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ORIGINAL ARTICLE

Implementing and assessing an evidence-based electrolyte dosing order form in the medical ICU☆

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Summary The purpose of this study was to evaluate the efficacy, safety, and nursing acceptability of a nursing initiated, evidence-based order form to replace potassium, magnesium, and phosphate in the MICU.
Methods: This retrospective study compared patients receiving electrolyte replacement with the order form to matched historical control patients receiving traditional electrolyte replacement (no order form). The primary outcomes were absolute change in serum concentrations and the proportion of doses achieving normal serum concentrations. Other outcomes were adverse events as documented in the medical record and nursing acceptability as assessed by survey.
Results: The 2 groups (12 in each group) were similar. The order form and control groups received 36 and 62 potassium doses, 14 and 48 magnesium doses, and 34 and 13 phosphorus doses, respectively. Doses of all three electrolytes were significantly larger with the order form. Absolute changes in potassium, magnesium, and phosphorus serum concentrations for the order form group and control group were 0.36 ± 0.42 versus 0.11 ± 0.43 mmol/l ($p < 0.01$), 0.56 ± 0.69 versus 0.13 ± 0.40 mequiv./l ($p = 0.07$), and 0.53 ± 0.82 versus 0.66 ± 0.83 mg/dl ($p = 0.63$), respectively. Normal serum concentrations achieved for each electrolyte replacement dose in the order form group and control group were 72% versus 18% ($p < 0.001$), 86% versus 21% ($p < 0.001$), and 47% versus 62% ($p = 0.57$), respectively. No adverse events occurred. The nursing survey showed satisfaction and comfort using the order form.
Conclusions: The use of the order form provided greater efficiency for replacing potassium and magnesium but not phosphorus without increasing the occurrence of adverse events. The order form was well received by nursing staff.

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Introduction

Evidence-based medicine (EBM) is the critical evaluation and clinical application of results from rigorously controlled clinical trials and systematic reviews. EBM incorporated with clinical expertise can be used to derive a decision on patient treatment (Akobeng, 2005; Cook et al., 1996,1997; McQueen, 2001). The process of implementing EBM is often prohibited by the time required to disseminate information to health-care professionals, reluctancy of health-care professionals to accept scientific data rather than anecdotal experience, and lack of adherence to treatments by patients (Godlee, 1998; Green and Britten, 1998; Haynes and Haines, 1998; McQueen, 2001). Many shortfalls to implementation may be remedied by the development of national or international consensus guidelines, or the use of institution specific protocols that direct interventions (Browman, 2001; Davis and Taylor-Vaisey, 1997; Eccles et al., 1998; Grol et al., 1998; Haines and Donald, 1998; Vincent and Berre, 1998; Woolf, 1999). Previous examples of EBM, institution specific protocols involving the intensive care unit (ICU) include the management of sedation and analgesia (Adam et al., 2006; Bair et al., 2000; Brook et al., 1999; De Jonghe et al., 2005; Devlin et al., 1997; Gupta, 1999; Hadbavny and Hoyt, 1993; MacLaren et al., 2000; Maloney et al., 1997; Mascia et al., 2000; Micek et al., 2004), neuromuscular blockade (DeBlock et al., 1998; MacLaren et al., 2001), ventilator associated pneumonia (Cook et al., 1998; Dodek et al., 2004; Duane et al., 2002), and stress ulcer prophylaxis (MacLaren et al., 2006; Pitimana-aree et al., 1998). Only a single center report describes the development of an electrolyte replacement guideline but it was implemented as a pocket card with no assessment of clinical efficacy or safety (MacLaren et al., 1999). This article describes the development, implementation, and assessment of an EBM order form for replacing potassium, magnesium, and phosphate in the medical ICU (MICU) and nursing acceptability of the order form.

Background

The University of Colorado Hospital is an academic institution with a 373-bed complement including 48 ICU beds (medical, surgical, neurosurgical, burn/trauma). The daily medical duties in each ICU are provided by resident physicians from various disciplines, with precepting by a fellow physician. The care of patients in each ICU is the responsibility of an attending physician representing the disciplines of critical care/pulmonary, surgery, anesthesiology, and neurosurgery. Morning multidisciplinary rounds have been performed for several years in each ICU, with representatives from pharmacy, dietary, nursing, respiratory therapy, and palliative care being present. Although pharmacy and dietary have been heavily involved with the care of patients, the dosing of replacement electrolytes has varied according to ICU and physician practices. Several problems have been evident, including incomplete repletion, multiple dosing, unnecessary measurements of serum electrolyte concentrations, and excessive administration of fluid. Historically, the independent administration of potassium chloride and potassium phosphate for the treatment of hypokalemia and hypophosphatemia has contributed to hyperkalemic episodes. Nurses administering the electrolytes followed the recommendations for administering intravenous medications from an online intravenous drug administration policy guideline that was applicable to the institution as a whole. Unfortunately, this reference, which was created to facilitate the safe administration of intravenous medications to all patients regardless of hospital location, was perceived by many ICU healthcare professionals as being representative of EBM practice standards within the ICU. However, the recommendations in this policy were not specifically intended for the ICU, nor were they EBM.

Therefore, due to concerns about electrolyte replacement, the multidisciplinary members of the Critical Care Quality Assurance Committee decided to develop an EBM order form for electrolyte replacement, specifically potassium, magnesium, and phosphate. An interdisciplinary subcommittee consisting of two critical care nurses, two clinical ICU pharmacists, and one pulmonologist developed the dosing guidelines for the order form. The goal was to create an electrolyte order form that would be applicable across all ICUs. Procedurally, the order form would allow critical care nurses to evaluate and replete the electrolytes as needed, once a physician ordered it as a standing order set in a patient's medical record.

Methods

Order form development

A literature review using MEDLINE (for the period January 1966 to October 2005) was conducted using paired MeSH terms (Medical Subject Headings) for keyword identification of potassium, magnesium, phosphate, electrolytes, critical care,

intensive care, replacement, repletion, clinical protocols, surgery, hypokalemia, hypomagnesemia, and hypophosphatemia. All citations involving humans were retrieved and the bibliographies reviewed to obtain pertinent articles not identified in the original search. The members of the subcommittee each informally assessed all the review articles and studies for information relevant to the patients admitted to the MICU (Alaniz and Rice, 1993; Clark et al., 1995; Dickerson et al., 2001; Hamill et al., 1991; Hamill-Ruth and McGory, 1996; Hebert et al., 1997; Kraft et al., 2005; Kruse and Carlson, 1990; Kruse et al., 1994; MacLaren et al., 1999; Perreault et al., 1997; Rosen et al., 1995; Sacks et al., 1997; Taylor et al., 2004; Vannatta et al., 1981,1983). The members of the subcommittee met to discuss the articles and to formulate rough drafts of dosing guidelines for each electrolyte according to normal renal function. All members of the Critical Care Quality Assurance Committee reviewed the rough drafts, and discrepancies, concerns, and questions were discussed among the members. Some concerns arising as a result of this review included ''higher-than-expected doses'' for intravenous magnesium and phosphate replacement, absence of a guideline for calcium replacement, omission of reasons not to use the order form, the need for clarification of ''normal renal function'', and controversy surrounding the application of these guidelines to all ICU patients as practice standards. As a result, the order form was modified to reduce the doses of magnesium and phosphate. These modifications were done with the knowledge that they deviated from EBM, but would facilitate implementation of the order form as a practice standard. An EBM guideline for calcium replacement was not developed at this time on the basis potassium, magnesium, and phosphate administration posed a more immediate need for modification. The addition of clinical situations that stipulated when not to use the order form (diabetic ketoacidosis, arterial pH < 7.20 or > 7.60, and renal replacement therapy) and administration information provided guidelines that could be used as practice standards for electrolyte replacement in all ICUs. The term ''normal renal function'' was replaced by graduated dosing schemes for all electrolytes based on a calculated estimate of glomerular filtration rate (GFR) using the Modification of Diet in Renal Disease (MDRD) equation. The MDRD GFR is automatically calculated and displayed by the laboratory computer system for males with serum creatinine concentrations $\geq$1.5 mg/dl and females with serum creatinine $\geq$1.3 mg/dl. The committee decided that normal renal function would be defined as a GFR > 50 ml/min/1.73 m^2 and that renal insufficiency would be further subdivided into two groups, 25—50 ml/min/1.73 m^2 (moderate) and < 25 ml/min/1.73 m^2 (severe). The doses for these two subgroups were decreased to avoid accumulation and subsequent supratherapeutic concentrations. The revised order form was redistributed to the Critical Care Quality Assurance Committee because it differed from the original form, and it was accepted with only minor changes or clarification. The final order form gave doses for potassium, magnesium, and phosphate as a function of MDRD GFR to achieve serum concentrations of 4.0 mmol/l, 2.0 mequiv./l, and 3.1 mg/dl, respectively, for adult patients in the ICU provided none of the following were present: diabetic ketoacidosis, arterial pH < 7.20 or > 7.60, or renal replacement therapy (Appendix A).

Order form implementation

Members of the Critical Care Quality Assurance Committee suggested trialing the order form in the MICU as an experimental pilot. Once the order form was properly evaluated for efficacy and safety, it was to be implemented in other ICUs. The purpose of this report is to describe the development and implementation of the order form and provide efficacy and safety results of the MICU trial. This study was designed as an analysis of before and after order form implementation. This report also describes the results of a survey intended to assess nurses' acceptability of the order form. The investigational review board of the University of Colorado Health Sciences Center approved the study prior to data collection. Because this project was deemed a practice improvement initiative, patient consent was not required and a Health Insurance Portability and Accountability Act waiver was obtained.

The MICU nurses and staff were educated by one of the two clinical pharmacists or the MICU nurse educator for two weeks prior to the implementation of the order form. Physician order entry is not available at the University of Colorado Hospital. Instead, orders are scanned so pharmacists are provided an image of the order. The pharmacy order entry process was streamlined by creating a template for the order form, thus allowing the patient's medication profile and medication administration record to be efficiently updated. Implementation occurred when resident physicians were rotating to provide education during their ICU orientation program. Physicians were encouraged to use the order form and told to adhere to the doses provided in the order form.

Data collection

Data were collected for three months (November 2005—January 2006) after implementation. Medical records were audited only after discharge. A matched historical control group was selected by conducting drug utilization reports for the electrolytes in the MICU for the same 3-month period 1 year prior to implementing the order form. The control group was matched to patients that received the order form based on their diagnosis, Acute Physiologic and Chronic Health Evaluation II (APACHE II) score, GFR, and age.

Patients $\geq$ 18 years of age admitted to the MICU were eligible for inclusion. Patients were excluded if they met one of the reasons for not using the order form. The following data, if available, were collected: demographic information including age, gender, weight, height, primary diagnosis, secondary diagnoses, past medical history; APACHE II score; ICU medications; nutritional intake including route, calories (kcal/(kg d)), protein (g/(kg d)), and propofol dose; ventilatory support status; and laboratory parameters including serum concentrations of calcium, glucose, creatinine, blood urea nitrogen (BUN), total bilirubin, albumin, alanine aminotransferase (ALT), and aspartate aminotransferase (AST). Data collected for comparative evaluations were serum electrolyte concentrations of potassium, magnesium, and phosphate before and after each replacement dose; doses of electrolyte replacement used; time to obtaining serum electrolyte concentrations after completion of the replacement dose; number of doses; and MDRD GFR. The following adverse reactions were assessed: hyperkalemia, hypermagnesemia, hyperphosphatemia, electrocardiogram (ECG) changes, arrhythmias, neuromuscular function, hypocalcemia, and adjusted calcium-phosphate product $\geq$55.

Nursing acceptability of the order form was assessed using a nine-point scale of five statements. The statements were designed to evaluate nurses' attitudes regarding the safety, ease of use, satisfaction, comfort, and patient applicability of the order form. Sixty-five nursing staff members were educated and subsequently surveyed. Surveys were distributed via e-mail at 6 and 12 weeks into the trial period. Hardcopies were available at all times in the MICU. All responses were directed to the nurse educator.

Data analysis

The primary outcome assessed was the absolute change in serum concentrations of each electrolyte with the order form compared to the control group. Secondary outcomes assessed were doses used, the number of doses of each electrolyte, the proportion of replacement doses achieving normal serum concentrations, adverse events, and nursing acceptability. Twenty replacement doses (10 in each group) were needed for each electrolyte to demonstrate a 30% difference in the absolute change in concentration between groups assuming standard deviations of 20% (Alaniz and Rice, 1993; Clark et al., 1995; Dickerson et al., 2001; Hamill et al., 1991; Hamill-Ruth and McGory, 1996; Hebert et al., 1997; Kraft et al., 2005; Kruse and Carlson, 1990; Kruse et al., 1994; MacLaren et al., 1999; Perreault et al., 1997; Rosen et al., 1995; Sacks et al., 1997; Taylor et al., 2004; Vannatta et al., 1981, 1983). Continuous data are reported as mean $\pm$ S.D. unless otherwise specified. Comparisons of continuous variables between groups used unpaired Student's *t*-test or Mann—Whitney *U*-test. Comparisons of continuous variables within groups used paired Student's *t*-test or Wilcoxon Signed Rank test. Nominal data were analyzed by χ^2 test or Fisher's exact test. All tests were two tailed, and a *p*-value of $\leq$0.05 was considered significant. Statistical analyses were performed with SAS software, version 8.0 (SAS Institute, Cary, N.C.). Survey results were assessed using the Rand/UCLA appropriateness method. Briefly, the median response score was categorized according to the nine-point scale so that a median response of 1—3 represented disagreement with the statement, 4—6 represented impartiality with the statement, and 6—9 represented agreement with the statement.

Results

Twenty-four patients were identified as having the electrolyte replacement order form used during the 3-month period. Eight patients were excluded because complete medical records were unavailable, three patients were excluded because electrolyte replacement was not administered (i.e. ordered but never needed), and one patient was excluded because renal replacement therapy was initiated prior to electrolyte replacement administration. Twelve matched patients were identified from a cohort of 31 patients. Therefore, a total of 24 medical records (12 in each group) were audited resulting in 98 potassium doses, 62 magnesium doses, and 47 phosphate doses.

Patient groups were similar in terms of demographic variables (Table 1). Three patients in each

Table 1 Patient demographic data and baseline characteristics

	Control ($n = 12$)	Order form ($n = 12$)
Age (years)	55.7 ± 14.04	49.2 ± 12.48
Gender (M/F)	6/6	9/3
APACHE II score	16.3 ± 5.03	15.8 ± 7.57
Actual body weight (kg)	83 ± 30.81	84.3 ± 25.59
Ideal body weight (kg)	64.83 ± 9.58	74.33 ± 14.27
Mechanically ventilated *n* (%)	7 (58)	11 (92)
Primary diagnosis *n* (%)		
Cardiovascular	2 (17)	3 (25)
Gastrointestinal	3 (25)	3 (25)
Hepatic	1 (8)	1 (8)
Neurologic	3 (25)	2 (17)
Respiratory	2 (17)	2 (17)
Sepsis	1 (8)	1 (8)
Medication *n* (%)		
Beta blockers	2 (17)	1 (8)
Beta adrenergic agents	4 (33)	4 (33)
Catecholamines	3 (25)	7 (58)
Corticosteroids	6 (50)	5 (42)
Insulin	3 (25)	7 (58)
Loop diuretics	7 (58)	6 (50)
Enteral nutrition	4 (33)	6 (50)
Potassium sparing diuretics	2 (17)	2 (17)
SMX/TMP[a]	1 (8)	2 (17)
Potassium free MIVFs[b]	5 (42)	2 (17)
Routine laboratory data		
Glucose (mg/dl)	123.5 ± 0.65	140.44 ± 55.96
Serum creatinine (mg/dl)	1.23 ± 0.54	1.13 ± 0.70
BUN (mg/dl)	29 ± 23.12	24.23 ± 24.79
Calcium (mg/dl)	7.85 ± 0.65	7.85 ± 0.83
Albumin (g/dl)	1.98 ± 0.76	2.60 ± 0.82
AST (U/l)	96.83 ± 202.12	207.75 ± 409.7
ALT (U/l)	40.78 ± 40.21	142.33 ± 237.52
Total bilirubin (mg/dl)	1.40 ± 1.13	2.85 ± 2.68

[a] SMX/TMP = sulfamethoxazole/trimethoprim.
[b] MIVFs = maintenance intravenous fluids.

group had renal insufficiency. The mean GFR for these six patients was 34 ± 8.1 ml/min/1.73 m^2 and the mean serum creatinine concentration was 2 ± 0.3 mg/dl. Parenteral nutrition was not administered. Mean time to follow-up labs for replacement dose assessment were 7.92 ± 5.48 h for the order form group and 8.09 ± 5.29 h for the control group. Six (50%) order form patients and four (33%) control patients were receiving enteral nutrition when electrolyte replacement was ordered. The daily caloric intake in these patients was 11.94 ± 6.62 total kcal/kg and 11.75 ± 9.94 total kcal/kg, respectively. The daily protein intake was 0.71 ± 0.26 and 0.56 ± 0.34 g/kg, respectively. Five order form patients and four control patients were receiving propofol for 2.33 ± 2.53 and 5.15 ± 5.44 kcal/(kg day), respectively.

Potassium (Table 2)

Eleven (92%) order form patients received 36 replacement doses of potassium and 12 (100%) control patients received 62 replacement doses of potassium. The mean intravenous dose was significantly higher with the order form resulting in a greater absolute mean increase in serum concentration when compared to the control group. Despite having a significantly lower mean serum potassium concentration before replacement, the proportion of doses achieving normal concentrations was approximately four-fold greater with the

Table 2 Potassium replacement results

	Control ($n = 12$)	Order form ($n = 11$)	p-value
Total number of doses (iv/po)	62/0	34/2	0.12
Mean intravenous dose (mequiv.)	32.7 ± 9.6	38.6 ± 7.6	0.006
Concentration before replacement (mmol/l)	3.49 ± 0.27	3.32 ± 0.24	0.002
Concentration after replacement (mmol/l)	3.58 ± 0.38 ($p = 0.7$ vs. before)	3.68 ± 0.47 ($p < 0.001$ vs. before)	0.28
Absolute concentration change (mmol/l)	0.11 ± 0.43	0.36 ± 0.42	0.003
Doses therapeutic n (%)	11 (18)	26 (72)	<0.001

Table 3 Magnesium replacement results

	Control ($n = 11$)	Order form ($n = 7$)	p-value
Total number of doses (iv/po)	47/1	12/2	0.13
Mean intravenous dose (g)	2.2 ± 0.7	3.8 ± 0.7	<0.001
Concentration before replacement (mequiv./l)	1.63 ± 0.22	1.39 ± 0.19	0.004
Concentration after replacement (mequiv./l)	1.76 ± 0.34 ($p = 0.02$ vs. before)	1.96 ± 0.73 ($p = 0.009$ vs. before)	0.15
Absolute concentration change (mmol/l)	0.13 ± 0.40	0.56 ± 0.69	0.07
Doses therapeutic n (%)	10 (21)	12 (86)	<0.001

order form. No adverse reactions were attributed to potassium replacement.

Magnesium (Table 3)

Seven (58%) order form patients received 14 replacement doses of magnesium and 11 (92%) control patients received 48 replacement doses of magnesium. The mean intravenous dose with the order form was nearly double the dose of the control group, resulting in a trend towards a greater absolute mean increase in serum concentration with the order form. Despite having a significantly lower mean serum magnesium concentration before replacement, the proportion of doses achieving normal concentrations was approximately four-fold greater with the order form. No adverse reactions were attributed to magnesium replacement.

Phosphate (Table 4)

Eleven (92%) order form patients received 34 replacement doses of phosphate and 8 (67%) control patients received 13 replacement doses of phosphate. The mean intravenous dose with the order form was double the dose of the control group but the mean absolute increase in serum concentrations was similar between groups. The mean serum phosphate concentration before administration was significantly lower in the control group. The proportion of doses achieving normal concentrations was similar between groups. No adverse reactions were attributed to phosphate replacement.

Table 4 Phosphate replacement results

	Control ($n = 8$)	Order form ($n = 11$)	p-value
Total number of doses (iv/po)	11/2	27/7	0.6
Mean intravenous dose (mmol)	14.6 ± 4.7	28.8 ± 10.8	<0.001
Concentration before replacement (mg/dl)	1.92 ± 0.30	2.25 ± 0.46	0.02
Concentration after replacement (mg/dl)	2.58 ± 0.95 ($p = 0.014$ vs. before)	2.78 ± 0.76 ($p < 0.001$ vs. before)	0.44
Absolute concentration change (mmol/l)	0.66 ± 0.83	0.53 ± 0.82	0.63
Doses therapeutic n (%)	8 (62)	16 (47)	0.57

Table 5 Nursing acceptability survey

Statement (responses = 36)	Response rating (1—9 with 9 indicating most agreement)									Median
	1	2	3	4	5	6	7	8	9	
(1) The electrolyte order form allows you to safely care for patients	1	1	3	2	8	2	15	2	2	7
(2) The electrolyte order form is easy to understand and use	1	1	8	6	7	1	11	0	1	5
(3) The electrolyte order form improves your satisfaction with electrolyte management	2	1	6	5	3	3	14	2	0	6
(4) You are comfortable administering the electrolyte doses as prescribed in the order form	0	3	4	2	2	2	15	6	2	7
(5) The electrolyte order form may be used in most patients you care for in the ICU	0	1	6	2	4	4	11	3	5	7

Survey of nurses (Table 5)

Thirty-six (55%) surveys were returned. Nurses were in agreement that they were comfortable using the electrolyte order form and that it was safe. Furthermore, the nurses felt it could be applied to most ICU patients. Impartial responses were obtained for whether nurses believed the order form was easy to understand and use; and whether the use of the order form improved their satisfaction with electrolyte management.

Discussion

The primary findings of this retrospective evaluation indicate (1) the use of an EBM electrolyte replacement dosing order form effectively and safely replenished potassium and magnesium serum concentrations but not phosphate concentration compared to matched control group and (2) nurses were comfortable using the order form. The authors are unaware of other studies that have used the MDRD equation for the purpose of dosing medicinal agents in renal insufficiency. While few patients had renal insufficiency in our study, no adverse events were observed despite numerous doses suggesting that the MDRD equation may be safely applied to electrolyte replacement.

The effective replacement dose for potassium and magnesium in critically ill patients varies between studies (Hamill et al., 1991; Hamill-Ruth and McGory, 1996; Hebert et al., 1997; Kruse and Carlson, 1990; Kruse et al., 1994; Sacks et al., 1997). In general, however, these patients require relatively large doses to replenish intracellular concentrations. Patients in our study being treated with the order form were more likely to attain normal serum concentrations of potassium and magnesium. This is likely due to the administration of larger doses with the order form compared to the control group. The use of larger doses also allowed for greater efficiency as the number of replacement doses needed was substantially reduced. The mean absolute change in serum potassium concentration of 0.36 ± 0.42 mmol/l is consistent with the results of other studies that showed changes of 0.25—1.1 mmol/l depending on the dose administered and baseline serum concentration (Hamill et al., 1991; Kruse and Carlson, 1990; Kruse et al., 1994). Similarly, the mean absolute change in serum magnesium concentration of 0.56 ± 0.43 mequiv./l achieved with the order form is consistent with the results of other studies that demonstrated changes of 0.6—0.88 mequiv./l using slightly larger doses than we administered (Hamill-Ruth and McGory, 1996; Hebert et al., 1997; Sacks et al., 1997). For both potassium and magnesium replacement, we deviated from EBM and chose to use slightly lower doses in order to minimize the occurrence of adverse events and ensure clinical acceptability of the order form across all ICUs.

The results of phosphate replacement therapy were largely unexpected as only half the replacement doses with the order form attained normal serum concentrations. Despite the doubling of the dose compared with the control group, the mean absolute increases in serum phosphate concentrations were similar. The lack of efficacy with the order form may be explained by deviations in dosing from EBM that were required to ensure clinical acceptability. Other studies demonstrated elevations of serum phosphate concentrations of 0.7—1.34 mg/dl compared to 0.53 ± 0.82 mg/dl observed in our study with the order form (Alaniz and Rice, 1993; Clark et al., 1995; Dickerson et

al., 2001; Perreault et al., 1997; Rosen et al., 1995; Taylor et al., 2004; Vannatta et al., 1981, 1983). While many of these studies used mean doses similar to our order form group, the most successful study of phosphate replacement used doses based on patient weight adjusted for baseline serum concentrations which resulted in doses larger than what we used (Clark et al., 1995). We deviated from this primary study of weight-based phosphate replacement to simplify the ordering process and standardize doses in an effort to prevent adverse events associated with calculating and communicating the dose. In addition, the process of communicating a calculated dose from the bedside nurse to the order entry pharmacist would reduce efficiency. Of note, a recent study published after the implementation of our order form suggests that effective replacement of serum phosphate concentrations requires the administration of high doses, even approaching 1 mmol/kg in cases of severe hypophosphatemia (Brown et al., 2006). While the Critical Care Quality Assurance Committee has discussed altering the phosphate dosing scheme to require higher doses, the consensus has been not to modify the order form because the present doses represented a deviation from our institutional standard of practice as indicated by the doubling of the mean dose compared to the control group.

The authors are unaware of any studies that have used the MDRD equation to adjust dosing of agents in critically ill patients with varying degrees of renal function. Historically, MDRD was not used in patients with fluctuating renal function, or who were critically ill (Garcia-Naveiro et al., 2005; Kuan et al., 2005; Levey et al., 1999; Stevens et al., 2006). Many physiologic and therapeutic aspects associated with critical illness may distort the MDRD results. For example, the amount of fluid and type of fluid these patients receive could inadvertently affect weight and serum concentrations of albumin and BUN. However, Hoste et al. compared the predictive ability of the five variable MDRD, the simplified MDRD, and a modified Cockcroft—Gault equation to a measured urine creatinine clearance in critically ill transplant patients (Hoste et al., 2005). The results showed modest but significant correlation ($p = 0.012$) between the five variable MDRD and the measured urinary creatinine clearance. One of the weaknesses in this study was that the measured urinary creatinine collection was only a 1-hour collection and not a traditional 24 h collection. Furthermore, the 28 patients in this study possessed stable serum creatinine concentrations which may not be applicable to all ICU patients. Unfortunately, our study had few patients with renal insufficiency, in part, because renal replacement therapy was a reason not to use the order form. In addition, patients with renal insufficiency tend not to have reduced serum concentrations of these three electrolytes because they are largely renally eliminated. While additional evaluation of the order form in patients with renal insufficiency is warranted, we believe it is safe as no adverse events were observed.

Effective implementation of any order form requires prescribing practices to change which depends on the opinions of recognized leaders, acceptance by those using the order form, reminders of prescribing changes, immediate feedback, and continuous education (Davis and Taylor-Vaisey, 1997). The endorsement of the order form by the Critical Care Quality Assurance Committee demonstrated the importance of electrolyte replacement to all ICU healthcare professionals. Every effort was made to ensure the order form was user friendly and operationally efficient. The survey of bedside nurses was conducted to identify issues with the order form. The results indicate that nurses were generally satisfied with the order form and comfortable using it. As a result, the order form has been implemented in the burn/trauma and neurosurgery ICUs with plans for extension into the surgical ICU.

Possible limitations of this study include the small sample size and the limitations naturally inherent with retrospective descriptive studies. We used a matched control group to minimize these limitations. However, eight order form patients were excluded due to incomplete medical records, which was likely the result of the chart audit occurring shortly after patients were discharged. The number of replacement doses of each electrolyte, however, met our sample size calculation. Unfortunately, the limited sample size prevented adequate assessment of the order form for enteral replacement and in patients with renal insufficiency. Accurate documentation of electrolyte replacement, subsequent serum electrolyte concentrations, and the occurrence of adverse events are difficult to extrapolate from a chart audit. There was no effort made to enforce the use of the order form as it was and remains optional. Therefore, it is not possible to ascertain whether selection bias of patients or physicians occurred. For example, perhaps the order form was preferentially not used in patients with renal insufficiency because physicians feared the possibility of inducing adverse events as a result of supranormal concentrations. The fact that enteral replacement was rarely used despite several patients receiving enteral nutrition suggests that even when the order form was used, bias existed toward intra-

venous replacement. Therefore, compliance and adherence to the order form was not assessed.

In summary, the order form effectively and efficiently replaced potassium and magnesium but not phosphorus. No adverse events were observed and the order form was well received by nursing staff.

Appendix A

Final version of the electrolyte replacement order form at the University of Colorado Hospital.

Dispensing by non-proprietary name under formulary system is permitted, unless checked here: ❑

Date: / / Time:

Attending Physician: **UPI#:**

Ordering Healthcare Provider: **GME/UPI#:** **Pager:**

Service:

Allergies:

Diagnosis:

Designate preferred clinical location:
Note: Admission Order Form must be completed

Condition of Patient:

Contraindications to using this guideline (if any are present, do NOT use this guideline):
☐ Active diabetic ketoacidosis ☐ Arterial pH in previous 24 hours less than 7.20 or greater than 7.60
☐ Renal replacement therapy

TESTS
For **intravenous** replacement, check: ☐ basic metabolic panel, ☐ magnesium, ☐ phosphate _____ hours (usually FOUR hours) after last replacement dose is finished.
For **enteral** replacement, check: ☐ basic metabolic panel, ☐ magnesium, ☐ phosphate every morning during replacement.

DOSING PARAMETERS
For all dosing tables, check patient's most recent serum creatinine (Cr) concentration. If Cr less than 1.5 for males or less than 1.3 for females, follow dosage regimen recommended in tables for GFR greater than 50 mL/minute. If serum Cr equal or greater than 1.5 for males or Cr equal or greater than 1.3 for females, check laboratory value for modified diet in renal disease (MDRD) assessment of glomerular filtration rate (GFR) and follow dosage regimen recommended in tables for reported GFR.

MEDICATIONS

☐ Minimize intravenous admixture fluid for electrolyte replacement doses.

ALWAYS consider the validity of the lab value prior to initiating replacement therapy.

POTASSIUM REPLACEMENT

	Glomerular Filtration Rate (GFR in mL/minute)		
Serum / Plasma Potassium level	**Greater than 50**	**25 – 50**	**Less than 25**
3.0 – 3.9 mmol/L	40 mEq potassium chloride solution via enteral route every 6 hours x 4. If enteral route NOT available, 20 mEq potassium chloride IV x 2.	40 mEq potassium chloride solution via enteral route every 12 hours x 2. If enteral route NOT available, 20 mEq potassium chloride IV x 1.	20 mEq potassium chloride solution via enteral route every 12 hours x 2. If enteral route NOT available, 10 mEq potassium chloride IV x 1.
Equal or less than 2.9 mmol/L (if equal or less than 2.4 mmol/L, notify MD)	20 mEq potassium chloride IV x 3	20 mEq potassium chloride IV x 2	20 mEq potassium chloride IV x 1

Preferred intravenous rates: equal or less than 10 mEq/hour (peripheral); equal or less than 20 mEq/hour (central)
Maximum rate: equal or less than 40 mEq/hour (emergency); Maximum intravenous dose = 240 mEq in 24 hours
Magnesium repletion should be considered when potassium replacement is initiated.

MAGNESIUM REPLACEMENT

Glomerular Filtration Rate (GFR in mL/minute)			
Serum / plasma Magnesium level	**Greater than 50**	**25 - 50**	**Less than 25**
1.1 – 1.9 mEq/L	Magnesium gluconate 1000 mg via enteral route every 6 hours x 4. If enteral route NOT available, 2 grams magnesium sulfate IV x 2.	Magnesium gluconate 1000 mg via enteral route every 12 hours x 2. If enteral route NOT available, 2 grams magnesium sulfate IV x 1.	Magnesium gluconate 500 mg via enteral route every 12 hours x 2. If enteral route NOT available, 1 gram magnesium sulfate IV x 1.
Equal or less than 1.0 mEq/L (if equal or less than 0.7 mEq/L, notify MD)	2 grams magnesium sulfate IV x 4	2 grams magnesium sulfate IV x 2	2 grams magnesium sulfate IV x 1

Magnesium gluconate 500 mg tablet = 27 mg magnesium.
Preferred intravenous rate equal or less than 1.0 grams/hour. Maximum rate: equal or less than 4 grams/hour (emergency)
Maximum intravenous dose = 24 grams in 24 hours

PHOSPHORUS REPLACEMENT

Glomerular Filtration Rate (GFR in mL/minute)			
Serum / plasma Phosphorus level	**Greater than 50**	**25 - 50**	**Less than 25**
2.0 – 3.0 mg/dL	KPhos Neutral® (potassium phosphate) 1000 mg via enteral route every 6 hours x 4. If enteral route NOT available, 22.5 mmol sodium phosphate IV x 1.	KPhos Neutral® (potassium phosphate) 1000 mg via enteral route every 12 hours x 2. If enteral route NOT available, 15 mmol sodium phosphate IV x 1.	KPhos Neutral® (potassium phosphate) 500 mg via enteral route every 12 hours x 2. If enteral route NOT available, 7.5 mmol sodium phosphate IV x 1.
Equal or less than 1.9 mg/dL (if equal or less than 1.5 mg/dL, notify MD)	45 mmol sodium phosphate IV x 1	30 mmol sodium phosphate IV x 1	15 mmol sodium phosphate IV x 1

KPhos Neutral® (potassium phosphate) 250 mg tablet = 8 mmol phosphate, 13 mEq sodium, and 1.1 mEq potassium.
Every 7.5 mmol sodium phosphate contains 10 mEq sodium. Preferred intravenous rate equal or less than 5 mmol/hour.
Maximum rate: equal or less than 7.5 mmol/hour (emergency); Maximum intravenous dose = 135 mmol in 24 hours

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