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Stepped-Wedge Trial of Decision Support for Acute Kidney Injury on Surgical Units

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Introduction: Acute kidney injury (AKI) is common in the perioperative setting and associated with poor outcomes. Whether clinical decision support improves early management and outcomes of AKI on surgical units is uncertain.

Methods: In this cluster-randomized, stepped-wedge trial, 8 surgical units in Alberta, Canada were randomized to various start dates to receive an education and clinical decision support intervention for recognition and early management of AKI. Eligible patients were aged ≥18 years, receiving care on a surgical unit, not already receiving dialysis, and with AKI.

Results: There were 2135 admissions of 2038 patients who met the inclusion criteria; mean (SD) age was 64.3 (16.2) years, and 885 (41.4%) were females. The proportion of patients who experienced the composite primary outcome of progression of AKI to a higher stage, receipt of dialysis, or death was 16.0% (178 events/1113 admissions) in the intervention group; and 17.5% (179 events/1022 admissions) in the control group (time-adjusted odds ratio, 0.76; 95% confidence interval [CI], 0.53–1.08; $P = 0.12$). There were no significant differences between groups in process of care outcomes within 48 hours of AKI onset, including administration of i.v. fluids, or withdrawal of medications affecting kidney function. Both groups experienced similar lengths of stay in hospital after AKI and change in estimated glomerular filtration rate (eGFR) at 3 months.

Conclusion: An education and clinical decision support intervention did not significantly improve processes of care or reduce progression of AKI, length of hospital stays, or recovery of kidney function in patients with AKI on surgical units.

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AKI is common among hospitalized patients, particularly after major surgery where the incidence ranges from approximately 10% to 30%, depending on the type of surgery.[1–3] AKI has been associated with increased length of hospitalization, greater costs of care, short-term and long-term mortality,[4–6] as well as the development of and progression to chronic kidney disease, and kidney failure.[7–9] Clinical practice guidelines for AKI have been available since 2012;[10] however, translation of knowledge about AKI identification and management across care settings has been limited.[2,11,12] Gaps in recognition and timely response to AKI are reported to occur frequently,[13–16] including in perioperative care.[2,11,17]

To improve recognition and responses, AKI alert systems have been implemented in several health systems;[18,19] however, randomized trials evaluating their impact on health outcomes have demonstrated limited efficacy.[15,16,20] Limitations of previous trials include very broad inclusion criteria that have included patients with AKI from heterogenous clinical settings and causes, which have made standardized recommendations challenging to implement within these trials. Furthermore, few previous trials of AKI alerts have

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included links to point-of-care clinical decision support providing clear guidance for management of AKI, limiting the potential of these interventions to improve care and outcomes.[21,22]

We implemented clinical decision support tools that linked recognition with management guidance for AKI[23] in the perioperative setting, accompanied by an education program, and evaluated these tools on surgical units in Alberta, Canada. We evaluated the effect of this intervention on processes of care for AKI, the primary outcome of progression of AKI, and secondary outcomes of days in hospital and kidney function at discharge and at 90 days post-AKI.

METHODS

Study Design

The SUPPORT AKI (Strategy for Uptake of Processes for Recognizing and Responding To AKI) trial was a pragmatic, stepped-wedge cluster randomized trial that randomly assigned hospital general or vascular surgery units in Alberta, Canada to 1 of 8 start dates between March 2018 and September 2019 for a multifaceted AKI decision support intervention. Each unit contributed data before receiving the intervention for a period ranging from 9 to 75 weeks, with continued data collection ranging from 9 to 75 weeks after introduction to the intervention, such that by the end of the trial all units had been exposed to the intervention. Detailed methods are provided in the Trial Protocol (Supplementary Figures S1–S5, Supplementary References[S1–S20]). The study was approved by the Health Research Ethics Boards of the Universities of Alberta and Calgary, which granted a waiver of patient consent because the intervention was directed at physicians, promoted evidence-based practices, and the risk to patients was low. The study was conducted and reported in accordance with the extension to the CONSORT statement for stepped-wedge cluster randomized trials.[24]

Participants

General and vascular surgery units from 4 hospitals in the 2 major cities (Edmonton and Calgary Zones) in Alberta were selected to participate. For each unit, all Alberta residents were included in the trial if they were aged ≥18 years at the time of hospital admission and developed stage 1 or greater AKI according to the NHS England AKI patient safety alert serum creatinine criteria during their hospital stay.[18] Patients receiving dialysis were excluded from receiving alerts, and from the study.

Intervention

The intervention was comprised of unit-level organizational planning, health care provider education, and decision support components. First, meetings were held with staff, including managers, nurses, and pharmacists from each unit, to develop a systematic process with specific roles and responsibilities for who would identify patients with an AKI alert on each unit and communicate it to a responsible physician. Second, unit staff and surgery residents rotating on the participating units received an educational session about AKI recognition, management, and orientation to the decision support tools available at each center for AKI recognition and management. Education was provided to residents at the start of rotations on a unit and at academic half day, and the education to unit staff was provided immediately prior to the period they started to receive the intervention. Training material and links to the provincial knowledge topic on AKI were provided. Third, nurses, pharmacists, and physicians received an AKI clinical decision support intervention, which included electronic AKI alerts according to the NHS England AKI patient safety alert algorithm,[18] identification of currently prescribed medication that may affect kidney function, and an AKI order set for AKI management. At the time of the study, the 4 participating units from the Calgary Zone used a common electronic medical record (EMR; Sunrise Clinical Manager, Allscripts Inc), which was used to deliver the AKI alerts linked to identification of medications that may affect kidney function and an electronic version of the AKI order set,[23] as previously described.[23] The 4 participating units from the Edmonton Zone did not use an EMR system at the time of the study, and received AKI alerts through a separate Tableau (Tableau Software, Seattle, WA, 2018) reporting system that generated a daily list of patients on each unit who had met criteria for AKI in the last 48 hours, and a paper AKI order set that was added to the hospital chart of patients identified with AKI that provided guidance on monitoring and management, including i.v. fluid management and review of medications that may affect kidney function.

Outcome Measures

The primary outcome was progression of AKI during the index hospitalization, defined as an increase in AKI stage based on the Kidney Disease: Improving Global Outcomes serum creatinine staging criteria, initiation of acute dialysis, or death.[25] Prespecified process of care outcomes were obtained from hospital medical records and included investigations for AKI with urinalysis, kidney ureter bladder ultrasound, and consultation with internal medicine or nephrology during hospital admission; as well as therapeutic responses within 48 hours of AKI onset, including a composite of i.v. fluid administration, discontinuation of a diuretic medication, or discontinuation of another medication that may

affect kidney function (including nonsteroidal antiinflammatory, angiotensin-converting enzyme inhibitor, angiotensin receptor blocker, calcineurin inhibitor, antifungal, or aminoglycoside antibiotic). Prespecified secondary clinical outcomes were obtained from hospital medical records and provincial hospital, or laboratory data sources and included progression to Kidney Disease: Improving Global Outcomes stage 2 or 3 AKI based on serum creatinine criteria, acute dialysis, death, days in hospital following AKI onset, and change in eGFR 3 months after AKI. In addition, we evaluated a *post hoc* secondary outcome of recovery of kidney function, defined as a return of serum creatinine before hospital discharge to within 1.2-fold of the baseline value or within 0.3 mg/dl of baseline for patients with stage 1 AKI based only on the absolute serum creatinine increase criteria.[26] Previously validated ICD-10-CA/Canadian classification of intervention coding algorithms were applied to Alberta Health Services databases to identify acute dialysis.[25,27] Implementation outcomes included the frequency of use of the AKI order set among patients in the intervention group, ascertained for all patients from the units that used an EMR (Calgary Zone), and by chart review for a 40% random sample of patients from the units that used paper charts (Edmonton Zone).

Randomization and Start Date Concealment

Surgical units were randomized to 1 of 8 start dates by an independent statistician, with randomization stratified by health zone (Edmonton vs. Calgary). The start-date assignment was concealed from physicians and other members of the research team until the month before their scheduled introduction date to allow sufficient time to plan the education sessions at the initiation of the intervention. Given the nature of the intervention, blinding of the physicians, hospital unit staff, and members of the research team was not possible.

Statistical Analysis

Based on an anticipated 30% incidence of progression of AKI, with an intracluster correlation between units of 0.010, and projection that 1206 patients would develop AKI on the participating hospital units over a 23-month duration of the trial, we estimated 80% power to detect a 30% relative reduction in the primary outcome of AKI progression, at an alpha level of 0.05, using the 8 units randomly assigned to 8 start dates.[28,29]

Analyses compared outcomes of patients on units who were receiving the intervention at the time they developed AKI (intervention group) versus those on units not yet receiving the intervention (control group) and were performed according to the intention-to-treat approach (Supplementary statistical analysis plan, Supplementary Table S1). Multilevel logistic regression was used to estimate odds ratios and 95% CIs for categorical outcomes; and mixed effects linear regression was used to estimate differences for continuous outcomes, with random effects for surgical unit and patient (to account for clustering by unit and repeat admissions for the same patient), and fixed effects for calendar time (by month to adjust for secular trends).[24] Multivariable-adjusted analyses were performed for each outcome that included further adjustment for prespecified variables of patient age, biologic sex assigned at birth, diabetes mellitus, heart failure, baseline eGFR, and type of surgery as fixed effects. Effects on the primary outcome and the composite therapeutic response process of care outcome were examined in prespecified subgroup analyses according to whether patients were from the units that implemented the decision support intervention in an EMR versus units that used the paper-based order set for decision support. Modification of the treatment effect by time was tested by including an interaction term between treatment and month in the time-adjusted models.

RESULTS

Study Population

A total of 2135 admissions with AKI from 2064 patients occurred on the participating surgical units during the trial (Figure 1). The numbers of patients with AKI on each unit ranged from 29 to 230 across the 8 participating surgery units in the control period, and from 26 to 232 during in the intervention period. There were small differences in age and some surgery types between the intervention and control groups; however, no differences in other patient demographic characteristics, comorbidities, baseline eGFR, or AKI stage at onset of AKI were observed between the groups (Table 1).

Primary Composite Outcome: Progression of AKI

Over the 21-month duration of the trial, 178 of 1113 patients (16.0%) with AKI admitted on units receiving the intervention had progression of AKI, as compared with 179 of 1022 patients (17.5%) with AKI admitted on units in the control period (Table 2). In the primary analysis accounting for clustering and adjusted for time, the intervention resulted in no significant difference in the odds of AKI progression (time-adjusted odds ratio, 0.75; 95% CI: 0.53–1.07; $P = 0.11$). Results were similar in multivariable analyses further adjusting for age, sex, diabetes mellitus, heart failure, baseline eGFR, and type of surgery (adjusted odds ratio 0.76;

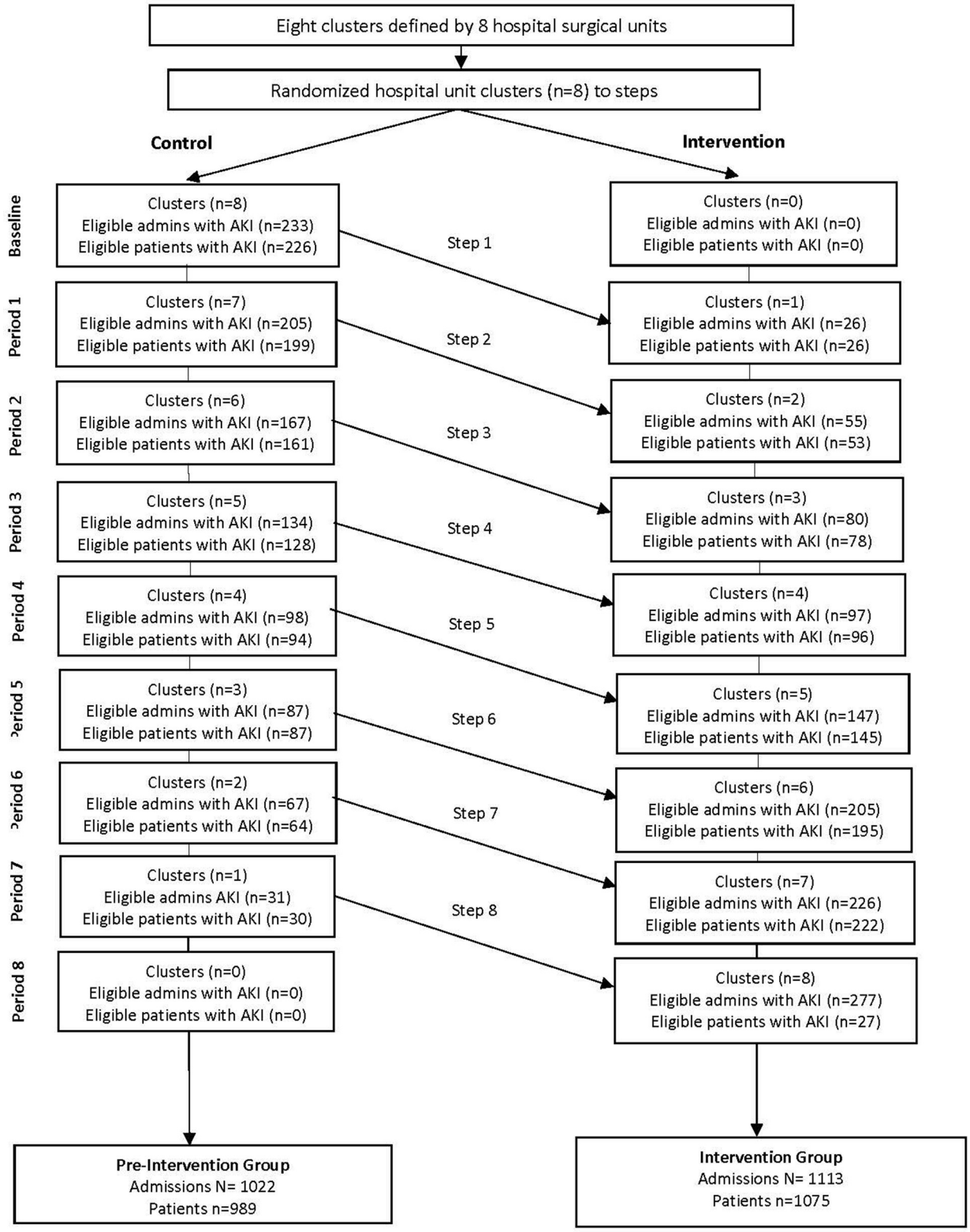

Figure 1. Cohort formation. AKI, Acute kidney injury.

95% CI: 0.53–1.08; $P = 0.12$). There was no evidence of effect modification according to care on units that implemented the decision support intervention in an EMR versus those that used the paper-based order set for decision support (interaction term P-value = 0.46; Figure 2). There was no evidence of effect modification by time (interaction term between exposure to intervention and month; P-value = 0.78).

Secondary Clinical Outcomes

The number of days patients were in hospital following AKI were not significantly different in the intervention

Table 1. Baseline characteristics

Variable	Intervention (N = 1113 admissions)	Control (N = 1022 admissions)
Number of patients	1075	989
Age, mean (SD)	65.1 (15.2)	63.5 (17.2)
Sex, *n* (%)		
Female	446 (40.1)	439 (43.0)
Male	667 (60.0)	583 (57.0)
Surgery type, *n* (%)		
Anorectal	44 (4.0)	34 (3.3)
Breast	2 (0.2)	1 (0.1)
Cardiac	65 (5.8)	38 (3.7)
Head and neck	35 (3.2)	32 (3.2)
Intra-abdominal	408 (36.7)	345 (33.8)
Musculoskeletal (MSK)	175 (15.7)	180 (17.6)
Neurosurgery	7 (0.6)	11 (1.1)
Ophthalmologic	2 (0.2)	1 (0.1)
Retroperitoneal	33 (3.0)	33 (3.2)
Skin and soft tissue	73 (6.6)	106 (10.4)
Thoracic	15 (1.4)	17 (1.7)
Lower urologic/gynecological	21 (1.9)	22 (2.3)
Vascular	234 (21.0)	202 (19.8)
Comorbidities, *n* (%)		
Alcohol misuse	46 (4.1)	30 (2.9)
Atrial fibrillation	29 (2.6)	18 (1.8)
Cancer, lymphoma	8 (0.7)	5 (0.5)
Cancer, nonmetastatic	109 (9.8)	69 (6.8)
Chronic pain	15 (1.4)	11 (1.1)
Chronic pulmonary disease	41 (3.7)	40 (3.9)
Cirrhosis	21 (1.9)	18 (1.8)
Congestive heart failure	63 (5.7)	88 (8.6)
Connective tissue disease-rheumatic disease	3 (0.3)	8 (0.8)
Dementia	17 (1.5)	32 (3.1)
Diabetes	320 (28.8)	316 (30.9)
Epilepsy	5 (0.4)	6 (0.6)
Hepatic disease	112 (10.1)	104 (10.2)
Hypertension	234 (21.0)	261 (25.5)
Inflammatory bowel disease	19 (1.7)	25 (2.4)
Metastatic carcinoma	114 (10.2)	88 (8.6)
Multiple sclerosis	4 (0.4)	4 (0.4)
Myocardial infarction	42 (3.8)	32 (3.1)
Parkinson's disease	6 (0.5)	5 (0.5)
Peptic ulcer disease	11 (1.0)	8 (0.8)
Peripheral vascular disease	56 (5.0)	40 (3.9)
Severe constipation	55 (4.9)	65 (6.4)
Stroke or TIA	8 (0.7)	15 (1.5)
Laboratory variables		
Baseline Serum creatinine, median (IQR) mg/dl	1.0 (0.7–1.4)	1.0 (0.7–124)
Baseline eGFR[a], mean (SD), ml/min per 1.73 m^2	70 (34)	70 (35)
Baseline eGFR[a] categories, *n* (%), ml/min per 1.73 m^2		
≥60	691 (62.1)	609 (59.6)
45–59	151 (13.6)	154 (15.1)
30–44	118 (10.6)	96 (9.4)
15–29	75 (6.7)	75 (7.3)
<15	78 (7.0)	88 (8.6)
KDIGO Stage[b] at AKI Onset, *n* (%) 3		
Stage 1	780 (70.1)	691 (67.6)
Stage 2	164 (14.7)	178 (17.4)
Stage 3	169 (15.2)	153 (15.0)
Hospital Record Systems, *n* (%)		
Paper-based charting	555 (49.9)	582 (57.0)
Electronic medical record	558 (50.1)	440 (43.0)

AKI, acute kidney injury; CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; IQR, interquartile range; KDIGO, Kidney Disease: Improving Global Outcomes; TIA, transient ischemic attack.
[a]Calculated using the 2009 CKD epidemiology collaboration equation.
[b]Based on serum creatinine criteria.

and control groups (median [interquartile range] 7 [3–17] vs. 8 [3–19] days, respectively; mean log difference, -0.2; 95% CI: -1.6 to 1.5) (Table 3) and there were no significant differences between the groups in recovery of kidney function by time of discharge (73.3% vs. 70.9%, respectively; time-adjusted odds ratio 1.12 [95% CI: 0.84–1.49]), or change in kidney function at 3 months after AKI onset (mean difference in change in eGFR -0.3 [95% CI: -3.6 to 2.9] ml/min per 1.73 m^2). There were no significant differences between the intervention and control groups in any of the individual components of the primary composite outcome, including progression to Kidney Disease: Improving Global Outcomes stage 2 or 3 AKI based on serum creatinine changes (10.9% vs. 12.3%; time-adjusted odds ratio, 0.90; 95% CI: 0.57–1.42), acute dialysis (8.4 vs. 9.5%; time-adjusted odds ratio 0.86 [95% CI: 0.53–1.39]), or death (7.4% and 7.7%; time-adjusted odds ratio, 0.76 [95% CI: 0.47–1.24]).

Process of Care Outcomes

No significant differences between the intervention and control groups were observed for the frequency of investigation with a urinalysis (57.3 vs. 58.7%; time-adjusted odds ratio 0.96 [95% CI: 0.70–1.30]), kidney ureter bladder ultrasound (16.9 vs. 20.9%; time-adjusted odds ratio 0.76 [95% CI: 0.52–1.11]), or consultation with nephrology or internal medicine specialist (13.8 vs. 15.1%; time-adjusted odds ratio 0.76 [95% CI: 0.53–1.10]) (Table 4). There was no significant difference between the intervention and control group in the percentage of patients who received a therapeutic response for AKI within 48 hours of onset (35.2 vs. 40.0%; time-adjusted odds ratio 0.89 [95% CI: 0.67–1.18]), including i.v. fluid administration, discontinuation of a diuretic, or discontinuation of medication that may affect kidney function. This effect on the composite outcome of a therapeutic response was not modified by whether patients were from units that implemented the decision support intervention in an EMR versus those that used the paper-based order set for decision support (P-interaction = 0.47, Figure 2).

Table 2. Effect of intervention on the primary and secondary clinical outcomes

Outcomes	Intervention	Control	Time-adjusted model			Multivariable-adjusted model[a]		
	n/total *N* procedures (%)	*n*/Total *N* procedures (%)	Odds ratio (95% CI)	*P*-value	ICC	Odds ratio (95% CI)	*P*-value	ICC
Primary outcome								
Progression of AKI[b]	178/1113 (16.0)	179/1022 (17.5)	0.75 (0.53–1.07)	0.11	0.013	0.76 (0.53–1.08)	0.12	0.007
Secondary outcomes								
Stage 2 or 3 KDIGO AKI[c]	111/1019 (10.9)	115/936 (12.3)	0.90 (0.57–1.42)	0.65	0.054	0.94 (0.59–1.49)	0.80	0.049
Acute dialysis	94/1113 (8.4)	97/1022 (9.5)	0.86 (0.53–1.39)	0.53	0.056	0.93 (0.57–1.52)	0.77	0.050
Death	82/1113 (7.4)	79/1022 (7.7)	0.76 (0.47–1.24)	0.28	0.017	0.74 (0.45–1.23)	0.25	NR
Recovery of kidney function[d]	816/1113 (73.3)	725/1022 (70.9)	1.12 (0.84–1.49)	0.43	0.002	1.15 (0.86–1.54)	0.36	0.006

AKI, Acute Kidney Injury; CI, confidence interval; eGFR, estimated glomerular filtration rate; ICC, intraclass correlation coefficient (ICC could not be estimated); IQR, interquartile range; KDIGO, Kidney Disease: Improving Global Outcomes; NR, not reported.
[a]Multivariable models included adjustment for time, age, sex, diabetes mellitus, heart failure, baseline eGFR, and type of surgery.
[b]Defined as progression to a higher serum creatinine-based KDIGO AKI stage, receipt of dialysis, or death.
[c]Excludes patients meeting stage 3 KDIGO AKI serum creatinine criteria at onset.
[d]Recovery of kidney function was defined as a return of serum creatinine before hospital discharge to within 1.2-fold of the baseline value or within 0.3 mg/dl of baseline for patients with stage 1 AKI based only on the absolute serum creatinine increase criteria.

Implementation Outcomes

Among the 558 patients in the intervention group from the units using an EMR, the AKI order set was used for 243 patients (43.5%). Among 242 patients (43.6%) in the intervention group randomly selected for manual chart review from the centers using paper charts, use of the AKI order set was identified in the chart for 34 patients (14.0%).

DISCUSSION

This multifaceted intervention, which included education and clinical decision support designed to improve the recognition and initial management of patients with AKI hospitalized on surgery units, resulted in no effect on investigation or management of AKI with i.v. fluids, or alternation of medications that may affect kidney function. This intervention, in turn, had no effect on the progression of AKI based on increase in serum creatinine, treatment with acute dialysis, or death, a finding that was consistent across units that implemented decision support tools using an EMR system or paper-based tools. There was no difference observed in the frequency of recovery of kidney function and the number of days patients were in hospital after AKI onset, and no significant differences in eGFR at 3 months with or without the intervention.

Previous trials in hospitalized patients have examined the effects of AKI alerts and decision support on processes of care and outcomes. Selby *et al.*[15] reported that a multifaceted intervention, including AKI alerts, an AKI care bundle, and an education program implemented within a stepped-wedge trial delivered to all hospitalized patients at 5 sites in the United Kingdom had no effect on the primary outcome of 30-day mortality, or the prespecified secondary outcome of progression of AKI stage, including receipt of acute kidney replacement therapy; however, hospital length of stay was reduced during the intervention period among patients with a length of stay greater than the median of 9 days.[15] Analysis of process of care measures among a subgroup of patients from this study identified increased documentation of measures promoted by the

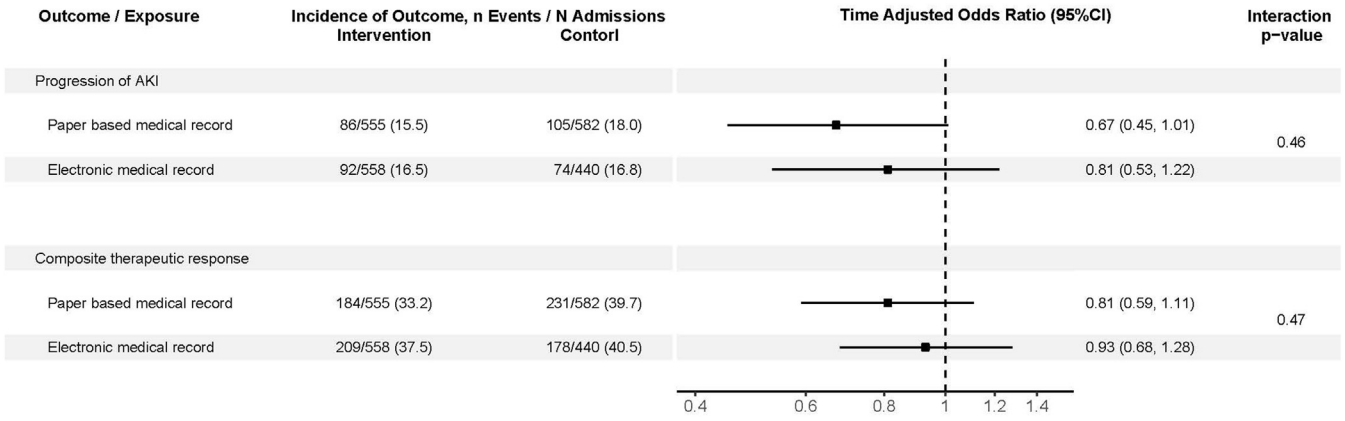

Figure 2. Subgroup analyses for effect of the intervention on the primary outcome of AKI progression and the composite process of care outcome. AKI, Acute kidney injury.

Table 3. Effect of intervention on time in hospital and eGFR 3 months after discharge

Outcomes	Intervention[a] ($N = 1113$ admissions)	Control[a] ($N = 1022$ admissions)	Time-adjusted model			Multivariable-adjusted model[b]		
			Mean difference (95% CI)	*P*-value	ICC	Mean difference (95% CI)	*P*-value	ICC
Time in hospital following AKI[c], d	7 (3–17)	8 (3–19)	-0.2 (-1.6 to 1.5)	0.81	0.011	0.1 (-2.2 to 2.78)	0.96	0.012
Change in eGFR[d], ml/min per 1.73 m^2	-1.3 (21.5)	-0.8 (22.9)	-0.3 (-3.6 to 2.9)	0.85	0.011	-0.2 (-3.4 to 2.9)	0.88	0.007

eGFR, estimated glomerular filtration rate; ICC, Intraclass correlation coefficient.
[a]Values are median (interquartile range) days for time in hospital and mean (standard deviation) for change in eGFR.
[b]Multi-variable models included adjustment for time, age, sex, diabetes mellitus, heart failure, baseline eGFR, and type of surgery.
[c]Values represent median (IQR) number of days in hospital after AKI onset in intervention and control groups. Time- and multivariable-adjusted models report the mean difference in log-transformed number of days in hospital for the intervention versus control groups.
[d]Values represent mean (SD) change in eGFR from pre-AKI baseline to 3 months post-AKI. Time and multi-variable adjusted models report the mean difference in change in eGFR for the intervention versus control groups.

care bundle, including AKI recognition, urinalysis, medication review, and fluid assessment despite the limited effects on clinical outcomes. Wilson *et al.*[16] tested an EMR-based AKI alert with an associated AKI order set in a patient-level randomized trial including all adult inpatients from 6 hospitals in the United States.[16] In addition, this intervention had no effect on the composite primary outcome of progression of AKI, receipt of acute dialysis, or death; with only small absolute increases observed in process of care outcome for documentation of AKI in the problem list, urinalysis, or i.v. fluid orders; and no effect on nephrotoxic medication use. In a subsequent trial by the same group, a randomized trial of a decision support intervention specifically targeted at medication-associated AKI[30] demonstrated a modest effect on discontinuation of medications of interest, but no effect on the primary outcomes of progression of AKI, dialysis, or death. Our cluster randomized stepped-wedge trial builds upon these studies findings by evaluating a similar intervention incorporating education with point-of-care decision support for AKI restricted to a hospital surgical care setting. In our trial, the intervention did not significantly change measurable processes of care or relevant clinical outcomes of AKI.

Our trial was designed to focus on care on surgical units based on previous consultation with stakeholders that suggested this setting would be well-suited to a quality improvement intervention to improve AKI recognition and management due to barriers in knowledge, attitudes, and behaviors that were prevalent because of competing demands on health care providers working in perioperative care.[2] This education and informatics intervention was felt to be appropriately tailored to the clinical setting because it was perceived to be relevant to hemodynamic, volume status, and medication effects that are more uniform contributors to AKI in perioperative settings than AKI that occurs from a variety of causes in other medical settings and which often require distinct approaches to investigation and treatment.[31,32] However, we found that implementing education and point-of-care clinical decision support was ineffective in changing the practices of surgical care providers in our setting and that despite standardizing processes for recognition of patients with AKI on these units, there was limited uptake of order sets provided to support clinical actions. Education interventions often have limited effects in group settings, which may have limited the effectiveness of the intervention in our study because

Table 4. Effect of intervention on processes of care

Outcomes	Intervention	Control	Time-adjusted model			Multivariable-adjusted model[a]		
	n/total *N* Procedures (%)	*n*/total *N* Procedures (%)	Odds Ratio (95% CI)	*P*-value	ICC	Odds Ratio (95% CI)	*P*-value	ICC
Urinalysis	638/1113 (57.3)	600/1022 (58.7)	0.96 (0.70–1.30)	0.77	0.228	0.97 (0.70–1.33)	0.85	0.244
Ultrasound KUB	188/1113 (16.9)	214/1022 (20.9)	0.76 (0.52–1.11)	0.15	0.133	0.75 (0.52–1.10)	0.14	0.118
Consultation (nephrology or IM)	153/1113 (13.8)	154/1022 (15.1)	0.76 (0.53–1.10)	0.13	NR	0.83 (0.58–1.21)	0.34	NR
Composite therapeutic response	392/1113 (35.2)	409/1022 (40.0)	0.89 (0.67–1.18)	0.26	0.022	0.88 (0.66–1.17)	0.24	0.023
i.v. fluid administration	274/1113 (24.6)	298/1022 (29.2)	0.88 (0.65–1.19)	0.29	0.049	0.86 (0.63–1.67)	0.32	0.070
Discontinuation of a diuretic[b]	37/186 (19.9)	20/117 (17.1)	1.53 (0.58–3.94)	0.39	0.043	1.50 (0.54–4.13)	0.43	0.078
Discontinuation of a medication[c] affecting kidney function	74/241 (30.7)	36/133 (27.1)	1.62 (0.70–3.72)	0.26	0.205	1.44 (0.61–3.42)	0.40	0.208

AKI, acute kidney injury; CI, confidence interval; eGFR, estimated glomerular filtration rate; ICC, intraclass correlation coefficient (ICC could not be estimated); IM, internal medicine; KUB, kidney ureter bladder; NR, not reported.
[a]Multivariable models included adjustment for time, age, sex, diabetes mellitus, heart failure, baseline eGFR, and type of surgery.
[b]Eligible patients were those on a diuretic at the time of AKI onset.
[c]Eligible patients were those on a medication affecting kidney function at the time of AKI onset, which included a nonsteroidal antiinflammatory, angiotensin-converting enzyme inhibitor, angiotensin receptor blocker, calcineurin inhibitor, antifungal, or aminoglycoside antibiotic.

we attempted to deliver education to large groups of nurses, pharmacists, and surgery residents who were the front-line care providers for the target population in our hospitals.[33,34] Clinical decision support has been shown to have positive effects on process of care for other clinical conditions, particularly when implemented with automatic provision within routine clinical workflow, at the time and location of decision making, when information is provided in a manner that is actionable, and with use of computer-based tools that include documentation of action.[21,35] Our decision support may have been less effective because alerts with decision support were implemented without requirements for documentation of responses, the unit processes developed incorporated providers who checked alerts separately from the physician using the order sets for tests and medications, and there was daily change over in care providers on many of the units, which made integrating the decision support within decision-making workflow challenging. Half of the units did not have a computer-based EMR within which to implement the decision support and relied on paper-based tools to deliver decision support. This approach appeared to be less effective with less use of the AKI order set, although we did not find that the intervention had more positive effects on processes of care on the units with EMRs than on those with paper-based systems. It is also possible that a lack of audit and reporting to providers and leadership accompanying this intervention may have reduced accountability and motivation to change. Further surveys and interviews with health care providers from these units will explore which of these or other explanations underlie the lack of intended behavior changes by health care providers in our study. The findings from our study can help inform the design of future interventions that might have greater effectiveness on processes of care for AKI in perioperative as well as other clinical contexts.

The strengths of this study include the guideline-based and stakeholder-informed development of the intervention, pragmatic design of the intervention and its implementation, and evaluation using processes of care as well as clinical outcomes. The study has several limitations. We used a cluster randomized trial design to reduce bias; however, the stepped-wedge design may have been vulnerable to contamination due to physicians-in-training moving between rotations on wards that were already receiving the intervention to those in the preintervention phase waiting to crossover, thereby changing care processes on these units before the date they were intended to receive the full intervention. Although this could have attenuated the effect of the intervention measured by the trial, we did not detect effect modification by time to confirm such a contamination effect. Furthermore, the incidence of the primary outcome of the trial was lower than anticipated from our historical data, which may be due to detection of less progressive or severe forms of AKI or better management of AKI during the more recent era of the trial. This reduced the power of the trial and prevented us from detecting a potentially smaller difference in the incidence of progression of AKI to a higher stage, dialysis, or death, than we designed the trial to detect.

In conclusion, we found that an intervention combining education and clinical decision support designed to improve the initial recognition and management of AKI on surgical units did not result in significant improvements in processes of care or outcomes for AKI. Our findings are relevant to decision makers considering strategies to improve the quality of perioperative care.

DISCLOSURE

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DATA AVAILABILITY STATEMENT

Data cannot be made available to other researchers due to contractual arrangements with Alberta government agencies who are the data custodians. Information on how researchers may make requests to obtain a representative dataset from these custodians may be obtained from https://absporu.ca/research-services/. Study protocols, training materials, and educational resources are available from the authors upon request.

AUTHOR CONTRIBUTIONS

MTJ and ZT had full access to the data and took responsibility for the integrity of the data and accuracy of the analysis. MTJ, ED, and NP came up with the study concept, designed and supervised the study, secured funding, and developed the study protocol. MTJ, ZT, and NP gathered

and verified the data. MTJ and ZT analyzed and interpreted the data. ZT did the statistical analyses. MTJ and NP drafted the report. All authors revised the report. MTJ, and NP provided administrative, technical, and material support. This study is based in part on data provided by Alberta Health Services. The interpretation and conclusions contained herein are those of the researchers and do not necessarily represent the views of Alberta Health Services. Alberta Health Services does not express any opinion in relation to this study.

SUPPLEMENTARY MATERIAL

Supplementary File (PDF)

Supplemental References.

Figure S1. Cluster randomized, stepped-wedge trial design.

Figure S2. Acute kidney injury stage alert from the Calgary Zone electronic medical record.

Figure S3. Acute kidney injury dashboard from the Calgary Zone electronic medical record.

Figure S4. Acute kidney injury order set from the Calgary Zone electronic medical record.

Figure S5. NHS England Patient Safety Alert algorithm of acute kidney injury Identification.

Table S1. Surgical categories by Canadian Classification of Health Intervention (CCI) codes using ICD-10-CA from hospitalization data.

Stepped-Wedge Cluster Randomized Trial CONSORT Extension Reporting Checklist.

Trial Protocol.

Trial Statistical Analysis Plan.

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