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Review Article

An integrative review of potassium replacement protocol use in critical care: Development, use and critical care nurse autonomy

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ABSTRACT

Background: Potassium replacement protocols are used to standardise practice, reduce risk, and ensure timely potassium replacement, but there is considerable variability in their development and use, particularly as part of critical care nursing practice.
Aim: To synthesise the research evidence on how potassium replacement protocols are used in adult critical care; and how critical care nurses' role and practice is influenced by a potassium replacement protocol. The research question was 'How are protocols used by intensive care clinicians to guide potassium replacement in adult critical care?'
Design: A structured integrative review was undertaken. A combination of keywords, synonyms, and Medical Subject Headings were used across the Ovid Medline and Embase databases. Records were independently assessed against inclusion and exclusion criteria. All papers were assessed for quality. A narrative synthesis was used to analyse and present the findings.
Results: Ten studies were included in this review from 4076 records identified. Narrative synthesis revealed five categories: *(i) protocol design* demonstrating variation in protocol mechanisms, *(ii) protocol rationale* eliciting reasonings for protocol implementation, *(iii) protocol use* describing how protocols were nurse-driven enabling nursing autonomy (*iv*) *protocol adherence* highlighting variability in protocol compliance and *(v) critical care nurse acceptability* and feasibility coupling greater shared responsibility for patient care and improved clinician satisfaction.
Conclusion: Safe, high-quality care, supported by evidence continues to be a priority. Protocolised potassium replacement can improve patient outcomes and promote nurses' autonomy, efficiency, and job satisfaction.
Implications for Clinical Practice: Recognising and promoting critical care nurses' expert assessment skills and clinical decision-making is essential for optimising efficient, safe, and high-quality patient care. Although protocol deviations are accommodated in protocol development, comprehensive documentation to justify protocol deviations is key to justifying practice. Understanding protocol deviations are crucial to inform future protocol development, improvements, and evaluation to further enhance critical care nursing practice.

Introduction

In critical care, protocol-driven care is common, underpinned by a long-standing tenet that evidence-based protocols can complement clinical judgement (Meade & Ely, 2002), ensure, or promote consistency in care and improve patient outcomes (Wall et al., 2001). In general, protocol-driven care allows clinicians, such as critical care nurses, to complement and utilise their clinical judgement to improve patient outcomes further empowering a sense of autonomy (Barto, 2019; Meade & Ely, 2002) an important perspective given the strong emphasis on recognising critical care nurses as highly educated, independent and autonomous leaders in the provision of critical care (Endacott et al., 2022).

Potassium has an essential role in many physiological functions including cellular metabolism, glycogen and protein synthesis, and regulation of action potential across cell membranes (Kraft et al., 2005). Achieving and maintaining potassium homeostasis can be particularly challenging in patients who are critically ill (Scotto et al., 2014). When

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intravascular depletion occurs, the priority is to ensure safe and efficacious repletion (Hammond et al., 2019). Yet there is wide variability in potassium repletion practices, including the pre-emptive administration of potassium in maintenance intravenous fluids (Scotto et al., 2014) and the use of a 'rule-of-thumb' approach (Hammond et al., 2019). A retrospective observational study conducted in a medical intensive care unit (ICU) evaluated the effectiveness and safety of a 'rule-of-thumb' approach, an estimation derived from marginal empirical evidence, demonstrated that the desired serum potassium concentration was only achieved in 35% of cases (Hammond et al., 2019).

Potassium replacement protocols are increasingly being used throughout adult critical care settings (Zielenski et al., 2017) to standardise practice, ensure uniform, effective, and timely therapy (Hijazi & Al-Ansari, 2005) and reduce actual or potential harm to patients (Webster et al., 2015; Zielenski et al., 2017). A retrospective observational study conducted in the USA with N = 300 medical patients treated using a potassium replacement protocol demonstrated a significant improvement in the time from blood collection to potassium replacement ($p < 0.0001$) and time to achieve target potassium level ($p < .05$) (Zielenski et al., 2017). Potassium replacement protocols are intended to standardise practice, but their application across critical care settings and how they inform critical care nurses' decision making is not well understood. Therefore, the aim of this integrative review was to synthesise research evidence on the use of potassium replacement protocols in adult critical care settings.

Methods

Aim

The primary aim of this integrative review was to synthesise research evidence on how potassium replacement protocols are used in adult critical care. A secondary aim was to understand how critical care nurses' role and practice is influenced by a potassium replacement protocol.

Review question

The research question was 'How are protocols used by intensive care clinicians to guide potassium replacement in adult critical care?'.

Design

To address the research question, an integrative review with a narrative synthesis was used. Due to the exploratory nature of the research question and anticipated diversity in study types that address the research question, this was considered the most appropriate approach. To guide this review, The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Equator Network, 2020) was used. A protocol was registered with PROSPERO (2022 CRD42022357055).

Inclusion and exclusion criteria

Studies were considered for inclusion if they reported data on the use of a potassium replacement protocol for the maintenance of normokalaemia and the treatment of hypokalaemia in critical care settings. Peer-reviewed qualitative, quantitative, and mixed-methods studies published in English, from database inception to August 2022, were eligible for inclusion. Research related solely to neonatal and paediatric populations were excluded, but those with mixed adult and paediatric populations were considered, if the data were separated. Thesis and dissertations, grey literature, non-research publications, and studies conducted in mixed settings or with mixed populations, where data could not be separated, were excluded (Table 1).

Table 1
Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Determined by Title and Abstract • Designs: All primary research • Settings: Adult critical care, intensive care, intensive therapy unit (or equivalent) • Focus: Clinician-initiated replacement of potassium *Determined by Full Paper* Outcome/s: • Clinician-initiated replacement of potassium according to a protocol • Description of how and when protocol is used and/or how the protocol is evaluated, and/or when a protocol is not used • Maintenance of normokalaemia or treatment of hypokalaemia Language: English (confirm with full paper) Publication type: Peer-reviewed publication	• Conducted in settings other than critical care • Conducted in neonatal or paediatric settingsConducted in mixed • (adult/paeds/neonatal) settings where the data cannot be separated • Systematic, literature, scoping reviews • Abstracts, conference papers, letters to the editor, commentary and opinion pieces • Theses and dissertations

Search strategy

In August 2022, a systematic search of Medline (via Ovid) and Embase databases was undertaken. No publication date limits were applied to the searches to ensure all primary research evidence related to the research question was captured. A comprehensive search strategy using all relevant words, synonyms and MeSH headings representing the concepts 'protocol', 'potassium replacement', 'serum potassium' and 'critical care' were searched to identify relevant papers (Table 2). The search was limited to English language only. The Medline search is provided as an exemplar in Supplementary file 1.

Table 2
Search terms.

Term	Keyword
"Critical care"	ICU
MeSH	CCU
"Intensive care"	HDU
	ITU
	"intensive therapy unit"
	"intensive care unit"
	"high dependency unit"
AND	
Protocol	Guideline
	Procedure
	Policy
	Algorithm
	"Instruction manual"
	"Standing order*"
	"nurse initiated"
	Protocol*
	"Clinical Protocol*"
AND	
Potassium	"Potassium Chloride"
	"Serum potassium"
	dyskalemia
	Hypokalaemia
	Hyperkalaemia
	Electrolyte
	"Electrolyte dosing"
	"Electrolyte replacement"
	"Potassium replacement"

Study selection

The citations of all retrieved studies were imported into Endnote, Version X9, (The EndNote Team, 2013) where duplicate citations were removed. Citations were then exported into Covidence (Veritas Health Innovation, 2022) where additional duplicate records were identified and removed. Screening of titles and abstracts was undertaken in Covidence (Veritas Health Innovation, 2022) by both researchers (XX, XX) blinded to each other's screening. Once initial screening was complete, conflicts were resolved through discussion. An Independent full-text review was then undertaken, and conflicts were resolved through discussion. Using the included papers, forward and backward chaining, which involved reviewing the reference list of included papers, and any newer publications that cited included papers was undertaken. One additional paper was identified that met the inclusion criteria. A PRISMA flowchart documenting the results of the search and screening process is provided in Fig. 1.

Data extraction and quality appraisal

Data were extracted using a tool developed by the researchers. Both researchers independently extracted data from three randomly selected studies, then compared extracted data and the extraction approach to ensure consistency. One researcher (KO) then independently extracted data from all remaining included studies, with the second researcher (MJB) confirming the accuracy of extraction. The quality of all papers was independently assessed by two researchers using a tool suitable for qualitative and quantitative research (Caldwell et al., 2011). An *a priori* decision was made to not exclude papers based on quality scores but, rather, to use the quality scores to describe the quality of the research evidence.

Data analysis

Given the heterogeneity of data across studies, a narrative synthesis approach (Popay et al., 2006), which primarily relies on the use of words and text to explain and systematically summarise findings, was used. This approach goes beyond the act of directly describing and summarising the main features of included studies, enabling investigation of similarities and differences between studies, and exploration of relationships within the data, resulting in a summary of knowledge that may be used to inform practice or policy (Lisy & Porritt, 2016). Analysis was initially undertaken independently by one researcher (KO), reviewed by a second researcher (MJB), and then collaboratively so that differences and disagreements could be resolved, and the final synthesis findings determined.

This integrative review included 10 papers published between 2008 and 2021; eight studies were retrospective in design (Conley et al., 2021;

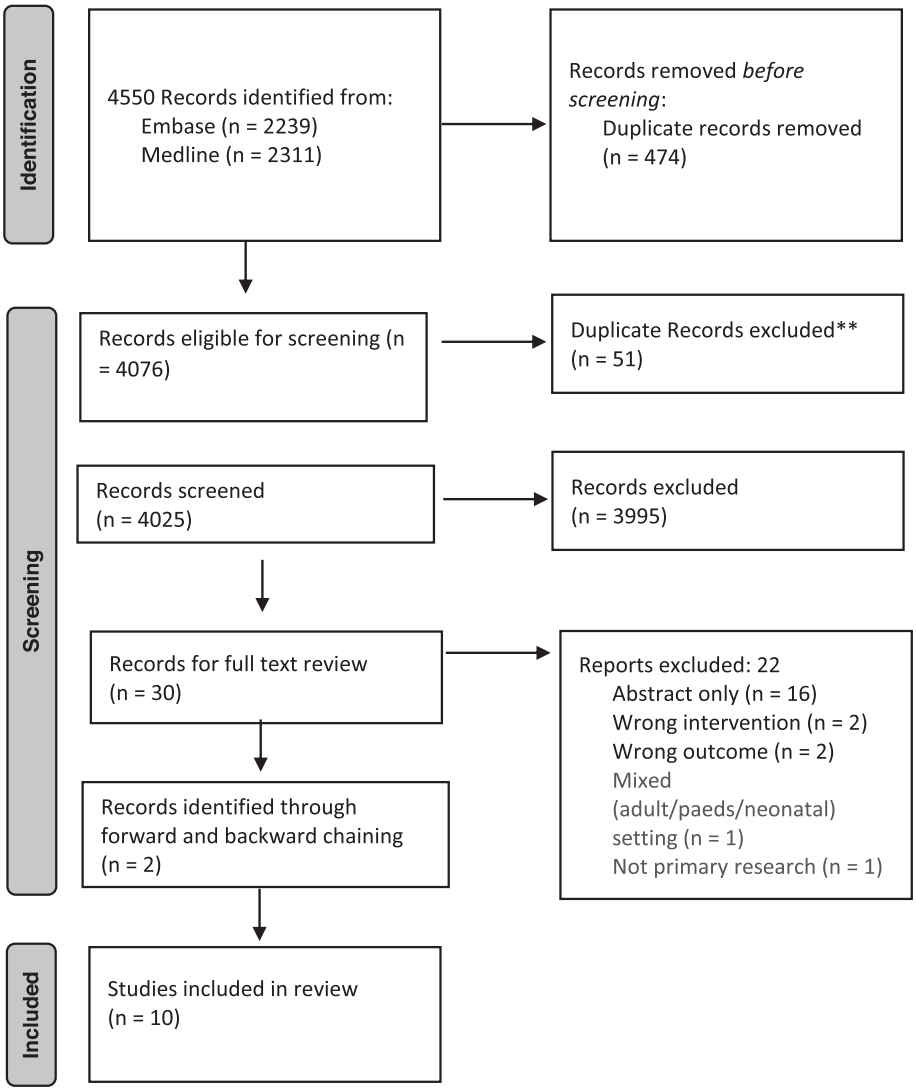

Fig. 1. PRISMA 2009 Flow Diagram. Adapted from Moher et al., (2009).

Couture et al., 2013; Hessels et al., 2015; Johnston et al., 2017; Kanji & Jung, 2009; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009), one used a quasi-experimental prospective design (Abdelgawad et al., 2020), and one was a before-and-after study (Hoekstra et al., 2010). The studies included a patient sample (N = 14,480), with evaluative feedback also elicited from nurses (N = 204) and medical staff (N = 60). Five studies were conducted in the USA (Conley et al., 2021; Johnston et al., 2017; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009), two studies in Canada (Couture et al., 2013; Kanji & Jung, 2009), two studies in the Netherlands (Hessels et al., 2015; Hoekstra et al., 2010) and one study in Egypt (Abdelgawad et al., 2020) (Table 3). The acceptability of potassium replacement protocols to critical care nurses is described, in addition to autonomy, satisfaction, timeliness, and usefulness (Table 4).

Quality appraisal scores for the included studies ranged from 8 to 10 out of 11, with lower scores attributed to missing detail such as justification of the methodology and method, and/or description of steps to address or mitigate actual/potential ethical issues. Further detail is provided in Table 5.

Findings

Narrative synthesis revealed five categories: protocol design, protocol rationale, protocol use, protocol adherence, and critical care nurse acceptability and feasibility.

Protocol design

Descriptions of the design of potassium replacement protocols varied, including an order set that a critical care nurse could commence when a low potassium result was identified (Todd et al., 2009), standing orders in the patient's medical record (Pearson et al., 2018), a preprinted order form that provided potassium replacement doses titrated according to serum potassium concentration (Abdelgawad et al., 2020; Couture et al., 2013; Kanji & Jung, 2009; Owen et al., 2008) and as a computerised/electronic protocol (Conley et al., 2021; Hessels et al., 2015; Hoekstra et al., 2010). In two studies, a computerised potassium replacement protocol was integrated alongside a previously established computerised glucose management protocol, known as GRIP-II, with artificial intelligence using clinical information entered by the nurse to generate advice and recommendations to guide critical care nurses in potassium repletion (Hessels et al., 2015; Hoekstra et al., 2010). In other studies, the potassium replacement protocol was a standalone computerised protocol, with doses titrated according to serum potassium concentration only (Conley et al., 2021) or in combination with patient clinical factors, such as creatinine level or evidence of diuresis (Hessels et al., 2015). In one study, the dosing algorithm was designed by a specialist nutrition support service to specifically meet the needs of trauma patients (Johnston et al., 2017).

Protocol rationale

The rationale for a potassium replacement protocol varied across studies. Efficacy in the correction of hypokalaemia (Couture et al., 2013; Kanji & Jung, 2009; Todd et al., 2009), timeliness in potassium replacement (Kanji & Jung, 2009; Pearson et al., 2018), and safety (Hoekstra et al., 2010) were common rationales underpinning protocol development. In other studies, the rationale for protocol development was to increase nurse autonomy (Owen et al., 2008), particularly in response to high nurse workloads and turnover (Abdelgawad et al., 2020) and as a way of promoting nurse efficiency in practice (Hoekstra et al., 2010) increase clinician acceptability (Owen et al., 2008) and nurse satisfaction (Kanji & Jung, 2009).

Protocol use

In eight studies, potassium replacement was described as nurse-driven or nurse-centric (Conley et al., 2021; Couture et al., 2013; Hessels et al., 2015; Hoekstra et al., 2010; Kanji & Jung, 2009; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009), enabling critical care nurses to autonomously evaluate and replete potassium as necessary, including the provision to override the protocol in instances where dosage requirements were inappropriate to meet the patients' clinical needs (Conley et al., 2021; Hessels et al., 2015; Hoekstra et al., 2010; Kanji & Jung, 2009; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009). In six studies, the researchers described that the protocols included guidance on the timing of subsequent blood draws to measure efficacy and guide additional potassium replacement (Conley et al., 2021; Couture et al., 2013; Kanji & Jung, 2009; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009). In the two studies involving the GRIP-II system, which has in-built artificial intelligence to guide nurse actions, the researcher state that nurses can overrule or adjust any recommendation provided by the protocol and that even when the recommended action is taken to replete potassium, evaluation remained the responsibility of the critical care nurse (Hessels et al., 2015; Hoekstra et al., 2010).

Seven studies described the criteria for which patients may be assessed as not suitable for management using a potassium replacement protocol. Patients with chronic heart failure, end-stage renal disease, acute renal failure, or insufficiency, (Abdelgawad et al., 2020; Todd et al., 2009) or those on renal replacement therapy (Couture et al., 2013; Owen et al., 2008) were excluded from management using a potassium replacement protocol. Patients with low urine output (<30 ml per hour) were ineligible (Abdelgawad et al., 2020; Pearson et al., 2018), and in cases where urine output decreased over time, the potassium replacement protocol was to be ceased (Todd et al., 2009). Those with diabetic ketoacidosis (Abdelgawad et al., 2020; Couture et al., 2013; Owen et al., 2008; Pearson et al., 2018; Todd et al., 2009), pregnancy-induced hypertension (Todd et al., 2009), those receiving parenteral nutrition (Pearson et al., 2018) or with significant hyperkalaemia (Hoekstra et al., 2010) were also deemed unsuitable for management using the potassium replacement protocol.

In one study (Conley et al., 2021) patients with renal insufficiency were included so that the safety of nurse-driven potassium replacement in this group could be evaluated. Evaluation of patient outcomes demonstrated the protocol was efficacious and safe in patients with renal insufficiency, with no differences in the incidence of hyperkalaemia compared to patients without renal insufficiency (Conley et al., 2021).

Protocol adherence

Five of the included studies examined protocol adherence in assessing the effectiveness of the protocol (Abdelgawad et al., 2020; Couture et al., 2013; Hoekstra et al., 2010; Kanji & Jung, 2009; Todd et al., 2009). Two studies (Abdelgawad et al., 2020; Kanji & Jung, 2009) analysed adherence by examining potassium replacement doses indicated as per the protocol versus doses given. The study by Abdelgawad et al. (2020) demonstrated 100% adherence of doses indicated and administered in the intervention group, a significant difference ($p <$ 0.001) from the control group with only 48% of doses administered, whereas the study by Kanji and Jung (2009) described no differences in the number of doses indicated but not given with 15% pre protocol versus 16% post protocol (p 0.85). Todd et al. (2009) further discussed that in the study group, an incorrect potassium dose was given 20% of the time. Adherence rates in the Hoekstra et al. (2010) steadily rose over the weeks following the introduction of the potassium protocol taking a total of 5 weeks to see compliance rates at 95%.

The study by Couture et al. (2013) demonstrated that adherence to the protocol was seen in improvements with potassium replacement prescriptions for 86.6% of patients, however adherence with follow-up monitoring as set out in the protocol was only completed in 49.6% of cases. Conversely, post replacement monitoring significantly improved

Table 3
Summary of included papers (n = 10).

Authors, year of publication	Country, setting & context	Aim and/or research question/s	Sample & sample size	Methodology & method	Primary Outcomes
Abdelgawad et al. 2020	Egypt. Three medical/surgical ICUs in a major adult urban teaching facility	To determine the efficacy of applying nurses driven electrolytes repletion protocol on electrolytes disturbance control among critically ill patients in busy high workload.	Newly admitted critically ill adult patients (N = 62)	Quasi-experimental prospective research design comparing usual care and potassium replacement according to a protocol	The potassium replacement protocol resulted in less hypokalaemia, higher total daily potassium replacement doses, no missed doses and shorter time interval from laboratory reporting to potassium replacement, compared to the control group. Application of the nurse driven electrolyte repletion protocol resulted in improvement in the effectiveness and timeliness of electrolyte replacement.
Conley et al. 2021	USA. Intensive Care Unit	To determine if a standardised nurse-driven potassium replacement protocol was safe in critically ill patients according to serum creatinine (SCr) above and below 2 mg/dL.	Critically ill patients receiving intravenous potassium replacement (N = 145). Two cohorts: Those with a SCr ≤ 2 mg/dL (n = 99) Those with a SCr > 2 mg/dL (n = 46)	Retrospective cohort evaluation.	Incidence of hyperkalaemia was not different between groups, and change in serum potassium was similar across groups. Of the total population, five patients experienced hyperkalaemia; none received hyperkalaemia treatment.
Couture et al. 2013	Canada. Surgical ICU in a tertiary care university hospital	To objective was to evaluate the effectiveness and safety of an electrolyte repletion protocol in a large, homogeneous group of postoperative cardiac surgery patients.	Adult cardiac surgery patients (N = 627). Two cohorts with similar baseline characteristics: Control group - before protocol implementation (n = 312) Intervention group - after protocol implementation (n = 315)	Retrospective before and after study.	The proportion of morning serum potassium values within the desired range was not significantly different between groups. The protocol group had more patients with 100% of the morning potassium values within the desired range (66.1% versus 56.8%, p = 0.018). Use of the protocol was independently associated with optimal maintenance of serum potassium concentration within the desired range in both the all-patient analysis (odds ratio [OR] 1.57, 95% confidence interval [CI] 1.03–2.37; p = 0.034) and the per-protocol analysis (OR 2.36, 95% CI 1.49–3.74; p < 0.001).
Hessels et al. 2015	The Netherlands. ICU including cardiothoracic, neurosurgery and medical subunits, in a university teaching hospital.	To evaluate the relationship between potassium levels and in-hospital mortality; and to evaluate the impact of a computerised protocol on potassium control.	Adult ICU patients (N = 10,451) admitted for > 24 h.	Retrospective observational cohort study	The overall in-hospital mortality was 21.8%, and potassium variability was independently associated with the outcome. Survivors had lower potassium variability in both early and late phases (p <.001). Overall, in-hospital mortality decreased from 23.3% to 19.9% after implementation of computerised potassium control, part of GRIP-II.
Hoekstra et al. 2010	The Netherlands. Surgical and thoracic-surgical ICU in an adult university teaching hospital	To evaluate if a computerised potassium regulation protocol in the ICU improved potassium regulation	ICU Patients (N = 2210)	Before and after study	Using the computerised protocol, 92% of patients received potassium infusion. The median potassium levels were similar before and after protocol implementation, but the level of potassium control improved with the incidence of hypokalaemia decreasing from 2.4% to 1.7% (p <.001) and hyperkalaemia from 7.4% to 4.8% (p <.001). Nurses considered the computerised protocol improved practice.
Johnston et al. 2017	USA. Trauma ICU	To evaluate the safety and efficacy of a guided IV potassium dosing algorithm for critically ill patients with traumatic injuries.	Adult trauma patients (N = 100)	Retrospective audit	Target serum potassium concentrations were achieved in 22%, 71%, and 100% of patients with mild, moderate, and severe potassium depletion who were supplemented according to the treatment algorithm. Safety of the dosing algorithm was verified as none of the patients experienced a

(*continued on next page*)

Table 3 (*continued*)

Authors, year of publication	Country, setting & context	Aim and/or research question/s	Sample & sample size	Methodology & method	Primary Outcomes
					post infusion serum potassium concentration > 5.2 mEq/L or had documentation of an adverse cardiac event. The algorithm was safe for patients with mild and moderate hypokalaemia and efficacious for those with moderate hypokalaemia.
Kanji & Jung. 2009	Canada. Medical-surgical ICU in a community hospital	To compare the effectiveness and timeliness of electrolyte replacement in an adult ICU before and after implementation of a protocol	Adult patients (N = 63) from two phases: Pre-protocol (n = 33) Post-protocol (n = 30)	Retrospective audit	The total number of low potassium levels experienced by all patients in the pre- and post-protocol phases were 156 and 23. Potassium doses used pre and post-protocol were similar. There was a reduction in the time to replacement for potassium from 79 to 60 min, but this was not significant.
Owen et al. 2008	USA Medical ICU	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.	Adult patients (N = 24) with similar variables were split to two groups: Control (pre-implementation) Intervention (post-implementation	Retrospective audit	11 (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 order form. No adverse reactions were attributed to potassium replacement.
Pearson et al. 2018	USA. Medical ICU in a military tertiary centre	To evaluate the effects of electrolyte replacement protocol implementation.	Adult patients (N = 726), split according to two groups: Pre-protocol (n = 100) Post-protocol (n = 626)	Retrospective audit	The median time to potassium replacement decreased from 180 (83–284) to 96 (40–197) minutes (p <.01). Post-protocol implementation, there were two instances of hyperkalaemia, compared to four episodes pre-protocol. Both residents and nurses provided positive feedback about time savings provided by the protocol, and overall satisfaction. Nurses also reported a significant in autonomy from pre- to post-protocol.
Todd et al. 2009	USA. Surgical ICU in a tertiary referral centre	To evaluate efficacy of a multidisciplinary electrolyte replacement protocol	Adult patients (N = 72) according to two groups: Pre-protocol (n = 21) Post-protocol (n = 51)	Retrospective cohort study	After implementation of the protocol, overall electrolyte replacement improved from 70% to 79% (p =.03), and its overall effectiveness increased from 50% to 65% (p =.01). After implementation, appropriate post replacement monitoring increased from 76% to 92% (p <.001), whereas its documentation improved from 89% to 95% (p =.04).

in the Todd et al. (2009) study from 79% pre-protocol to 92% (p 0.001) post protocol with similar improvements in documentation requirements from 89% pre-protocol to 95% (p 0.04) post protocol.

Critical care nurse acceptability and feasibility

Critical care nurse autonomy in managing electrolyte supplementation was described as promoting greater shared responsibility for patient care (Conley et al., 2021). In five studies, data were gathered from nurses to elicit their opinions on computerised potassium control (Hoekstra et al., 2010), as well as satisfaction with (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018), and acceptability of (Owen et al., 2008) potassium replacement protocols in the provision of critical care.

Hoekstra et al. (2010) used surveys to gather data about nurses' opinions on the potassium replacement protocol integrated into the previously established GRIP-II system. With a response rate of 60.1% (n = 76), the majority were in strong agreement that potassium control was

Table 4
Matrix of Acceptability to Critical Care Nurses.

Author/Year	Acceptability	Autonomy	Satisfaction	Timeliness	Usefulness
Abdelgawad et al 2020		x	x	x	x
Conley et al 2022		x			
Hoekstra et al 2010		x			
Kanji et al 2009		x	x	x	x
Owen et al 2008	x				
Pearson et al 2018		x	x	x	x

Table 5
Quality Appraisal.

Author/Year	Quality Appraisal (out of 11)	Critical Appraisal Comments
Abdelgawad et al 2020	8	Aims not clearly stated. Methodology not justified.
Conley et al 2022	9	Methodology not justified. No mention of if consent was obtained, or if a waiver was approved
Couture et al 2013	9	Methodology not justified. No mention of ethical approval or patient consent.
Hessels et al 2017	9	Methodology not justified. Literature review brief.
Hoekstra et al 2010	9	Aim of study only stated in abstract. Conclusion brief
Johnston et al 2017	9	Methodology not explicitly stated or justified.
Kanji et al 2009	10	No mention of ethical approval or patient consent.
Owen et al 2008	8	Purpose only stated in abstract. Methodology not described or justified.
Pearson et al 2018	9	Described as a quality improvement project, but no detail provided about steps to maintain patient anonymity. Purpose statement in abstract differs from the body of the paper.
Todd et al 2009	9	Ethics approval noted, but no potential ethical issues identified or addressed. No discernible conclusion.

important, the computerised protocol was simple to work with, and resulted in less frequent consultation with the attending physician. Nurse respondents also agreed that the computerised potassium replacement protocol was reliable and a good tool to regulate potassium with. Interestingly, given the GRIP-II system allowed for nurses to override system recommendations, the researchers reported that initially nurses complied with recommendations<20% of the time at commencement, but after five weeks, nurses followed system recommendations more than 95% of the time (Hoekstra et al., 2010).

In terms of nurse acceptability, Owen et al. (2008) surveyed nurse respondents and achieved a response rate of 55% (n = 36). Using a 9-point Likert scale, responses indicated nurses were in agreement that the protocol was easy to understand (median 5), suitable for use with most patients in the ICU (median 7), and promotes safe care of patients (median 7). Nurse respondents also indicated agreement (median 6), that the protocol improved their satisfaction with electrolyte management (median 6), and that they were comfortable administering doses as prescribed by the protocol (median 7) (Owen et al., 2008).

Three studies also sought to gather data on measures of satisfaction, such as usefulness, timeliness to replacement, overall satisfaction, and nurse autonomy (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018). Nurses' perceptions of the usefulness of the protocol to patient management were measured in three studies using a 5-point Likert scale, (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018). In the first, nurses scored the usefulness of the protocol at 4.7 out of 5 (mean ± SD 0.5, n = 27) (Kanji & Jung, 2009). In the second, scores for usefulness increased marginally from 4.7 (n = 60) pre- to 4.8 (n = 53) post-protocol implementation (Pearson et al., 2018). In the third study, whilst no data were collected pre-protocol implementation, nurses rated the electrolyte replacement protocol at 4.5 out of 5 (mean ± SD 0.7, n = 48) for usefulness in patient management and 4.4 out of 5 (mean ± SD 0.9, n = 48) for usefulness to nursing practice (Abdelgawad et al., 2020).

Nurse perceptions of timeliness to replacement were also measured in three studies (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018). Two studies measured timeliness using a 5-point Likert scale, with scores of 4.5 out of 5 (mean ± SD 0.8, n = 32) (Kanji & Jung, 2009) and 4.6 out of 5 (mean ± SD 0.7, n = 48) (Abdelgawad et al., 2020). By comparison, Pearson et al. (2018), reported a significant increase in satisfaction with timeliness from 2.6 to 4.5 out of 5 from pre- to post- protocol implementation ($p < .001$).

In the two studies that measured nurses' overall satisfaction with the potassium replacement protocol, scores reported were 4.4 out of 5 (mean ± SD 0.7, n = 32) (Kanji & Jung, 2009) and 4.3 out of 5 (mean ± SD 0.9, n = 48) (Abdelgawad et al., 2020). When comparing pre- and post-protocol, Pearson et al. (2018) reported a significant increase from 2.6 out of 5 (n = 60) pre-protocol to 4.8 out of 5 (n = 53) post-protocol implementation ($p < .001$). Pearson et al. (2018) also reported nurses' satisfaction with autonomy significantly increased from 1.6 to 4.9 out of 5 ($p < .001$) from pre- to post-protocol implementation (Pearson et al., 2018). An increase from 2.4 to 4.7 out of 5 for 'frequency of the need to see orders' is also significant ($p < .001$), similarly reflecting increased autonomous practice (Pearson et al., 2018). Likewise, Abdelgawad et al. (2020) reported a modest increase in nurse satisfaction with autonomy from 4.6 out of 5 (SD ± 0.6, n = 48) pre-protocol to 4.9 out of 5 (SD ± 0.3, n = 48) post-protocol implementation.

Autonomy was also measured by Kanji and Jung (2009) with respondents positively rating their autonomy to replace potassium as per the protocol at 4.8 out of 5 (mean ± SD 0.4, n = 32), and their satisfaction with the lack of need to seek orders for potassium replacement as 4.7 out of 5 (mean ± SD 0.7, n = 32). Two of the included studies similarly measured medical staff perceptions of nurse autonomy. In the study by Kanji and Jung (2009), physicians rated nursing autonomy as 4.8 out of 5 (mean ± SD 0.5, n = 4), and in the study by Abdelgawad et al. (2020), physicians rated nursing autonomy as 4.9 out of 5 (mean ± SD 0.3, n = 48).

Discussion

Protocols developed to enhance practice and patient outcomes have become commonplace within ICUs due to critically ill patients' increasing complexities and care requirements (Chang et al., 2012). This review identified that there is variation in how potassium replacement protocols are designed and intended to be used by critical care nurses. Although each protocol varied, so did the approach to their

development, according to the context and practices of the respective ICU. All potassium replacement protocols emphasised nurse autonomy in leading patient care, enhanced efficiency for all members of the treating team, and increased perceptions of acceptability. Ongoing organisational support for protocolised medication regimes such as these are essential to ensure protocol adherence and the ongoing provision of safe, high-quality evidence-based care (Abu-Baker et al., 2021; Dagne & Beshah, 2021).

When the design and development process is multidisciplinary and collaborative, protocols improve patient outcomes (Wall et al., 2001), increase patient safety (Kahol et al., 2011), reduce medical errors (Chang et al., 2012), and enhance routine clinical care (Holcomb et al., 2001; Meade & Ely, 2002). Protocol directed interventions contribute to highly efficient care and productive use of resources (Hijazi & Al-Ansari, 2005; Zimmerman et al., 2003). Importantly however, protocol driven care must also be underpinned by sound clinical judgement and expert decision making (Chang et al., 2012; Wall et al., 2001), with ICU nurses needing to possess a thorough knowledge of electrolyte homeostasis, the patient's clinical condition and responses to treatment and management (Kraft et al., 2005). Assessment, clinical judgement, and decision-making skills evolve over time through practice, experience, and continuous critical analysis (Kienle & Kiene, 2011); hence should be complemented by protocols (Meade & Ely, 2002) such as these, not replaced by them (Kraft et al., 2005). The use of protocols complemented by artificial intelligence and data driven computerised support systems were examined in two studies in this review (Hessels et al., 2015; Hoekstra et al., 2010). The computer support system demonstrated favourable reviews by critical care nurses and were designed to improve patient safety with features including medication labelling, administration instructions and the ability to override the potassium order based on clinical judgement (Hoekstra et al., 2010). Several studies included in this review demonstrated that critical care nurses rely on their expertise and clinical judgement in evaluating and replacing potassium as needed with further provisions allowed to override the protocol to meet the clinical needs of the patient.

Importantly, the findings from this review demonstrate that when critical care nurses are supported to use their understanding of the patient and their diagnosis, specialist knowledge, expertise, and autonomy to determine the suitability of a protocol for each patient case, increased nurse satisfaction resulted (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018). Importantly, protocol deviations should not be assumed to imply sub-optimal care. Rather when, there is a clinically justified reason, a protocol deviation that is accurately documented in the patient's medical record should be seen as demonstrative of a critical care nurse utilising their clinical judgment, expertise and specialist skills (Kahol et al., 2011). This study further demonstrated that protocols allowed for autonomous practice (Abdelgawad et al., 2020; Kanji & Jung, 2009; Pearson et al., 2018) within a critical care nurses' scope enhancing job satisfaction and a positive work environment.

Strengths and limitations

The focus of this review was not to measure potassium control or patient outcomes related to the repletion of potassium but to explore how nursing practice is influenced by the use of potassium replacement protocols. The strengths of this review included; blinded screening and quality appraisal by two independent researchers. Two researchers completed data extraction. The main limitation of this review was that we did not include the measurement of the efficacy of potassium replacement protocols or patient outcomes, which should be a concurrent consideration in further research. Although this review was founded on the comprehensive search of two databases, it is possible that some research evidence may have been missed. Articles not published in English were excluded potentially leading to a language bias.

Conclusion

This is the first review to date that has synthesised the research evidence on the use of potassium replacement protocols in adult critical care, and how a critical care nurses' role and practice are influenced by protocol use. Protocolised medications that are based on evidence support nurses in their clinical judgement and expert decision making improving the delivery of high-quality safe care with findings from this review demonstrating that protocol use increased nursing efficiency, autonomy, and satisfaction.

Recommendations

Protocol development should be underpinned by a clear rationale, be inclusive of all disciplines involved in patient care, and include provision for deviation from the recommendation according to individual patient circumstances and assessment. Further research is needed on ways to improve the design and development of medication protocols, and to understand the rationale underpinning protocol deviations, so that critical care nurses are supported in the delivery of high-quality safe care that is underpinned by critical judgement and decision making. Developing an understanding of how protocols can be complemented by data driven support tools should be a consideration within future research. An examination of relationships between protocol design, protocol efficacy and patient outcomes is also warranted, to further support critical care nurses' clinical decision making, autonomy, and efficiency in practice. Given critical care nurses are central to protocolised practices, such as potassium replacement protocols described in this paper, the inclusion of critical care nurses in future research studies is fundamental for influencing change in protocols.

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CRediT authorship contribution statement

Kylie O'Neill: Conceptualization, Methodology, Search conduct, Screening and quality appraisal, Data Extraction and Synthesis, Leading manuscript development. **Melissa J Bloomer:** Conceptualization, Methodology, Screening and quality appraisal, Data Checking, Synthesis, Manuscript Development.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iccn.2023.103524.

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