

Implementation of an integrated blood-warming pathway during continuous renal replacement therapy: a pre-post quality-improvement study

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Abstract

Background

Inadvertent hypothermia is common during continuous renal replacement therapy (CRRT) and reflects both extracorporeal heat loss and variation in warming and surveillance practices. We evaluated a standardized blood-warming and nursing-surveillance pathway in a mixed adult intensive care service.

Methods

This single-center, uncontrolled pre–post quality-improvement study compared a retrospective preimplementation service audit (1 February–30 April 2026) with a prospective implementation-period cohort (1 May–31 July 2026) in a 22-bed adult intensive care service in Saudi Arabia. The pathway specified a CRRT platform with integrated blood warming, temperature assessment at least every 4 h, escalation below 36°C, competency-focused nurse education, and recurrent audit-feedback. The primary outcome was the proportion of patients with at least one documented temperature < 36°C during CRRT; temperature < 35°C was a secondary outcome. We calculated exact binomial 95% confidence intervals (CIs), Newcombe–Wilson risk differences, unadjusted risk ratios, and two-sided Fisher exact P values.

Results

Seventy unique patients were included before implementation and 80 unique patients, representing 80 distinct CRRT-treated admissions, during implementation. Temperature < 36°C occurred in 49/70 patients (70.0%; 95% CI, 57.9%–80.4%) before implementation and 5/80 (6.3%; 95% CI, 2.1%–14.0%) during implementation (risk difference, – 63.8 percentage points; 95% CI, – 73.9 to – 50.0; risk ratio, 0.09; 95% CI, 0.04–0.21; $P < 0.001$). Temperature < 35°C occurred in 16/70 patients (22.9%; 95% CI, 13.7%–34.4%) and 0/80 (0%; 95% CI, 0%–4.5%), respectively ($P < 0.001$). All five implementation-period events were mild. No bleeding complication or circuit-clotting event was reported in the project log.

Conclusions

The pathway was associated with substantially less documented hypothermia and no recorded moderate or severe episode during implementation. Because patient-level case mix, CRRT exposure, temperature-measurement route, and component-level fidelity data were unavailable, the findings should be interpreted as a local quality-improvement association rather than proof of causal efficacy.

Trial registration

Not applicable. This was a servicelevel qualityimprovement initiative rather than a clinical trial, and patients were not assigned to alternative interventions for research purposes.

Background

Continuous renal replacement therapy (CRRT) is an established form of kidney support for critically ill adults with acute kidney injury, fluid overload, or severe metabolic disturbance when continuous treatment is preferred [1]. Prolonged extracorporeal circulation can expose blood and treatment fluids to ambient conditions, creating ongoing heat loss alongside other therapy-related risks [2].

Hypothermia in critically ill adults is associated with worse outcomes, although it may also be a marker of greater illness severity [3]. During CRRT, reported incidence ranges from about one quarter to more than one half of treated patients [4, 5]. Direct comparison between studies is difficult because thresholds, observation windows, temperature-measurement routes, CRRT dose, and device configurations differ.

Comparative studies suggest that integrated blood-warming systems can improve thermal control relative to older or standalone configurations [6–8]. Technical capacity alone, however, does not ensure reliable bedside practice. Recent nursing studies have identified variation in temperature-monitoring frequency, measurement site, knowledge, and confidence, supporting a combined approach that addresses both equipment and workflow [9, 10].

A local service review at King Fahd Military Medical Complex identified documented temperature < 36°C in 49 of 70 CRRT-treated patients (70.0%) and temperature < 35°C in 16 of 70 (22.9%), together with a mixed platform fleet and variable warming workflows. The improvement team set a local target of reducing documented temperature < 36°C to < 20% and eliminating temperatures < 35°C. We therefore implemented an integrated blood-warming and nursing-surveillance pathway and evaluated the change using an uncontrolled pre–post quality-improvement design. Reporting was guided primarily by SQUIRE 2.0, with complementary STROBE items and the JBI evidence-implementation model [11–13].

Methods

Study design, setting, and participants

This single-center quality-improvement study used an uncontrolled pre–post design at King Fahd Military Medical Complex, a 400-bed tertiary hospital in Dhahran, Saudi Arabia. The adult critical care service comprised 22 beds across an adult intensive care unit (AICU) and a surgical intensive care unit (SICU). The retrospective preimplementation service audit covered 1 February–30 April 2026. The prospective implementation period covered 1 May–31 July 2026 and included 12 scheduled weekly audit-feedback cycles.

The project team confirmed that the period-specific denominators represented 70 unique preimplementation patients and 80 unique implementation-period patients; the latter represented 80 distinct CRRT-treated admissions. No formal sample-size calculation was performed because all available records from the prespecified periods were used. The aggregate source data did not retain a record-level screening log, an item-level missingness report, or reliable patient-level demographic, illness-severity, and treatment-exposure variables. Adjusted comparisons were therefore not possible.

Ethics approval

The Armed Forces Hospitals Eastern Province Institutional Review Board, King Fahd Military Medical Complex, reviewed and approved the project through an expedited procedure (protocol AFHER-IRB-2026-015; review date 5 April 2026; effective date 23 April 2026). The committee classified the work as a minimal-risk quality-improvement evidence-implementation study using aggregate, deidentified clinical data and granted a waiver of informed consent. Preimplementation indicators were obtained retrospectively from routine service records, and prospective evaluation began after the approval became effective. No identifying information is reported.

Context and intervention

Before implementation, the service used CRRT platforms from multiple manufacturers and variable warming practices. The multidisciplinary improvement team included an intensivist CRRT coordinator, nursing champions, CRRT-trained nurses, medical staff, supply-chain representatives, and data support.

The pathway was introduced on 1 May 2026 and combined technical standardization with workflow redesign. During the first 2 weeks, the team finalized the written temperature-management protocol, delivered focused education, used simulation and bedside coaching, and supported competency assessment. For CRRT episodes managed under the standardized pathway, the intended platform was the PrisMax system with the integrated TherMax blood warmer (Vantive, Deerfield, IL, USA). The pathway called for temperature documentation at least every 4 h, escalation for temperature $< 36^{\circ}\text{C}$, recurrent multidisciplinary audit-feedback, and monthly stakeholder review. Exact episode-level delivery of each component could not be reconstructed from the aggregate dataset and was not assumed to be complete.

The working theory was that integrated blood warming would reduce technical variability and extracorporeal heat loss, while regular surveillance would reduce delayed recognition. A shared escalation algorithm, education, competency support, and audit-feedback were intended to reduce response failures and sustain reliable practice. Figure 2 summarizes the pathway and audit-feedback timeline.

Outcomes, fidelity measures, and data sources

The primary outcome was the proportion of CRRT-treated patients with at least one documented temperature $< 36^{\circ}\text{C}$ during therapy. Because pre-CRRT temperature and measurement route were not available in the aggregate dataset, the outcome could not distinguish pre-existing hypothermia from new hypothermia after CRRT initiation. Mild hypothermia was defined as 35.0°C to $< 36.0^{\circ}\text{C}$, moderate hypothermia as 34.0°C to $< 35.0^{\circ}\text{C}$, and severe hypothermia as $< 34.0^{\circ}\text{C}$. The principal secondary clinical outcome was temperature $< 35^{\circ}\text{C}$.

Patient-level CRRT modality, blood-flow rate, effluent dose, treatment duration, anticoagulation, warmer settings, minimum temperature, time below threshold, and exposure-normalized outcome rates were not available in the final analytic dataset. The completeness and timing of scheduled temperature observations also could not be quantified reliably.

The implementation plan included fidelity measures for use of the standardized platform and warmer, completion of 4-hourly temperature observations, escalation adherence, nurse education, competency validation, and audit-feedback. Source-verified opportunity-based numerators and denominators were not available for these components. Project-reported bleeding complications and circuit-clotting events were reviewed as balancing signals, using local project reporting rather than independent adjudication. Hyperthermia, hemolysis, alarm burden, treatment interruption, device malfunction, rescue-warming workload, and local costs were not systematically captured.

Statistical analysis

Categorical outcomes are presented as numbers and percentages. Exact Clopper–Pearson 95% CIs were calculated for event proportions. Pre–post comparisons used two-sided Fisher exact tests. Absolute risk differences were defined as implementation-period minus preimplementation values and calculated with Newcombe–Wilson 95% CIs. An unadjusted risk ratio with a log-scale 95% CI was calculated for temperature $< 36^{\circ}\text{C}$. A risk ratio was not reported for temperature $< 35^{\circ}\text{C}$ because the implementation-period event count was zero. No adjusted model was attempted because patient-level covariates were unavailable and only five implementation-period primary-outcome events occurred. P values are presented as exploratory measures of the crude between-period difference. Analyses were independently reproduced in Python 3.13.5 using SciPy 1.17.0 and statsmodels 0.14.6.

For operational context only, Additional file 1 presents an exploratory transfer scenario based on the US\$3,562 per-admission total-cost difference reported in a published US economic model [14]. The scenario applied 25%, 50%, 75%, and 100% of that estimate to the 80 confirmed implementation-period admissions and converted results at SAR3.75 per US dollar. It was not inflation-adjusted, did not use Saudi unit costs, and did not subtract equipment, consumables, training, maintenance, staffing, or other implementation costs. It must not be interpreted as measured institutional savings.

Results

Study cohorts

The confirmed denominators were 70 unique preimplementation patients and 80 unique implementation-period patients representing 80 distinct CRRT-treated admissions. The implementation-period cohort comprised 31 AICU and 49 SICU patients. Patient-level demographic, illness-severity, and treatment-exposure data were not available for a valid between-period baseline comparison.

Clinical outcomes

Documented temperature $< 36^{\circ}\text{C}$ occurred in 49/70 preimplementation patients (70.0%; exact 95% CI, 57.9%–80.4%) and 5/80 implementation-period patients (6.3%; exact 95% CI, 2.1%–14.0%). The implementation-period estimate and its upper 95% confidence limit were below the local target of 20%. The absolute risk difference was -63.8 percentage points (95% CI, -73.9 to -50.0), and the unadjusted implementation-to-preimplementation risk ratio was 0.09 (95% CI, 0.04–0.21; Fisher exact $P < 0.001$). Figure 1 displays the proportions and exact CIs.

Documented temperature $< 35^{\circ}\text{C}$ occurred in 16/70 preimplementation patients (22.9%; exact 95% CI, 13.7%–34.4%) and 0/80 implementation-period patients (0%; exact 95% CI, 0%–4.5%). The absolute risk difference was -22.9 percentage points (95% CI, -34.0 to -13.4 ; Fisher exact $P < 0.001$). All five implementation-period patients with temperature $< 36^{\circ}\text{C}$ had only mild hypothermia. The five events were recorded in AICU during audit weeks 7–8; AICU had 5/31 affected patients (16.1%; exact 95% CI, 5.5%–33.7%), whereas SICU had 0/49 (0%; exact 95% CI, 0%–7.3%). Event-linked patient characteristics and fidelity data were unavailable, so the unit and temporal patterns were not interpreted causally.

Implementation fidelity and balancing signals

Opportunity-based numerators and denominators were not available for integrated-warmer use, completion of 4-hourly temperature observations, escalation adherence, nurse education, competency validation, audit attendance, or complete-bundle delivery. Component-level implementation fidelity therefore could not be quantified.

No bleeding complication or CRRT circuit-clotting event was reported in the implementation-period project log. These events were not independently adjudicated, and the study was not designed or powered to establish comparative safety. No local cost outcome was measured; the supplementary economic scenarios are mathematical transfers of an external model only.

Discussion

In this single-center quality-improvement study, documented temperature $< 36^{\circ}\text{C}$ during CRRT was substantially less common during the implementation period than during the preimplementation audit, and no temperature $< 35^{\circ}\text{C}$ was recorded after the pathway was introduced. The implementation-period

estimate met the local target, and all residual events were mild. The crude difference was large, but the study design and aggregate data structure mean that it should be interpreted as a strong local improvement signal rather than a causal estimate of the bundle's effect.

The direction of the finding is consistent with comparative evidence that modern CRRT systems and integrated blood warming can improve thermal control [6–8]. Published incidence estimates nevertheless vary substantially with the temperature threshold, observation window, CRRT dose, measurement route, and device configuration [4, 5]. The contribution of the present work is therefore practical: it evaluates a bedside pathway that combined technical standardization with nursing surveillance rather than testing a blood warmer in isolation.

That distinction matters because reliable temperature management depends on both technology and human factors. The pathway paired the integrated warmer with scheduled observations, a shared escalation threshold, education, competency support, and recurrent feedback. Recent nursing studies similarly report variation in assessment frequency, measurement site, knowledge, and confidence during CRRT, reinforcing the need for standardized team processes [9, 10]. The present data cannot determine which component contributed most to the observed change.

Several limitations constrain interpretation. Patient-level age, sex, body size, illness severity, shock, vasopressor exposure, baseline temperature, CRRT modality, dose, blood flow, treatment duration, anticoagulation, warmer settings, ambient conditions, and cointerventions were unavailable. Differences in case mix or treatment exposure may therefore have contributed to the between-period contrast. In addition, baseline temperature and measurement route were not retained, so the outcome may include patients already hypothermic when CRRT began, and changes in surveillance completeness could have influenced detection. The absence of a concurrent control also leaves the analysis vulnerable to temporal changes unrelated to the pathway.

Implementation fidelity could not be linked directly to outcomes because exact numerators and denominators for the individual bundle components were unavailable. The clustering of five mild events in AICU during weeks 7–8 prompted local review, but it cannot establish adherence drift as the cause; a higher-risk case mix or other contextual pressures are also plausible. Future audit should retain episode-level data on expected and completed temperature observations, warmer use, escalation opportunities and actions, nurse training, competency assessment, and complete-bundle delivery using identical definitions across units.

The absence of project-reported bleeding or circuit clotting is reassuring only as an operational signal. The sample was too small to assess uncommon adverse events, the events were not independently adjudicated, and several relevant balancing measures were not collected. Future evaluations should include hyperthermia, hemolysis, alarms, treatment interruptions, filter life, rescue-warming burden, nursing time, and device problems, alongside a consistent temperature-measurement method.

The economic scenario also requires restraint. At 100% transfer, applying the published US estimate to 80 confirmed admissions produces a gross benchmark of US\$284,960 (SAR1,068,600), but this is not a measured local saving. The source model was driven largely by assumptions about intensive care length of stay and included manufacturer-affiliated authors [14]. A credible Saudi analysis would require prospective microcosting of equipment, consumables, maintenance, training, nursing time, external warming, filter use, treatment interruptions, and intensive care length of stay.

The study's strengths include confirmed raw denominators, prespecified temperature thresholds, implementation across both medical and surgical adult intensive care units, exact confidence intervals, and transparent separation of observed outcomes from unmeasured fidelity and economic assumptions. Its main limitations are the uncontrolled single-center design, absence of comparable patient and treatment characteristics, uncertain outcome ascertainment, short follow-up, and lack of sustainability data beyond July 2026.

A stronger next phase should use a prospective data dictionary, record baseline and serial temperatures using a consistent route, and retain patient characteristics, CRRT prescription and exposure, warmer settings, cointerventions, and component-level adherence. An interrupted time-series or controlled before-and-after design would improve causal inference, while longer follow-up would test sustainability. Local cost-consequence analysis would be needed before making an economic claim.

Conclusions

After introduction of a standardized blood-warming and nursing-surveillance pathway, documented hypothermia during CRRT was substantially less common, and no moderate or severe episode was recorded in the implementation period. The finding supports continued local use and prospective evaluation of the pathway. It does not, however, establish causal efficacy, comparative safety, or local cost savings because patient-level comparability, exposure, measurement, and fidelity data were incomplete.

Abbreviations

AICU
adult intensive care unit
AKI
acute kidney injury
CI
confidence interval
CRRT
continuous renal replacement therapy
ICU
intensive care unit

IRB

institutional review board

JB

Joanna Briggs Institute

QI

quality improvement

RR

risk ratio

SICU

surgical intensive care unit

SQUIRE

Standards for Quality Improvement Reporting Excellence

STROBE

Strengthening the Reporting of Observational Studies in Epidemiology.

Declarations

Ethics approval and consent to participate

The Armed Forces Hospitals Eastern Province Institutional Review Board, King Fahd Military Medical Complex, Dhahran, Saudi Arabia, approved the project through an expedited procedure (AFHER-IRB-2026-015; review date 5 April 2026; effective date 23 April 2026). The IRB classified the project as a minimal-risk quality-improvement evidence-implementation study using aggregate, deidentified clinical data and granted a waiver of informed consent.

Consent for publication

Not applicable. The manuscript contains no identifiable individual-level data, images, or videos.

Availability of data and materials

The aggregate deidentified data used and/or analyzed during the current study are not publicly available because they remain subject to King Fahd Military Medical Complex governance and privacy requirements, but may be available from the corresponding author on reasonable request and with institutional approval.

Competing interests

The authors declare that they have no competing interests.

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No external funding was received. Routine institutional quality-improvement resources supported implementation within clinical operations.

Authors' contributions

KS, SAG, and AK conceptualized the project, developed the methodology, supervised implementation, interpreted findings, and drafted the manuscript. WAQ, BS, JS, WG, AM, AAb, AAS, SHM, JM, AA, and EA contributed to implementation, clinical data interpretation, and critical manuscript revision. All authors read and approved the final manuscript and accept accountability for the work.

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Not applicable.

Artificial intelligence disclosure

OpenAI's ChatGPT (OpenAI, San Francisco, CA, USA) was used after completion of the quality-improvement project to assist with manuscript organization, and language editing. An OpenAI generative image tool was used during development of an optional graphical abstract; it was not used to generate or alter the study data or the analytic figures. No identifiable patient information or source patient-level data were entered into these tools. The tools were not used for patient selection, clinical data collection, source-data extraction, clinical assessment, or clinical decision-making. The authors reviewed and verified all numerical values, statistical outputs, references, and visual content against the source records, critically revised all AI-assisted material, and accept full responsibility for the accuracy, originality, interpretation, and integrity of the final manuscript.

Additional file

Additional file 1 (DOCX). Reporting checklists and exploratory economic transfer scenarios. The file contains completed SQUIRE 2.0 and complementary STROBE checklists mapped to the manuscript, together with a sensitivity table applying 25%, 50%, 75%, and 100% of a published US model estimate to 80 confirmed implementation-period admissions.

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Tables

Table 1
Hypothermia outcomes before and during pathway implementation

Outcome	Preimplementation audit (n = 70)	Implementation period (n = 80)	Unadjusted comparison
Temperature < 36°C	49/70 (70.0%; 95% CI, 57.9%–80.4%)	5/80 (6.3%; 95% CI, 2.1%–14.0%)	Risk difference – 63.8 percentage points (95% CI, –73.9 to –50.0); RR 0.09 (95% CI, 0.04–0.21); P < 0.001
Temperature < 35°C	16/70 (22.9%; 95% CI, 13.7%–34.4%)	0/80 (0%; 95% CI, 0%–4.5%)	Risk difference – 22.9 percentage points (95% CI, –34.0 to –13.4); RR not reported; P < 0.001
AICU: temperature < 36°C	Not available	5/31 (16.1%; 95% CI, 5.5%–33.7%)	Descriptive subgroup; not formally compared
SICU: temperature < 36°C	Not available	0/49 (0%; 95% CI, 0%–7.3%)	Descriptive subgroup; not formally compared
Risk differences are implementation-period minus preimplementation estimates with Newcombe–Wilson 95% CIs. Risk ratios are implementation-period/preimplementation estimates. P values are two-sided Fisher exact tests. A risk ratio was not reported for temperature < 35°C because the implementation-period event count was zero. AICU, adult intensive care unit; SICU, surgical intensive care unit; CI, confidence interval; RR, risk ratio.			

Table 2
Integrated pathway components and intended mechanisms

Component	Operational specification	Intended contribution
Platform standardization	Use the PrisMax system with integrated TherMax blood warming for CRRT episodes managed under the standardized pathway	Reduce variation in platform and warming configuration and limit extracorporeal heat loss
Temperature surveillance	Document patient temperature at least every 4 h during CRRT	Improve timely recognition of declining temperature
Escalation threshold	Follow a written response pathway and repeat assessment when temperature is < 36°C	Promote a consistent and timely response
Education and competency support	Focused teaching, simulation, bedside coaching, and competency assessment	Improve setup, monitoring, and response reliability
Audit-feedback	Twelve scheduled weekly cycles with monthly stakeholder review	Identify implementation drift, address barriers, and reinforce standard work
Balancing signals	Review project-reported bleeding complications and circuit-clotting events	Monitor selected unintended clinical or operational consequences
The intervention was implemented as a multicomponent pathway. Exact component-level adherence numerators and denominators were not available in the final analytic dataset and should not be inferred from this table.		

Figures

CRRT-associated hypothermia before and after pathway implementation

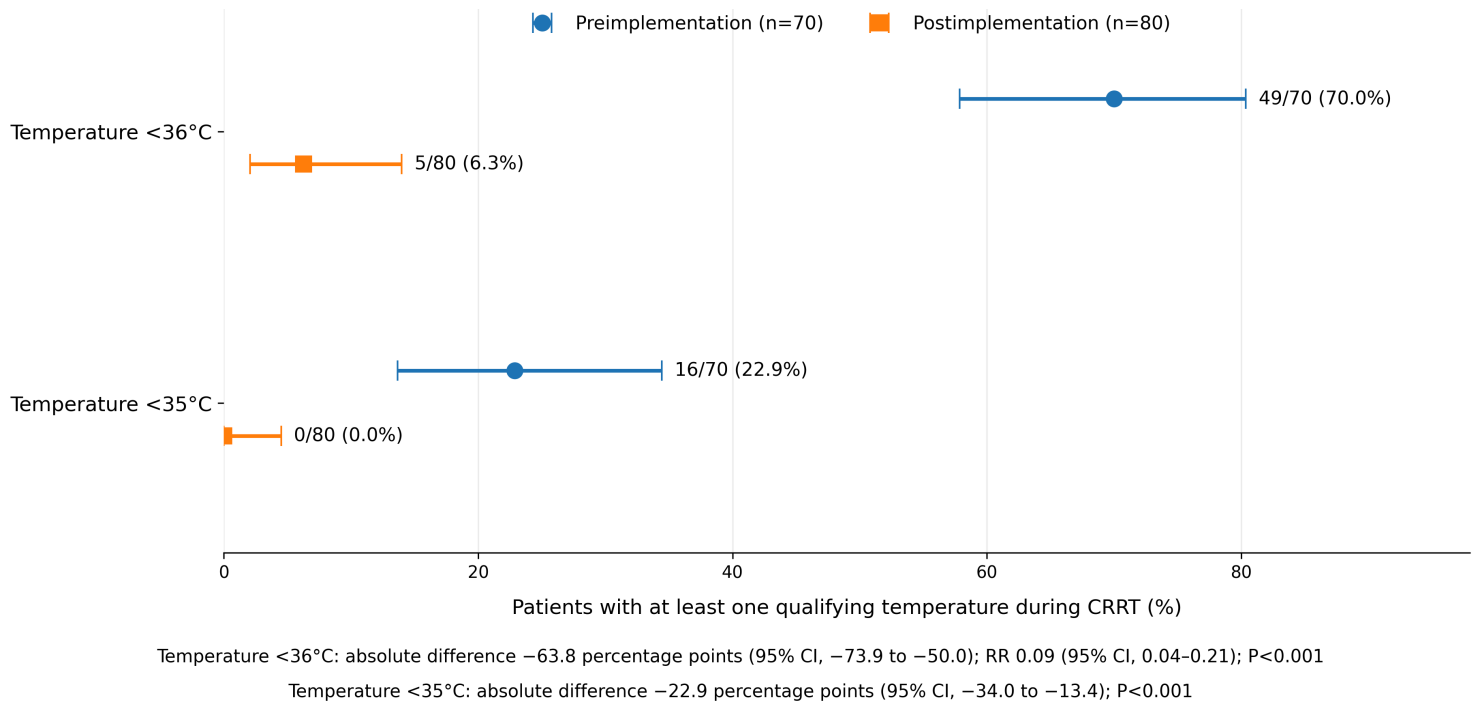
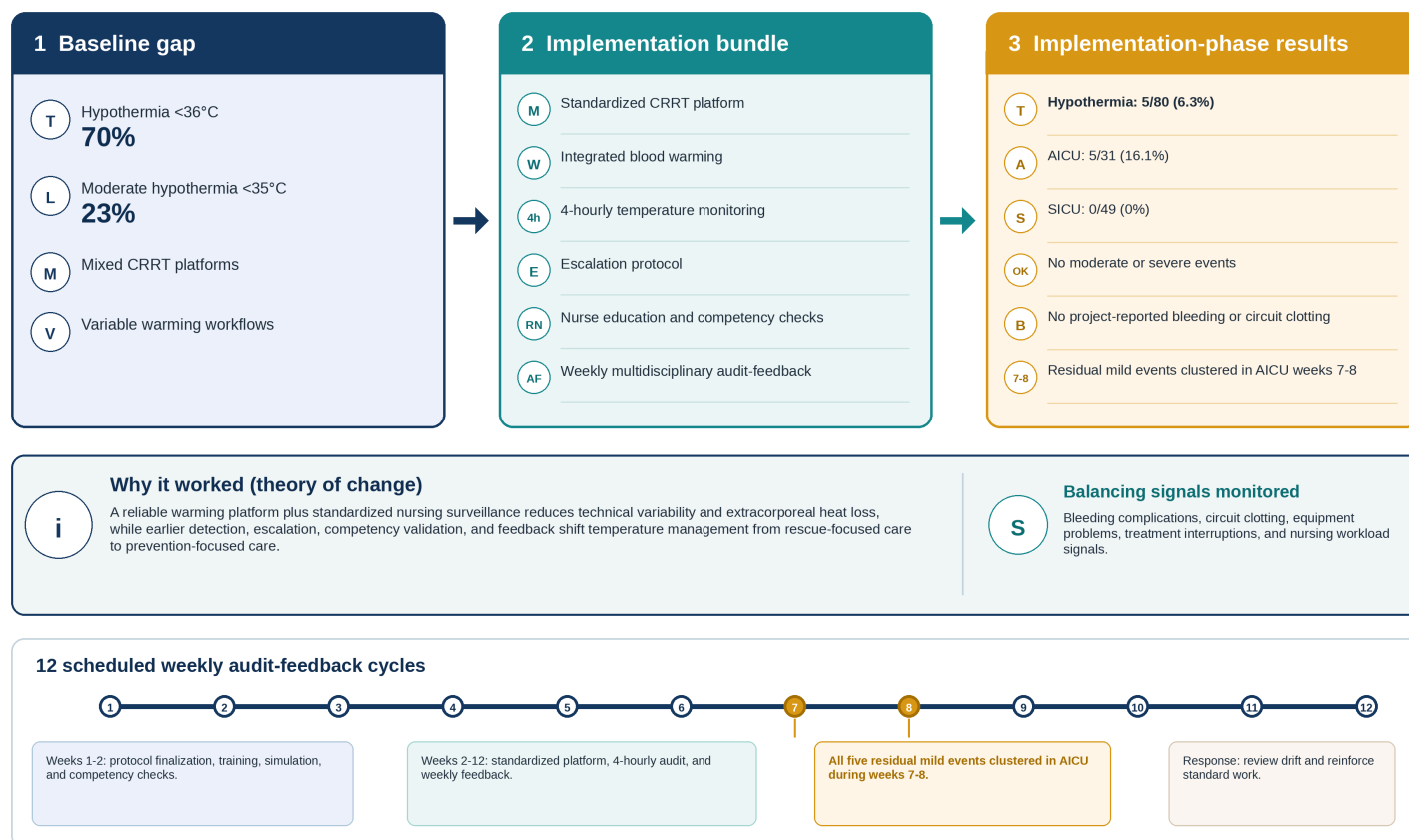


Figure 1

Hypothermia outcomes before and during pathway implementation. Points show the proportions of patients with at least one documented temperature <36°C or <35°C during CRRT; horizontal bars show exact Clopper–Pearson 95% CIs. Effect estimates are unadjusted. CRRT, continuous renal replacement therapy; CI, confidence interval; RR, risk ratio.

Integrated blood-warming and nursing surveillance pathway

Quality-improvement study across a 22-bed mixed medical-surgical adult ICU service



CRRT, continuous renal replacement therapy; ICU, intensive care unit; AICU, adult intensive care unit; SICU, surgical intensive care unit.

Figure 2

Integrated blood-warming and nursing-surveillance pathway with audit-feedback timeline. The figure summarizes the baseline practice gap, intervention bundle, working theory of change, balancing signals, and 12 scheduled weekly audit-feedback cycles. Preimplementation percentages correspond to 49/70 patients with temperature <36°C and 16/70 with temperature <35°C. During implementation, 5/80 patients had temperature <36°C and none had temperature <35°C. CRRT, continuous renal replacement therapy; ICU, intensive care unit; AICU, adult intensive care unit; SICU, surgical intensive care unit.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Additionalfile1ReportingChecklistsandEconomicScenarios.docx](#)
- [RenalReplacementTherapyGraphicalAbstract.png](#)