Nutrition Informatics Applications in Clinical Practice: a Systematic Review


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Abstract

Nutrition care and metabolic control contribute to clinical patient outcomes. Biomedical informatics applications represent a way to potentially improve quality and efficiency of nutrition management. We performed a systematic literature review to identify clinical decision support and computerized provider order entry systems used to manage nutrition care. Online research databases were searched using a specific set of keywords. Additionally, bibliographies were referenced for supplemental citations. Four independent reviewers selected sixteen studies out of 364 for review. These papers described adult and neonatal nutrition support applications, blood glucose management applications, and other nutrition applications. Overall, results indicated that computerized interventions could contribute to improved patient outcomes and provider performance. Specifically, computer systems in the clinical setting improved nutrient delivery, rates of malnutrition, weight loss, blood glucose values, clinician efficiency, and error rates. In conclusion, further investigation of informatics applications on nutritional and performance outcomes utilizing rigorous study designs is recommended.

Introduction

Biomedical informatics applications have been shown to improve efficiency and quality of health care delivery in management of diseases such as diabetes, cardiovascular disease, mental illness, and pediatric asthma, among others. Clinical decision support (CDS) systems also have demonstrated improvements in practitioner performance. For instance, a systematic review by Garg et al. found that the majority of the reviewed electronic health record systems (EHRs) improved clinicians’ performance in drug prescribing and dosing, preventative care, and disease management. Likewise, Jaspers et al. concluded that CDS systems have a positive effect on provider performance regarding drug prescribing and preventive reminders.

In the clinical setting, studies have found that poor nutritional support can contribute to impaired patient condition and therapeutic complications. For example, incidence of blood glucose (BG) dysregulation is associated with adverse outcomes and increased mortality. Alternatively, carefully monitored nutritional support providing adequate kilocalories and protein leads to lower rates of mortality and improved clinical outcomes in observational studies. Despite the benefits, nutritional monitoring can be a complex task, requiring management of multiple data inputs, mastering complex calculations, and consuming significant time from clinicians.

Despite the growing body of research regarding health informatics technologies in medical patient management, no systematic reviews have been published describing the evidence for medical nutrition informatics applications. This paper aims to address that gap by summarizing the evidence of the effect of informatics applications containing CDS and computerized provider order entry (CPOE) features on 1) clinician workflow and error rate; 2) patient outcomes such as nutrient delivery, blood glucose management, malnutrition and weight loss; and 3) quality of nutrition support in various clinical settings. We use the term CDS to cover a broad variety of tools, from simple calculators to advanced algorithms. Where this use might cause confusion, we clarify the type of tool being discussed.

Methods

We conducted a systematic review of the peer-reviewed literature using three search databases: MEDLINE/PubMed, Scopus, and CINAHL (the Cumulative Index to Nursing & Allied Health Literature). Search criteria were designed broadly to include as many results as possible and employed keywords to search title, abstract, and MeSH (Medical Subject Heading) terms. A search was conducted on CINAHL using the keywords “nutrition AND informatics.” The following search terms were used for PubMed and Scopus databases: ("Nutrition Therapy"[Mesh] OR...

For all searches, we further limited relevant results to those published in the English language within the past ten years (January 1, 2004 and onward). Papers were accepted if they contained a clinical and a dietetic focus, an emphasis on CDS and/or CPOE applications, and human subjects of any age or disease state. Four reviewers independently assessed the set of returned titles and abstracts using those predefined inclusion criteria. Publications deemed irrelevant were excluded and duplicates were removed. Any discrepancies in the review process were resolved through unanimous consensus. We conducted a hand search of article bibliographies and related citations for additional sources. Upon completion of the initial abstracts search, we screened each paper in full for applicability, and identified final articles to be included in the systematic review. In total, sixteen studies were selected for analysis. The search process is illustrated in Figure 1.

![Figure 1. Schematic of Search Strategies](image)

**Results**

**General Overview**

A diverse set of locations and healthcare systems around the world are represented in this review. Of the sixteen included studies, three were conducted in Greece, two in the Netherlands, two in the United States, one in Switzerland, one in France, one in the Philippines, one in Norway, one in Denmark, one in Belgium, one in Austria, and one in Spain.

Of these studies, eleven examined the impact of a variety of CDS tools and CPOE systems on clinical patient outcomes and quality of nutrition care, two described features and validation of a computerized tool, four discussed effects on clinician workflow (for example, time saving features), and four assessed impact on rates of calculation and order error. Of the articles assessing the effect of informatics applications on patient care, five studies examined effects on BG values, four related to use of computerized tools, four assessed energy or macronutrient delivery and achievement of prescribed nutritional support rate, one discussed unintentional clinical weight loss, and one studied recognition of malnutrition.

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Systems varied regarding decision support and ordering features. Thirteen programs recommended nutrition and/or insulin interventions based on patient data, five contained computerized nutrition support ordering capabilities, five produced electronic alerts and reminders, three reported daily energy delivery totals from multiple sources, three conducted computerized patient screening, two produced feedback based on patient progress, and one developed automated meal plans based on patient needs. The focus of these research articles generally fell within three major groupings: nutrition support for adults and neonates, BG management, and other nutrition applications. The design and duration of these studies varied widely among these three groups. Of the studies addressing impact of computerized interventions on patient outcomes, some featured a control group, though many did not. Others assessed features based on simulations, system descriptions, validation studies, or reductions in rates of calculation error.

**Adult Nutrition Support**

The ability to integrate and display nutritionally relevant patient data from multiple sources is a unique feature of computerized information systems. One CDS system synthesized data from delivered enteral or parenteral nutrition as well as macronutrient contributions from patient medications to provide a complete picture of nutrient delivery. Similarly, Berger et al. described one system able to synthesize energy totals from multiple sources, including glucose, lipids, and protein from medications and feeding, in addition to inputs from nutritional support. As a result of these data management features, clinicians responded well to the better graphical display of weight curves, energy balances, and total lipid, glucose, and protein deliveries with computerized systems. This display resulted in acceleration of nutrition support infusion rate when a deficit was observed. The assimilation of multiple data sources contributed to coordination and continuity of patient care when this information was available over prolonged time periods. Furthermore, some systems allowed the user to extract data to be analyzed by other computer programs for spreadsheet creation or statistical analysis.

Error rates were demonstrated to be lower in calculations performed by CDS in contrast to manual methods. Paschidi et al. developed a software tool for computation of parenteral nutrition prescriptions in adult patients based on validated estimated nutrient needs calculations. When compared to calculations completed without the assistance of a computer program, researchers observed a significant decrease in errors among a random selection of patients. In general, use of computer-based nutritional support applications were shown to save time spent performing calculations.

Multiple studies employed use of computerized alerts, warnings, and feedback features to aid in selection and maintenance of nutrition support prescriptions. Decision support systems acted as a guide for the prescriber, monitoring delivered nutritional therapy, and warning of mismatched calculations and potential complications. Electronic warnings were implemented into nutrition support applications to identify values outside a normal range and/or in need of correction. Clinicians could take the initiative to seek out assistance, clicking on an “advice” button to receive recommendations for type and amount of nutritional formula. Alternatively, some feedback features were automatic. One system contained programmed informative messages intended to supplement clinician knowledge. Another sent the patient’s care team a daily email containing a comparison of delivered nutrition support to recommended calculations.

Patient outcomes were clearly and positively improved by informatics tools. The number of patients achieving early and adequate nutritional support increased significantly after the deployment of computer-aided support, in some cases nearly doubling, along with decreases in ICU (intensive care unit) length of stay after utilization of an “advice” button and daily feedback regarding achievement of nutrient delivery. In a study examining a total of 166 patients, higher numbers of critically ill patients received at least 80% of prescribed nutrition therapy for kilocalories (79% vs. 45%, p<0.001) and protein (37% vs. 3%, p<0.001) when a computer system was used for calculation of nutrition support prescriptions, with continued improvements over time. The same authors also reported that the group receiving computer input had increased percentages of patients prescribed at least 120% of recommended kilocalories. Berger et al. described the impact of an EHR on quality of nutritional support among 109 adult intensive care and burn patients. Though energy delivery was below target in both a unit containing a computerized system and one without, it was significantly higher and closer to desired level in the unit with computer support providing recommendations and feedback for discrepancies between calculated needs and actual energy delivery. Additionally, moderately and severely burned patients exhibited lower levels of weight loss when on the unit containing an EHR with these decision support features.
Improved energy delivery and avoidance of weight loss were not the only benefits observed in electronic CDS and CPOE systems. Llido reported that among 135,888 patients, malnourished individuals were recognized promptly based on a computerized screening program, leading to an increase in rates of referrals of these underweight patients to dietitians and nutrition support professionals from 37% to 100%.[30] The percentage of critical care patients seen by nutrition support teams also increased from 10% to 99%.[30] Computer systems used to calculate appropriate parenteral nutrition orders contributed to early identification of metabolic complications (25% increase in identification post-implementation).[20] Additionally, one study reported a significant decrease in occurrence of ICU-acquired infection among a group of 95 patients whose nutrient needs were calculated using a computer program.[29] However, the same study found no significant difference in mortality or length of ICU stay between the intervention and control group.[29] Nutrition support findings are summarized in Table 1.

**Table 1. Adult Nutrition Support Applications**

<table>
<thead>
<tr>
<th>Source</th>
<th>Population</th>
<th>System Features</th>
<th>Performance Outcomes</th>
<th>Patient Outcomes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Llido, 2005</td>
<td>Hospital inpatients receiving NS</td>
<td>CDS, computerized patient screening</td>
<td>Data recording, nutrition support referrals, NSS patient care.</td>
<td>–</td>
<td>Entry of height/weight data in record increased from 30% to 90%. Referrals to NSS increased from 37% to 100%. Patients covered by NSS increased from 38.8% to 83%. Critical care patients seen by NSS increased from 10% to 99%.</td>
</tr>
<tr>
<td>Berger et al., 2006</td>
<td>Adult ICU patients receiving NS</td>
<td>CDS, integration of multiple data sources</td>
<td>Calculation time and completion</td>
<td>Energy delivery, weight loss</td>
<td>Computations were more complete and took less time in intervention group (2 min/patient vs. 11 min/patient, p=0.001). Proportion of postpyloric feeding days was higher in units with computer systems (p=0.003). Additionally, energy delivery was higher than control (84% goal vs. 41% goal, p&lt;0.001) though both were under target. Among burn patients, computer managed group exhibited lower levels of weight loss (0.7 kg vs. 5.7 kg, p=0.034).</td>
</tr>
<tr>
<td>Paschidi et al., 2006</td>
<td>–</td>
<td>CDS, electronic alerts</td>
<td>Calculation time, rates of errors, identification of metabolic complications</td>
<td>–</td>
<td>Use of system resulted in 83% decrease in time required for calculations, 56% decrease in erroneous calculations, and 25% increase in early identification of metabolic complications.</td>
</tr>
<tr>
<td>Mirtallo et al., 2009</td>
<td>Inpatients receiving NS</td>
<td>CDS, CPOE, electronic alerts</td>
<td>–</td>
<td>–</td>
<td>Staff felt that the application improves continuity of care and saves time. Features included the ability to extract data to spreadsheets for analysis.</td>
</tr>
<tr>
<td>van Schijndel et al., 2009</td>
<td>Adult ICU patients receiving NS</td>
<td>CDS, integration of multiple data sources</td>
<td>–</td>
<td>Nutrient delivery</td>
<td>CDS system increased percentage of patients receiving adequate nutrition from 30.2% to 56.5% with a decrease in ICU length of stay.</td>
</tr>
<tr>
<td>Consell et al., 2013</td>
<td>Adult ICU patients receiving NS</td>
<td>CDS</td>
<td>–</td>
<td>Achievement of nutrition goals</td>
<td>No significant difference in duration of NS between groups. Computer group showed increased prescription of at least 120% of recommended kcals (12% vs 1% of patients, p&lt;0.05). Calorie intake was higher with CDS (average 1793 kcals vs. 1508 kcals, p&lt;0.01), as was nitrogen intake (8.1 g/day vs. 6.9 g/day, p&lt;0.01). Computer group showed less frequent occurrence of ICU-acquired infection (59% vs. 41%, p=0.03), though there was no significant difference in mortality or length of ICU stay.</td>
</tr>
</tbody>
</table>

NS=nutrition support, CDS=computerized decision support, NSS=nutrition support services, ICU=intensive care unit, CPOE=computerized provider order entry

**Neonatal Nutrition Support**

Premature and sick neonates frequently require nutrition support for adequate hospital recovery.[21] Nonetheless, therapeutic errors can result in serious complications,[36] so impacts on patient safety are routinely studied in neonatal nutrition support applications. A summary of the reviewed neonatal nutrition support applications is found in Table 2. Lehmann, Conner, and Cox researched an online CPOE system allowing for automated total parenteral nutrition (TPN) calculations in a neonatal ICU. Two years after implementation, an 89% reduction in total calculation errors was observed, amounting to a total of 1.2 errors per 100 orders vs. the initial rate of 10.8 errors per 100 orders.[27] Likewise, Skouroliaikou et al. developed a computer program to assist in formulating and administering TPN to pre-term and sick-term neonates.[21] TPN orders prepared by the computer program contained no errors, compared to physicians’ orders, which had an error rate of 2.98%.[21]
Further, CPOE systems in the neonatal ICU setting were met with enthusiasm from clinical staff. Results from staff-administered questionnaires rated computer systems as easier to learn and to use than paper systems, and as a better protection against errors.25 Changes in clinician workflow were also noted, with an average decrease from 7 minutes to 1 minute spent completing TPN orders, representing a reduction in clinicians’ workload.21

<table>
<thead>
<tr>
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<th>Patient Outcomes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lehmann et al.,24 2004</td>
<td>Neonatal ICU patients</td>
<td>CPOE, CDS, electronic alerts</td>
<td>Rates of error, calculation time</td>
<td>–</td>
<td>There was a 100% reduction in incomplete TPN order forms at 2 years. An 89% reduction in errors (including adherence to osmolality guidelines, calculations, and other knowledge deficiencies) was observed (1.2 errors per 100 orders vs. 10.8 errors per 100 orders at baseline).</td>
</tr>
<tr>
<td>Skouroliakou et al.,23 2005</td>
<td>Pre-term and sick-term neonates</td>
<td>CPOE, CDS, electronic alerts</td>
<td>Rates of error, calculation time</td>
<td>–</td>
<td>Manual calculations contained an error rate of 2.98% vs. 0% error rate with computer calculations (p&lt;0.001). The new system resulted in an average of 1 minute time per calculation vs. 7 minutes without the computer (p&lt;0.05).</td>
</tr>
</tbody>
</table>

ICU=intensive care unit, CPOE=computerized provider order entry, CDS=computerized decision support

**Blood Glucose Management**

A substantial number of studies investigated CDS and CPOE systems on BG management during nutrition therapy, as shown in Table 3. In general, informatics tools were utilized to balance delivery of nutrition with management of BG levels. Hoekstra demonstrated a viable method for initiating nutrition support while managing target BG values in 23 predominantly surgical ICU patients.24 By utilizing an incremental step-up method of PN initiation in addition to a CDS system for continuous monitoring of insulin infusions, adequate caloric and nutrient allocation was achieved within 24 hours while consistently maintaining BG levels under acceptable parameters for the greatest majority of measurements in patients.24 Similarly, another CDS system in a neurotrauma ICU allowed for provision of 93.5% of estimated resting energy expenditure for adult patients (n=6) vs. 129.5% in the control group (n=6) while also maintaining BG levels at an average lower than that of the control group.25

In addition to adequate nutrient delivery, CDS aided in the management of BG levels. Pachler et al. described a computer algorithm for management of mechanically ventilated adult ICU patients.36 Taking into account current BG concentration, insulin dosage, and carbohydrate content of nutrition support formula, calculations were determined for insulin infusion rate and timing of next BG sample. Under these conditions, the intervention group exhibited lower average BG concentrations and hyperglycemic index levels compared to the control group.36 Among these same patients, the total carbohydrate administration rate was no different between intervention and control group. Meyfroidt et al. found that a glucose alert system for adult ICU patients employing pop-up alerts in response to abnormal values decreased mean BG values, decreased hyperglycemic index levels, decreased glycemic penalty index levels, and decreased proportion of measurements within the hyperglycemic range.35 There were no significant differences in hypoglycemic index, or proportion of measurements in the hypoglycemic range, however.35 Another study found that a CDS and CPOE system for neonatal patients had no effect on instances of hypo- or hyperglycemias pre- and post-intervention, despite a modest reduction in time for simple calculations, and major reduction in time for complex calculations.27

**Other Nutrition Applications**

Apart from parenteral and enteral nutritional support informatics applications, several programs have been developed to assist with patient screening and oral feeding, as illustrated in Table 4. de Ulibarri et al. implemented a nutritional risk screening and referral system based on laboratory parameters in an adult hospital population not undergoing aggressive therapeutic procedures or suffering from severe diseases.35 Compared to validated measures, the system had a screening sensitivity of 92.3% and a specificity of 85%.35 In a related study, Fossum et al. found that a CDS system used for risk screening in nursing homes for the elderly resulted in significantly reduced rates of malnourishment among a baseline of 491 individuals when compared to institutions without such a program.31 However, the same study found no effect on rates of pressure ulcer formation,31 even though nutritional status is considered an important predictor of the condition.
### Table 3. Blood Glucose Management Applications

<table>
<thead>
<tr>
<th>Source</th>
<th>Population</th>
<th>System Features</th>
<th>Performance Outcomes</th>
<th>Patient Outcomes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pachler et al., 2008</td>
<td>Adult ICU patients</td>
<td>CDS</td>
<td>–</td>
<td>Mean BG, hyperglycemic index</td>
<td>Median BG decreased in computer group (5.9 mMol/L [106.3 mg/dL] vs. 7.4 mMol/L [133.3 mg/dL] control, p&lt;0.001). Hyperglycemic index decreased in computer group (0.4 mMol/L [7.2 mg/dL] vs. 1.6 mMol/L [28.8 mg/dL] control, p&lt;0.001). Total carbohydrate administration rate was not significantly different between groups.</td>
</tr>
<tr>
<td>Hoekstra et al., 2010</td>
<td>Adult ICU patients</td>
<td>CDS</td>
<td>–</td>
<td>Caloric intake, BG levels</td>
<td>With CDS system, caloric intake goal was reached at median 18 hours, maximum 24 hours for all patients. The greatest majority (95.5%) of BG measures were below 10 mMol/L (180.2 mg/dL).</td>
</tr>
<tr>
<td>Meyfroidt et al., 2011</td>
<td>Adult ICU patients</td>
<td>CDS, electronic alerts</td>
<td>–</td>
<td>Mean BG, hyperglycemic index, glycemic penalty index, number of hypoglycemic events</td>
<td>System resulted in a decrease in mean BG level from 112 mg/dL to 110 mg/dL (p=0.002), a decrease in glycemic penalty index from 20 to 19 (p=0.029), and a decrease in hyperglycemic index from 10 mg/dL to 9 mg/dL (p=0.04). There was a decrease in hypoglycemic episodes from 6.5% to 4.0% (p=0.043).</td>
</tr>
<tr>
<td>Pielmeier et al., 2012</td>
<td>Adult ICU patients</td>
<td>CDS</td>
<td>–</td>
<td>Mean BG, caloric intake</td>
<td>CDS system increased percentage of BG measurements within 5-8 mMol/L (90.1-144.1 mg/dL) (76% intervention vs. 51% control, p=0.05). Mean BG in CDS group was 7.0 mMol/L (126.1 mg/dL) vs. 8.0 mMol/L (144.1 mg/dL) control, p=0.05). Mean caloric intake in computer group was 93.5% of estimated needs vs. 129% in control. Insulin infusion rates did not significantly differ between groups.</td>
</tr>
<tr>
<td>Maat et al., 2013</td>
<td>Neonatal ICU patients</td>
<td>CPOE, CDS, multiple data source integration</td>
<td>Prescribing time</td>
<td>Incidence of hypo- or hyperglycemic events</td>
<td>The computer system resulted in a time reduction of 16% for simple calculations (basic glucose dosing guidance) and reduction of 60% for complex calculations (total glucose delivery from all sources including nutrition support and drug vehicles). There was no significant difference in pre- and post-CPOE mean incidence of hypo- or hyperglycemias.</td>
</tr>
</tbody>
</table>

ICU=intensive care unit, CDS=computerized decision support, BG=blood glucose, CPOE=computerized provider order entry

### Table 4. Other Nutrition Applications

<table>
<thead>
<tr>
<th>Source</th>
<th>Population</th>
<th>System Features</th>
<th>Performance Outcomes</th>
<th>Patient Outcomes</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossum et al., 2011</td>
<td>Elderly nursing home residents</td>
<td>Computerized screening, CDS</td>
<td>–</td>
<td>Risk for a prevalence of pressure ulcers and malnutrition</td>
<td>The CDS system significantly reduced rates of malnourishment (defined as inadequate nutritional status) when compared to institutions without such a program (9% decrease in malnourished residents in intervention vs. 3.9% increase control, p&lt;0.05). There was no significant effect on pressure ulcer formation.</td>
</tr>
<tr>
<td>Skourolaikou et al., 2009</td>
<td>Adult hospital patients not receiving NS</td>
<td>Automated meal planning</td>
<td>Rates of error, data recording, calculations</td>
<td>–</td>
<td>The system resulted in a reduction in errors occurred during data recording, calculation of daily requirements, and menu planning (88% decrease, p=0.05). Dietitians experienced a minimization of time spent on menu planning after program implementation (68% decrease, p=0.05). There was no significant effect on days of hospitalization.</td>
</tr>
<tr>
<td>Ignacio de Ulibarri et al., 2005</td>
<td>Adult hospital patients</td>
<td>Computerized screening, CDS</td>
<td>Validation with accepted screening methods</td>
<td>–</td>
<td>The CDS had a screening sensitivity of 92.3% and a specificity of 85% when compared to validated measures.</td>
</tr>
</tbody>
</table>

CDS=computerized decision support, NS=nutrition support
Skouroliakou et al. published an implementation brief describing an application of nutrition informatics in oral nutrient delivery for hospitalized patients. This system was developed to prepare dietary prescriptions, calculate nutritional requirements, store patients’ dietary records, produce automatic daily menus, and generate reports on food lists and menu costs for patients receiving nutritional support by mouth. As a result of that implementation, a reduction in errors occurred during data recording, during calculation of daily requirements, and during menu planning. Additionally, authors reported a minimization of time spent by dietitians on menu planning after program implementation. For patients, no significant effect on days of hospitalization was found related to use of this tool.

**Discussion**

This systematic review examined a wide range of medical CDS and CPOE informatics applications in clinical dietetics. Overall, the benefits described in the reviewed articles were numerous. Specifically, improved patient outcomes included lower rates of weight loss, increased nutrient delivery, fewer acquired infections, more stable BG values, and lower rates of malnutrition, in addition to increased referrals to nutrition support teams. Furthermore, improved clinician workflow and fewer calculation errors were noted in multiple studies. Researchers reported high rates of acceptance of CDS and CPOE systems among clinical staff. However, studies produced conflicting results regarding the influence of computerized interventions on length of hospital stay, with a tendency toward no effect. Only one study assessed mortality outcomes: here, researchers found no significant effect. Taken together, these results suggest that use of informatics applications contribute to an improvement in metabolic management, but they offer a conflicting and incomplete picture of overall patient outcomes.

Although reviewed studies showed significant improvements in error reduction among adult and neonatal nutrition support ordering, in only one study was the absolute error number reduced to zero. One might argue that any level of error is unacceptable, particularly among system-generated calculations. It is important to note the synergistic relationship between CDS and CPOE systems and clinical care providers. Though CDS systems may generate automated calculations, this result is dependent on completeness of input patient data as well as clinicians’ adherence to suggested electronic alerts and reminders. Regardless of the demonstrated value of CDS systems, there is no substitution for qualified human clinical judgment in delivery of healthcare. Even the most well designed system might not produce perfect results without accurate human knowledge and attention to detail. Clinician oversight in regards to prescription and delivery of adult and neonatal nutrition support is always necessary to ensure best patient outcomes.

Interestingly, there was a more effective reduction of errors in the neonatal nutrition support systems than in adult nutrition support systems. It could be that neonates and sick term infants are more likely to have a similar set of clinical needs and treatments than is seen in the large variety of adult patients of various disease states. However, the authors are more inclined to think that user interface may have the greatest impact on error reduction. For example, the system described by Skouroliakou generates a set of yes/no questions for the user to determine parameters for preparation of TPN. This type of simplification of input may clarify the most important clinical parameters when prescribing nutrition support. Particularly in hectic environments such as an adult or neonatal ICU, simplified but thorough CDS systems will be the most useful in assisting nutrition support prescription.

Some tools may be better suited to particular clinical situations than others. In particular, the reviewed studies have demonstrated that clinical applications for TPN ordering are well suited for delivery of neonatal care. Additionally, blood glucose management systems have a potential application in all clinical areas, from ICU to medical floors to neonatal care. Likewise, nutrition informatics applications have a place in multiple types of hospitals; for rural hospitals, CDS systems may supplement and inform clinical decision making when specialized nutrition professionals may not be readily available. Although every clinician can benefit from use of CDS systems, CPOE is best suited for ordering providers such as physicians, physician’s assistants, and pharmacists. EHRs designed with multiple CDS features will fulfill the greatest number of needs, with access privileges for clinicians specific to need.

Although this review discusses nutrition informatics applications in clinical practice, the potential of informatics goes beyond inpatient use. Recent technological innovations targeting patient self-management, especially through mHealth apps, suggest clinical efficacy. Oenema et al. reported that an Internet-delivered computer-tailored lifestyle intervention program resulted in lower saturated fat intake based on a validated food-frequency questionnaire. In addition to modifications to patient behavior, computerized systems have the potential to impact outcomes such as weight management. For example, research has suggested that online “feedback” features such as
progress charts and physiological calculators are the best predictor of weight loss in internet-based weight control programs.\textsuperscript{38}

There are also implications for chronic disease management. Albisser described a Web-based graphical user interface designed to provide decision support regarding medication dosing and lifestyle factors such as diet and exercise for individuals managing insulin-dependent diabetes.\textsuperscript{29} Any actions taken by the user were documented by the system and linked back to an online registry, where these data were available for review and/or intervention by the patient’s provider. This application suggests the potential integration of patient-facing technologies and clinical care coordination,\textsuperscript{39} particularly in diseases requiring joint patient-provider supervision. These findings seem to suggest that decision support features in online programs and applications designed for patient self-management might contribute to positive clinical outcomes in a variety of diseases.

This study had several limitations. First, results included only those published in English, potentially excluding meaningful studies written in other languages. Second, this paper is necessarily limited by the methods used in the primary research reviewed. The largest majority of the studies reviewed in this paper employed a quasi-experimental study design (n=10, 62.5%). Several other papers were published as a system description,\textsuperscript{20,26} proof of concept study,\textsuperscript{24} or validation study.\textsuperscript{25} Only two studies employed a controlled trial method, one with group randomization,\textsuperscript{32} and one an “open” design.\textsuperscript{34} As such, overall results should be considered preliminary findings in the area of nutrition informatics applications and interpreted with some caution. Future research should consider more rigorous methods, including randomized controlled trials utilizing large sample sizes. Finally, a meta-analysis was impossible due to significant differences in reported outcomes. However, the positive results described herein suggest that further research examining the benefit of informatics interventions, specifically those incorporating CDS and/or CPOE, will strengthen the case for nutrition informatics applications in the clinical setting.

Furthermore, it is important to note the stage of development of each informatics approach when assessing reported results. Though studies showed positive outcomes, not all computer systems had been implemented in an actual clinical patient-care setting.\textsuperscript{20} It is possible that systems that look promising in the early stages may not translate to practical use in patient care. Therefore, studies set in a clinical venue are needed for further conclusions. Although the studies included in this review provide examples of informatics tools used in nutritional management, very few specifically addressed patient health outcomes. The effect of CDS and CPOE systems on length of hospital stay, weight loss, wound healing, and mortality represent important markers of nutrition care efficacy. Overall, the impact of informatics on patient outcomes remains an understudied area of research in all medical informatics applications, including those used for nutrition care.

Use of informatics applications is relevant for Registered Dietitians as well as other nutrition care professionals. Specifically, the integration of informatics systems into clinical practice may increase practitioner efficiency as well as improve the quality of nutrition care. For example, Skouroliaiakou described an informatics application developed to specifically improve efficiency and performance of dietitians in meal planning and menu assessment.\textsuperscript{22} Llido demonstrated that use of an informatics system resulted in increased involvement of clinical dietitians in all aspects of patient care, including referrals to nutrition support services.\textsuperscript{30} Additionally, in the application described by Mirtallo et al., Registered Dietitians were consulted throughout the development and initiation process for system evaluation and feedback, ensuring optimized nutrition care functionality.\textsuperscript{26}

For Registered Dietitians, CDS systems present an opportunity to enhance quality of patient care as well as number of malnourished and critically ill patients seen by nutrition care practitioners. Many healthcare institutions implement a screening procedure for patients who qualify for a dietitian referral; often dietary technicians or the dietitians themselves complete this screening task. Automated systems such as the one described by Llido\textsuperscript{12} may be helpful in identifying these at-risk patients and initiating nutrition care contact sooner while reducing the workload of hospital personnel. Among critical care patients, nutritional status is often an area of concern as many patients are unable to meet nutrition needs for at least some portion of their hospital stay depending on the severity of their medical status. Increased referrals to nutrition services likely represent an early identification of potential need for alternative support in at-risk patients especially susceptible to malnutrition. When tailored to reflect the screening parameters set forth for a particular hospital, systems developed to correctly identify patients in need of nutrition intervention ensure that the standard of nutrition care is upheld.

We would argue that nutrition professionals can use the research from this review to advocate for informatics systems to assist in delivery of nutrition support and metabolic management, to improve calculation accuracy when writing prescriptions, and to assist in screening and early identification of nutritional concerns. Furthermore, these
applications make possible the direct integration of evidence-based recommendations for clinical nutrition care into ordering systems, including standardized processes for nutrition support ordering, delivery, and monitoring.40

In conclusion, acceptance of nutrition informatics applications is increasing in inpatient and outpatient healthcare, both nationwide and worldwide. Appropriate nutrition monitoring and support is an integral part of ensuring hospital recovery and positive patient outcomes. Given this, computerization of the nutrition care process in particular could impart significant benefits for patient outcomes, practitioner performance, and institutional cost.31,42 Further research is recommended to provide evidence for integrating informatics applications into routine clinical nutrition practice.

References


