friendly process for PN order entry and workflow. Data regarding the volume and types of PN orders at our institution during the period are described in Table 1.

Over the next several years, the design of the PN orders and the logic supporting them were reevaluated and refined in an ongoing manner in response to clinical practice changes, quality-improvement needs, and evolving technology.

Using CDS to Manage PN Component Shortages

The frequency and severity of drug shortages have become increasingly problematic for hospitals in the United States. Managing drug shortages requires significant time and effort on the part of the pharmacy department to find and acquire alternative medications and educate prescribers on the safe and effective use of a product that may be unfamiliar. A multiple-choice survey of pharmacy directors in the southeastern United States performed by Caulder et al found that respondents reported drug shortages contributing to 1%–5% error rates in hospitals. They also concluded that 60% of the time, drug shortages created unsafe conditions and possible negative impacts across a health system.[27] Similarly, a recently published study demonstrated a significant increase in mortality in patients receiving alternative vasopressors during the national shortage of norepinephrine in 2011. In this study, patients with septic shock during the shortage had a 3.7% increased risk of mortality compared with patients treated outside the shortage period.[28]

Recent PN component shortages have included amino acids, electrolytes, trace elements, intravenous multivitamins, ILE, and L-cysteine.[29] Boullata et al published a gap analysis in 2013 that included a survey completed by nurses, pharmacists, and physicians, predominantly from hospital settings. In their report, 70% of respondents indicated that PN-related product shortages interfered with the ability to meet micronutrient needs, and 16% stated that product shortages directly affected patient outcomes.[30] Case reports

in the literature describe a variety of nutrition deficiencies that have occurred as a direct result of these shortages, including one case in which a patient was diagnosed with copper and zinc deficiencies related to individual trace elements not being available.[31] Similarly, a retrospective review at a 1242-bed academic medical center found a 4-day-longer hospital stay in patients who underwent a laparotomy for small-bowel obstruction and received PN postoperatively during periods of PN product shortages at their institution.[32] They found that patients had a longer hospital stay, longer PN therapy courses, and 51% higher hospital costs when compared with times without PN drug shortages. These findings demonstrate the potential for negative patient outcomes during times of PN product shortages.

In addition, a survey of PN-related shortages was conducted by The Institute for Safe Medication Practices in 2014.[33] Up to 28% of respondents (n = 234, 81% pharmacists) reported an error related to the inability to obtain a product and/or use of an alternate product, and 1 out of every 4–5 respondents reported preventable adverse outcomes.[33] Storey et al evaluated this risk specific to PN ingredient shortages and identified 1311 errors over a 2-year time period.[34] Although a minimal number of these errors were associated with harm, the overall number of errors was significant and concerning, considering the potential harm that could result.

Based on data from the Food and Drug Administration (FDA), the number of medication shortages appears to have peaked in 2012 and decreased since that time.[35] Recently, however, there have been a number of medication shortages as a result of natural disasters—most notably the impact on drug supply in late 2017 and into 2018, particularly with regard to sterile solutions, seen after Hurricane Maria devastated Puerto Rico.[36,37] In response to drug shortages and the threat they pose to public health, the FDA enacted the Food and Drug Administration Safety and Innovation Act in July 2012, which mandated that manufacturers notify the FDA of any "discontinuance or interruption in the product of prescription drugs that are life-saving, life-sustaining or intended for use in the prevention or treatment of a debilitating disease or condition."[38] ASPEN has also responded by creating a subcommittee of the Clinical Practice Committee to help manage PN product shortages. This subcommittee evaluates shortages as they develop and provides recommendations for alternative products and methods to conserve currently available product. They also partner with other organizations to provide accurate, timely, and comprehensive advice in multiple formats that are easily accessible by clinicians directly involved in the care of these patients.[39,40] ASPEN has published guidelines for health systems to follow to conserve supplies for patients at greatest risk. These documents include specific considerations for each component experiencing a shortage and recommendations for how to manage these items.[40-45]

Implementing these recommendations through CPOE/EHR systems can streamline PN ordering and verification processes, minimize confusion, and decrease the need for additional interventions. CDS can be especially helpful by providing information about components in short supply, suggested conservation measures, and suggested substitutions to the prescriber at the point of order entry, allowing them to make decisions in the normal course of care. The customization of CDS to include shortages and substitutions also allows dose and compatibility checking to proceed normally, avoiding the time-consuming process of notifying prescribers by telephone to modify orders after they have been placed.

Although the CDS supporting PN ordering at our institution was not developed with the intent to manage component shortages, the flexibility of the MLMs and the ability to deploy logic changes into the production environment immediately made it a valuable tool for protecting patients from shortage-associated errors. For example, when a particular electrolyte was unavailable, the PN order templates and associated MLMs could be quickly reprogrammed to remove the affected product and adjust the remaining electrolytes to compensate. During the time of a calcium gluconate shortage, changes were made to limit the amount included in adult PNs in order to conserve product for neonates. When trace-element solutions were unavailable, our institution modified the orders, logic, and file transfer process to accommodate the ordering of individual trace-element components in quantities equal to or closely approximating the content of the multi–trace-element products. This change in particular required careful coordination with management and technical support at the compounding pharmacy vendor to validate that new or modified components in the PN orders were mapped to the appropriate components in the compounding software. By actively accounting for shortages in real time within the integrated CDS, all safety mechanisms built into the process of ordering, compounding, and administration remained intact even when multiple components were unavailable. The ability to inform providers about component shortages and provide recommendations at the point of order entry allowed for decreased confusion and easier ordering when providers needed to use products they may have been unfamiliar with.

CDS Changes Recorded at Our Institution

From the beginning of the implementation of Allscripts in 2005 until the transition to Epic in June 2014, the details of each CDS modification, including the date of the change, the initials of the programmer, and a description of the change, were added to the affected MLM(s). For the purposes of this paper, CPOE changes were classified

Table 2. Recorded Clinical Decision Support Changes of Parenteral Nutrition Orders in Allscripts.

CDS Changes	2009	2010	2011	2012	2013
Total number of changes	6	2	9	16	39
By population					
Adult	5	1	7	11	22
Pediatric	5	1	8	8	19
Neonatal	1	1	4	5	10
By type					
Clinical	5	1	2	0	0
Technical	0	0	0	1	2
Operational	1	0	2	2	1
Shortage	0	1	6	13	36

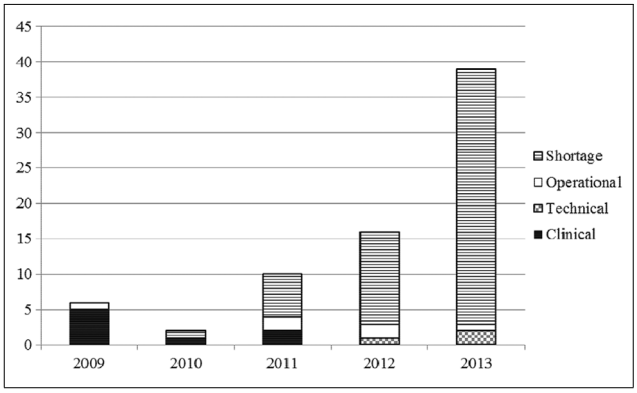

Figure 1. Number of clinical decision support changes by type.

into four different categories: clinical (modification of PN orders and/or logic to support a change in clinical practice), technical (modification as a result of system upgrades), operational (modification to support changes in dispensing practice), or shortage (modifications as a result of component shortage). We also stratified the changes by population affected (neonatal, pediatric, and adult). A single recorded change often encompassed more than 1 change type and affected more than 1 patient population. For this reason, the total number of changes for any given year may be less than the count of changes by type or population. We analyzed the changes recorded between 2009 and 2013, representing the five full years Allscripts was in use to order PN for all patient populations. A summary of these changes, including number of changes for each patient population, is presented in Table 2.

Figure 1 shows the number of changes made to the CDS each year divided by type of change (shortage, operational, technical, or clinical). Changes made early in the use of CPOE tended to be clinical and operational, as practice and technology evolved together. The increasing trend of shortage-related changes began in 2010 with 6 changes, increased in 2011 to 13 changes, and spiked dramatically

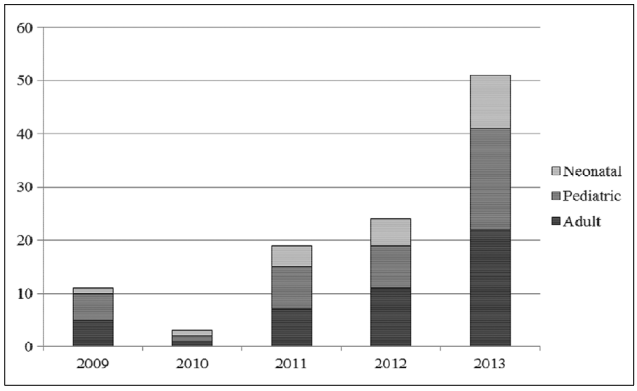

Figure 2. Number of clinical decision support changes by population.

in 2013 to 36 changes. The graph in Figure 2 divides the changes made in Allscripts by affected patient population (adult, pediatric, and neonatal) for each year of data collection. The majority of changes made to the MLM logic affected the adult and pediatric patient populations, evidence of the focused effort to conserve scarce resources for the most vulnerable neonatal patients.

CPOE Transition and Variation in PN Ordering Support

As our institution made the transition from Allscripts to Epic in 2014 (Epic version 2012), it became evident that not all previously customized components of the PN ordering system could be easily translated into the new EHR system. One example was for the ability to lock out PN order entry at a specified time of day, as described earlier. While that requirement could be easily enforced by MLMs within Allscripts, it could not be enforced in Epic. Although a significant amount of time was spent working with the vendor to develop functionality and determine workarounds, sacrifices were still made in the new build (eg, using a soft stop vs a hard stop as indicated above). Additionally, an unanticipated and significant work effort was required to continue the electronic transmission of PN order information to the external compounding pharmacy vendor. The transition to Epic required a total rework of the interface from a non-HL7, flat file–based transfer of PN orders to a full HL7 real-time interface. This required extensive technical support from consultants, the EHR vendor, and our institution's technical teams.

Another example was the ability of the MLMs to autopopulate prebuilt cycle instructions as long as a "standard" volume and cycle time were selected. This functionality did not exist in Epic at the time of Epic implementation at our institution, as the only rate-calculating function available was a flat volume divided by number of hours. This required a manual process to

convert the PN order to a separate "cyclic PN" order when starting to cycle, and a manual process for entering cycle instructions. Hence, PN prescribing and administration errors related to cycle rates were more common after the transition to Epic. However, some vendors have continued to work on PN-related improvements in their systems. In a recent Epic update, they have added a "PN cycle calculator" that allows for automatic calculation of a PN cycle based on volume, time, and defined parameters for calculating (clients can use the system defaults or define their own parameters). This has been a significant improvement in functionality and eliminated one of the gaps in the process.

Discussion

The many different components of PN, in combination with the complex processes of ordering, preparation, and administration, result in a high-risk medication product. PN therapy has become increasingly more complex with the addition of PN component shortages across the country. Recent surveys highlight the lack of standardization, the risk for error, and the great improvements needed within current systems. Organizations such as ASPEN have developed task forces and committees, as well as published guidelines regarding best practices to improve PN safety, much of which has centered on optimizing the use of EHRs and CDS in the PN use process, as well as managing PN-related medication shortages as safely and efficiently as possible.

Robust support for PN prescribing within commercially available EHR systems is lacking, although significant improvements have been made in some systems. Building and maintaining customized electronic solutions that support patient safety and the best practices recommended by ASPEN require a significant investment of time, effort, and resources by institutions. In some cases, these custom PN ordering solutions are developed outside of the commercially available EHR system because of the lack of functionality and/or inability of the vendor to support PN ordering. The development of an integrated PN ordering solution, even within a commercially available EHR system, requires a multidisciplinary approach and significant resources, but we believe the reward of an efficient, safe, and end user–friendly system far outweighs the cost. We also believe that our ability to respond to shortages by quickly reprogramming the CDS for PN orders enabled us to provide consistent and timely communication to patient care teams, to maintain the existing calculations and safety checks within the PN orders, and to prevent errors arising from the use of unfamiliar products.

It is up to individual institutions to analyze their entire PN use process and the systems supporting that process to identify how errors do or could occur, as well as opportunities to standardize processes and increase safety. Institutions must actively work toward the incorporation of new information systems and CDS tools to overcome such challenges. Resources must be made available for continuous maintenance of these systems as advances in technology and changes in clinical practice develop. As customers, institutions should work with EHR vendors to communicate concerns and gaps in the system and to encourage vendors to develop and improve integrated tools to support PN therapy in all clinical settings. We have been encouraged by improvements in the PN functionality within our current EHR platform (eg, PN cycle calculator functionality described above) and are optimistic about continued enhancements moving forward; requests from customers are one of the most important ways to affect these changes. Vendors also have an obligation to work with clinical care providers to optimize the use of technology and improve the interoperability between ordering and compounding systems. Expert and consensus-derived minimum standards for PN ordering in electronic systems are readily available and should serve as a roadmap to guide vendors in their development efforts. We echo and amplify ASPEN's "call to action" to enhance the functionality of current EHR systems. Improvements should be focused on providing a straightforward, easily customized PN ordering template that meets current standards and can be integrated with ACDs. The incorporation of well-designed and well-maintained technology into daily practice will help streamline the ordering process and allow for impactful improvement in the safety of PN prescribing and administration.

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Statement of Authorship

J. N. Lashinsky, J. K. Suhajda, M. R. Pleva, and M. D. Kraft equally contributed to the conception and design of the research; J. K. Suhajda and M. D. Kraft contributed to the acquisition and analysis of the data; J. N. Lashinsky, J. K. Suhajda, M. R. Pleva, and M. D. Kraft contributed to the interpretation of the data. All authors drafted the manuscript, critically revised the manuscript, agree to be fully accountable for ensuring the integrity and accuracy of the work, and read and approved the final manuscript.

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