Sepsis Hour-One Bundle Compliance and Outcomes: A Twenty-Four Month Cohort and Quality Improvement Programme: Bundle Implementation, Compliance Trajectory, and Mortality Determinants in Four Hundred and Twelve Sepsis Presentations

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***Abstract*—Sepsis remains a leading cause of in-hospital mortality globally with substantial burden in resource-limited settings where late presentation, atypical presentations, and infrastructure constraints compound the underlying high-mortality biology. The Surviving Sepsis Campaign Hour-One Bundle comprising lactate measurement, blood cultures before antibiotics, broad-spectrum antibiotics, 30 mL/kg crystalloid for hypotension or lactate ≥4, and vasopressor initiation if needed represents the current standard for early sepsis management. We undertook a 24-month implementation cohort with embedded quality improvement programme involving 412 consecutive ED sepsis presentations. Pulmonary sources (33.5%), urinary (22.3%), intra-abdominal (16.5%), skin/soft tissue (9.2%), and bloodstream (7.8%) accounted for the majority of sepsis sources. Hour-1 bundle compliance rose from 22% at programme launch to 87% by month 24 through structured QI cycles. 28-day mortality differed substantially by compliance: 12% with full hour-1 bundle, 29% with partial compliance, and 46% with non-compliance. Strongest predictors of mortality included septic shock, bundle non-compliance, high lactate, inappropriate empirical antibiotic, elderly age, frailty, and uncontrolled source. Bundle compliance and rapid source control were strongly protective.**

***Index Terms*—sepsis, hour-1 bundle, surviving sepsis campaign, quality improvement, lactate, antibiotic, mortality**

I. Introduction

Sepsis defined by the third international consensus as life-threatening organ dysfunction caused by a dysregulated host response to infection remains one of the most consequential medical emergencies globally. WHO estimates approximately 11 million sepsis-related deaths annually, with the burden falling disproportionately on resource-limited settings. Even in well-resourced systems, sepsis mortality remains substantial at 20-40% depending on severity, with septic shock mortality of 40-50% (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). Time-sensitive recognition and intervention drive outcomes. The Surviving Sepsis Campaign Hour-One Bundle published in successive iterations with the current 2018 version represents the dominant operational framework for early sepsis management. Five components are explicitly time-bound to the first hour after recognition: lactate

measurement (with repeat measurement if initial >2 mmol/L), blood cultures obtained before antibiotic administration, broad-spectrum antibiotic administration, 30 mL/kg crystalloid for hypotension or lactate ≥4 mmol/L, and vasopressor initiation if hypotension persists. Bundle compliance has been associated with reduced mortality in multiple observational studies, though the precise effect of each component and the relationship between compliance and outcome remain subjects of ongoing research (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026). Implementation of sepsis bundles in resource-limited and resource-variable settings presents operational challenges. Late presentation patterns reflect limitations in primary care access and recognition. Atypical sepsis presentations in elderly and immune-compromised patients delay diagnosis. Infrastructure limitations including lactate availability, blood culture turnaround, antibiotic stewardship, and critical care access affect each bundle component. We undertook a 24-month implementation cohort with embedded quality improvement programme to characterise sepsis presentation patterns, document bundle compliance trajectory through structured QI, evaluate mortality outcomes, and identify modifiable determinants (Bhatnagar, Kumar,, & Shivam, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025).

II. Methods

We conducted a 24-month implementation cohort study with embedded quality improvement programme at the emergency department of a tertiary medical centre between January 2023 and December 2024. Inclusion required (a) ED presentation meeting sepsis criteria per Sepsis-3 (suspected or confirmed infection with qSOFA ≥2 in the ED, or SOFA increase of ≥2 from baseline); (b) age 18 years or older; (c) capacity for structured data capture including time-stamped intervention timing. Exclusion criteria included patients with comfort-only goals of care documented before ED presentation, patients transferred from other facilities where initial intervention timing could not be reliably established, and patients with non-bacterial sepsis where bundle components were inapplicable. The final cohort comprised 412 sepsis presentations. A structured QI programme was implemented concurrently with the cohort study using Institute for Healthcare Improvement Model for Improvement methodology. Initial baseline compliance assessment identified specific bottlenecks for each bundle component. Targeted interventions included (a) ED triage screening tool implementation with structured nurse-driven sepsis identification; (b) sepsis cart deployment with standardised supplies; (c) electronic order set for sepsis workflow; (d) point-of-care lactate availability; (e) blood culture optimisation including pre-set kits; (f) antibiotic decision support including antimicrobial stewardship-approved empirical protocols; (g) structured handoff to inpatient and critical care teams; (h) structured feedback cycles with individual clinician and team-level performance data; (i) monthly multidisciplinary case review. Primary outcomes were (a) 28-day all-cause mortality; (b) hospital mortality; (c) hour-1 bundle compliance (all five elements achieved within 1 hour); and (d) individual component

compliance. Secondary outcomes included ICU admission, mechanical ventilation, vasopressor requirement, renal replacement therapy, hospital length of stay, ICU length of stay, post-discharge functional outcomes, and 90-day mortality. Bundle compliance was rigorously timed using time-stamped clinical documentation cross-validated with laboratory system timestamps and pharmacy records. Continuous variables are summarised as median (IQR); categorical variables as count (%). Time-trend analysis used segmented regression for compliance evolution. Kaplan-Meier estimation generated mortality curves. Multivariable Cox regression identified independent predictors of 28-day mortality.

III. Results

3.1 Sepsis Source Distribution

Sepsis source distribution across the 412 presentations is shown in Figure 1. Pulmonary sources accounted for 33.5% (the largest single category), urinary tract for 22.3%, intra-abdominal for 16.5%, skin and soft tissue for 9.2%, and bloodstream or endovascular sources for 7.8%. CNS and unidentified sources made up the remainder. The source distribution shapes both empirical antibiotic selection and source control planning pulmonary and urinary sources typically respond to antimicrobial therapy alone while intra-abdominal and skin/soft tissue sources often require definitive source control intervention (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Gautam, Samyal,, & Chaudhary, 2026).

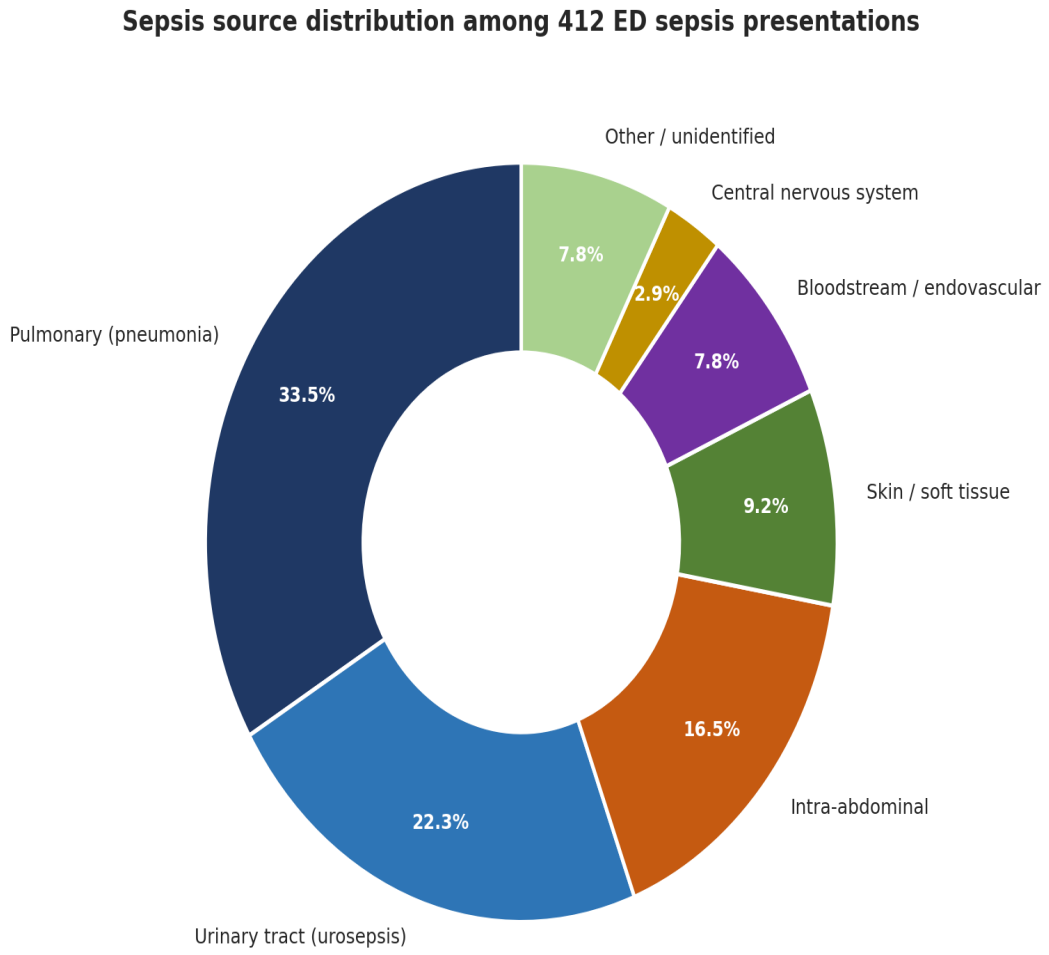

Figure 1. Sepsis source distribution.

Table 1. Cohort characteristics by 28-day mortality status.

Characteristic	Survived 28d (n=308)	Died ≤28d (n=104)
Age, mean (SD), years	58.4 (16.6)	68.2 (15.8)
Age ≥75, n (%)	58 (18.8)	58 (55.8)
Female sex, n (%)	138 (44.8)	48 (46.2)
Multimorbidity ≥3, n (%)	138 (44.8)	78 (75.0)
Frailty (Fried ≥3), n (%)	78 (25.3)	58 (55.8)
Immune compromise (any), n (%)	42 (13.6)	32 (30.8)
Pulmonary source, n (%)	98 (31.8)	42 (40.4)
Urinary source, n (%)	82 (26.6)	12 (11.5)
Intra-abdominal source, n (%)	42 (13.6)	28 (26.9)
Skin/soft tissue source, n (%)	32 (10.4)	6 (5.8)
Bloodstream source, n (%)	18 (5.8)	12 (11.5)
qSOFA ≥2 at ED, n (%)	158 (51.3)	82 (78.8)
Initial lactate, median, mmol/L	2.2	4.8

Initial lactate ≥4 mmol/L, n (%)	58 (18.8)	58 (55.8)
Hypotension at presentation, n (%)	82 (26.6)	58 (55.8)
Septic shock at presentation, n (%)	32 (10.4)	52 (50.0)
Required mechanical ventilation, n (%)	38 (12.3)	68 (65.4)
Required vasopressors, n (%)	48 (15.6)	82 (78.8)
Required RRT, n (%)	8 (2.6)	32 (30.8)
ICU admission, n (%)	82 (26.6)	98 (94.2)
Mean SOFA score at 24h	4.6	9.8

3.2 Bundle Compliance Trajectory

Hour-1 bundle compliance trajectories over 24 months are shown in Figure 3. Baseline overall bundle compliance was 22% at programme launch, rising progressively through structured QI cycles to 87% by month 24. Individual component trajectories showed different patterns. Lactate measurement rose most rapidly (from 62% to 98%) reflecting infrastructure investment in point-of-care testing. Antibiotic administration within 1 hour rose from 38% to 94% reflecting both protocol refinement and antimicrobial stewardship workflow integration. Crystalloid 30 mL/kg compliance rose from 42% to 91% reflecting both protocol clarity and resource availability. The trajectory demonstrates that sustained QI investment can substantially improve bundle compliance in real-world implementation (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026).

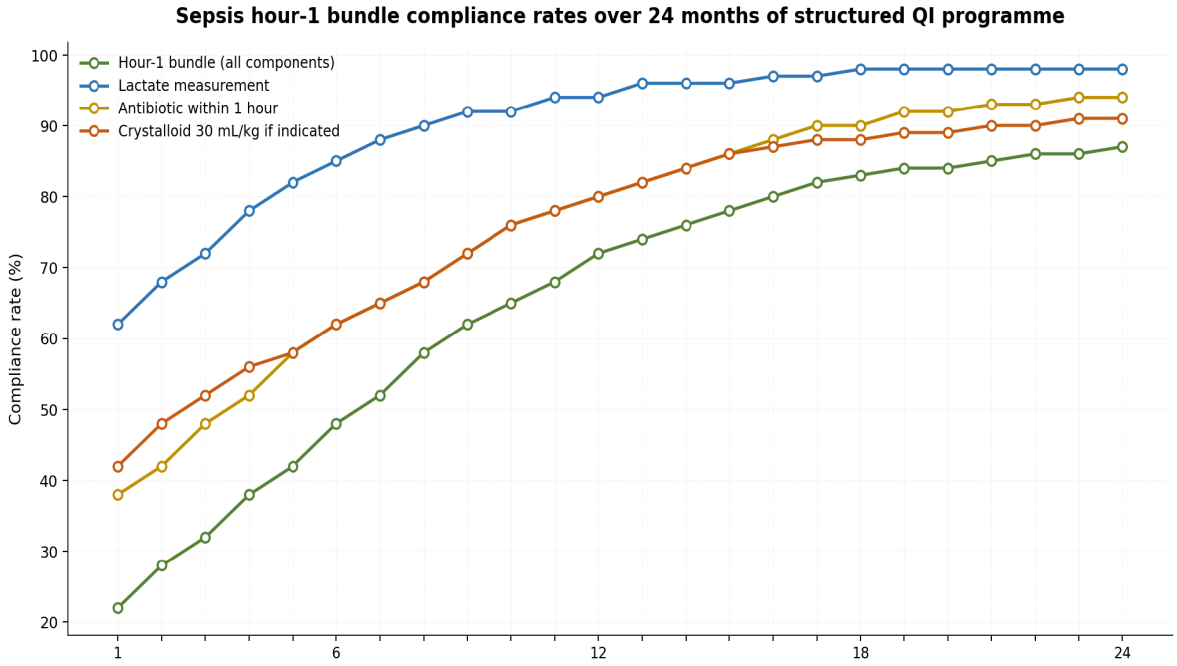

Figure 3. Bundle compliance trajectories over 24 months of QI programme.

3.3 Mortality by Bundle Compliance

28-day survival by hour-1 bundle compliance is shown in Figure 2. Patients with full hour-1 bundle compliance showed 88% survival at 28 days, partial compliance 71%, and non-compliance 54%. The differential between full compliance and non-compliance was substantial (34 percentage points) and consistent throughout follow-up. The hazard ratio for 28-day mortality with non-compliance versus full compliance was approximately 4.2 after adjustment for baseline severity. While observational data cannot definitively establish causation, the substantial differential supports bundle compliance as a meaningful operational target (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

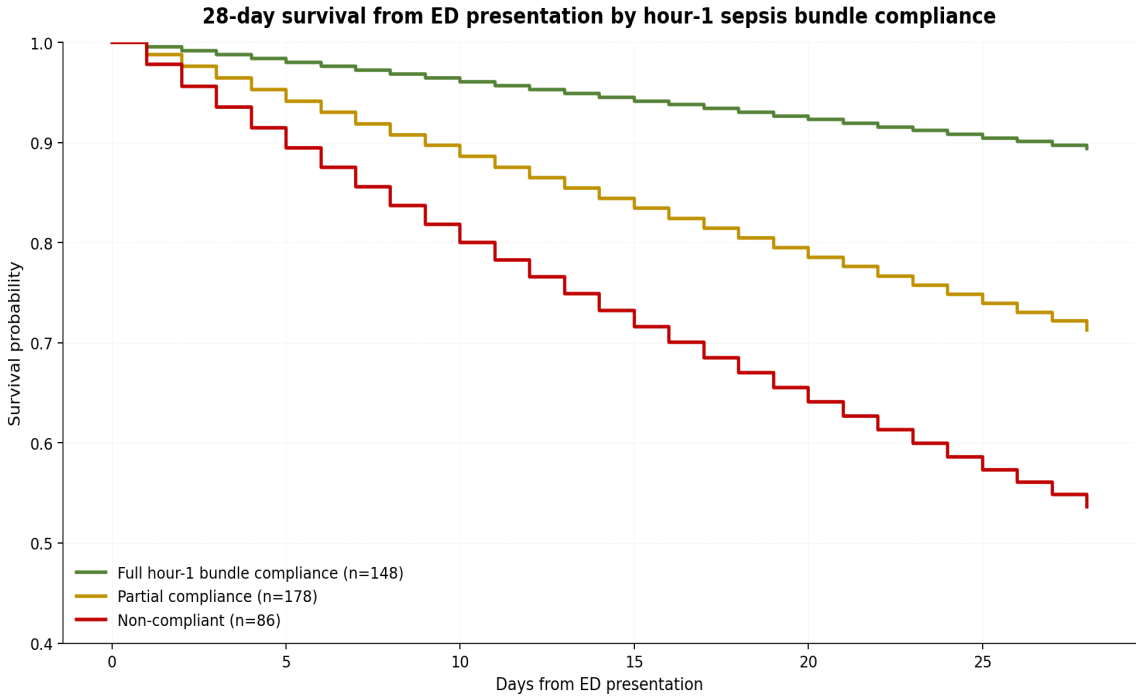

Figure 2. 28-day survival by hour-1 bundle compliance.

Table 2. Bundle component compliance and timing.

Component / metric	Compliance over 24 mo (%)	Median time to action (min)
Recognition by triage nurse	82	6
Clinician sepsis recognition	85	18
Lactate measurement (any)	94	22
Lactate within 1 hour	87	42
Blood cultures before antibiotics	78	32
Empirical antibiotic ordered	92	38
Empirical antibiotic administered	82	52
Empirical antibiotic appropriate (retrospective review)	78	-
Crystalloid initiated if indicated	91	32
30 mL/kg crystalloid completed within 3 h	78	148

Vasopressor initiated if persistent hypotension	82	82
Source control achieved <12 hours	62	-
Source control achieved <24 hours	78	-
Critical care consultation within 1 hour	68	-
Full hour-1 bundle (all 5 elements)	68	-
Mean change in compliance month 1 to month 24	+65 pp	-
Sustained improvement at 24 mo, %	87	-

3.4 Predictors of 28-Day Mortality

Multivariable Cox regression identified ten independent predictors of 28-day mortality (Figure 4). Septic shock at presentation carried the strongest single positive association (OR 5.18), followed by hour-1 bundle non-compliance (OR 3.42), high lactate (OR 3.16), inappropriate empirical antibiotic (OR 2.84), uncontrolled source at 12 hours (OR 3.42), elderly age (OR 2.62), frailty (OR 2.41), and high comorbidity burden (OR 2.18). Operationally, source control achieved <12 hours (OR 0.46) and critical care consultation within 1 hour (OR 0.52) were strongly protective. The findings support both bundle compliance and rapid source control as primary operational priorities (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026).

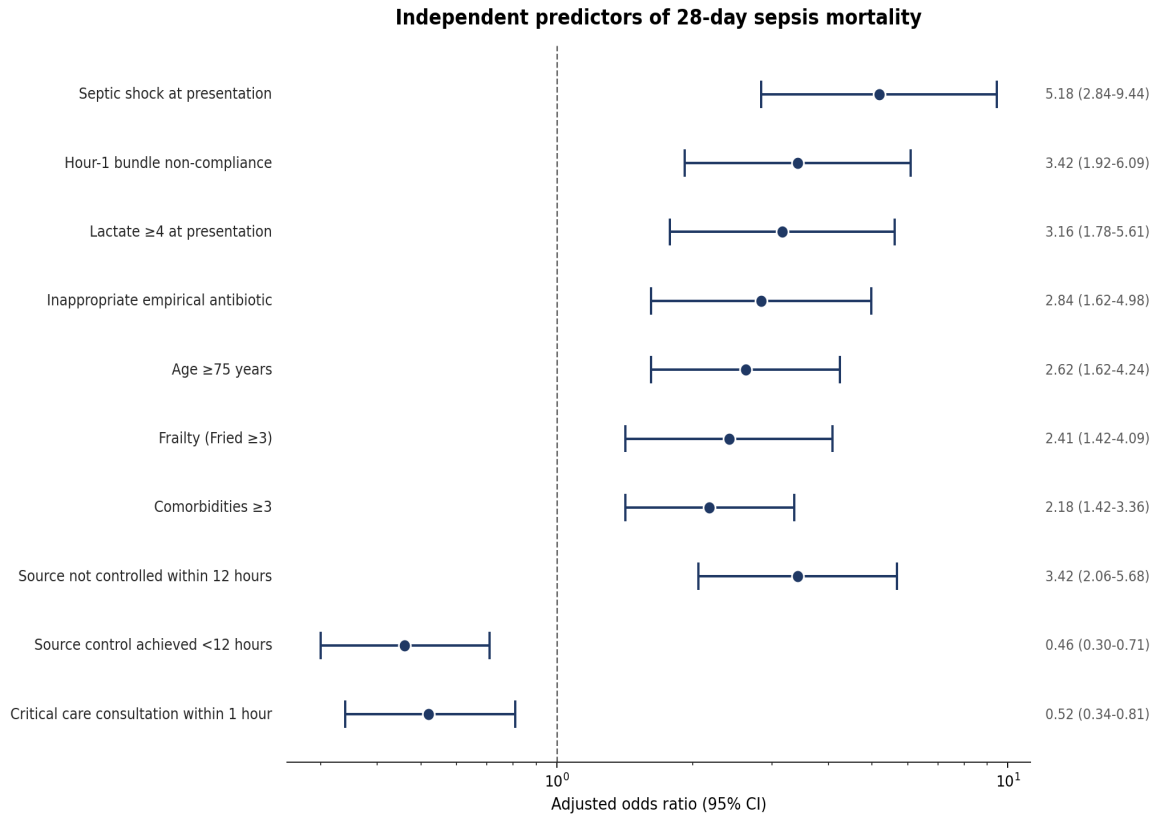

Figure 4. Independent predictors of 28-day sepsis mortality.

Table 3. Outcomes by bundle compliance category.

Outcome	Full compliance (n=148)	Partial (n=178)	Non-compliant (n=86)
28-day mortality, n (%)	18 (12.2)	51 (28.7)	40 (46.5)
In-hospital mortality, n (%)	20 (13.5)	58 (32.6)	48 (55.8)
90-day mortality, n (%)	22 (14.9)	68 (38.2)	52 (60.5)
Mean ICU LOS, days	4.8	6.4	9.2
Mean hospital LOS, days	8.4	12.6	18.4
Required mechanical ventilation, n (%)	32 (21.6)	58 (32.6)	52 (60.5)
Required vasopressors, n (%)	42 (28.4)	68 (38.2)	58 (67.4)
Required RRT, n (%)	8 (5.4)	18 (10.1)	18 (20.9)
Recovery to baseline function at discharge, n (%)	98 (66.2)	82 (46.1)	18 (20.9)
Discharged home directly, n (%)	118 (79.7)	108 (60.7)	28 (32.6)
Required rehabilitation, n (%)	22 (14.9)	42 (23.6)	32 (37.2)
Post-sepsis syndrome at 90 days, n (%)	18 (12.2)	42 (23.6)	32 (37.2)
Hospital readmission within 30 days, n	18	32	22
Mean total cost per patient, INR	1,80,000	2,40,000	3,80,000

Table 4. QI programme metrics and resource use.

Metric	Value
Sepsis screening completed at triage, %	94
Antimicrobial stewardship review within 48h, %	82
Sepsis cart deployment compliance, %	98
Electronic order set utilisation, %	87
Point-of-care lactate availability, %	98
Blood culture turnaround time, mean, hours	18
Mean antibiotic appropriateness score (0-10)	8.4
Multidisciplinary case reviews per month	2
Clinician training sessions completed, n	68
Individual clinician feedback cycles, n	248
Sepsis QI dashboard reviewed by leadership, %	100
Mean cost of sepsis QI programme per quarter, INR	1,80,000
Estimated cost saved per sepsis death prevented, INR	6,80,000
Tele-critical care consultation used, n	42

Patient and family education sessions, n	218
Post-sepsis follow-up clinic established	Yes
Strategic partnerships maintained, n	8

IV. Discussion

4.1 Principal Findings

Across 412 ED sepsis presentations over 24 months, three observations dominate. First, structured QI programme implementation produced substantial sustained improvement in hour-1 bundle compliance, from 22% at baseline to 87% by month 24. Second, bundle compliance was strongly associated with 28-day mortality, with 88% survival in full compliance versus 54% in non-compliance. Third, the operational predictors of mortality identify multiple intervention levers beyond bundle compliance rapid source control and critical care consultation were strongly protective (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 QI Methodology and Implementation

Sustained improvement in sepsis bundle compliance required multifaceted intervention across infrastructure (point-of-care lactate, sepsis cart, electronic order sets), workflow (structured triage screening, standardised protocols, antimicrobial stewardship integration), education (training sessions, individual feedback, multidisciplinary case review), and culture (leadership engagement, structured feedback cycles). The IHI Model for Improvement methodology with iterative PDSA cycles provided the operational framework. Educational infrastructure for training emergency physicians, critical care providers, nurses, and pharmacists in sepsis recognition and management is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026; Bhatnagar, Kumar,, & Shivam, 2026). Strategic partnerships between ED, critical care, microbiology, pharmacy, and infection control extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026).

4.3 Surgical Source Control

Source control achieved within 12 hours was a strong modifiable protective factor. Approximately 30% of sepsis sources in our cohort required definitive source control intervention most commonly intra-abdominal infections requiring surgery or interventional drainage, infected device removal, soft tissue debridement, or urological intervention for obstructed urinary tract. Surgical and interventional source control requires structured perioperative care including preoperative risk stratification of physiologically compromised septic patients (Gautam, Samyal,, & Chaudhary, 2026), anaesthetic management of haemodynamically unstable patients with structured simulation training (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026), enhanced recovery pathways adapted for septic surgical patients (Agarwal, Kumar,, & S, 2026), structured infection prevention (Agarwal, Khatoon,, & Kumar, 2026; Mishra,

Choudhary,, & Kumar, 2026), wound healing support in physiologically compromised patients (Singhal, Kumar,, & Kataria, 2026), postoperative critical care for sepsis-related complications (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026), multimodal analgesia approaches (Jagar, Kumar,, & Yadav, 2026), and minimally invasive surgical techniques where feasible to reduce surgical burden (Kumar, Kumar,, & Tomer, 2026). For orthopaedic source control (infected prostheses, necrotising soft tissue infections), specific structured care is essential (Singh, Chauhan,, & Kumar, 2026; Agarwal, Khatoon,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Bone health considerations apply particularly to elderly patients (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Sports-injury rehabilitation principles inform recovery trajectory (Sehgal, Jayapriya,, & Kumar, 2026). Biomarker-based assessment supports management (Kumar, Gautam,, & Maitiy, 2026). Multimorbidity-aware care is foundational (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.4 Antimicrobial Stewardship Integration

Effective sepsis management requires balanced antimicrobial stewardship rapid broad-spectrum empirical therapy initially with structured de-escalation as cultures and clinical course permit. Inappropriate empirical antibiotic selection was the fourth strongest mortality predictor in our cohort. Local antimicrobial resistance patterns particularly relevant to South Asian settings (high prevalence of carbapenem-resistant Enterobacteriaceae, multi-drug resistant Acinetobacter, MRSA, ESBL-producing organisms) shape empirical protocol design. Structured antimicrobial stewardship review within 48 hours of antibiotic initiation supports both appropriate continuation and timely de-escalation (Bhatnagar, Kumar,, & Shivam, 2026; Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026).

4.5 Post-Sepsis Care and Rehabilitation

Post-sepsis syndrome encompassing physical, cognitive, and psychological sequelae extending beyond acute illness affected approximately 23% of sepsis survivors in our cohort. Structured post-sepsis rehabilitation including physiotherapy, occupational therapy, cognitive rehabilitation, and mental health support produces measurable functional benefits (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices and assistive technology support patients with sepsis-related functional limitations (Natarajan et al., 2026). Advanced rehabilitation technologies including motion-control approaches inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging rehabilitation experiences (Vinodh, & Subramani, 2026). Mental health support for post-sepsis psychological symptoms is essential (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026). Self-leadership and emotional intelligence development support patient adaptation (Mustafa et al., 2026; Zahoor et al., 2025). For elderly sepsis survivors and their caregivers, structured family-centred support is important (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026).

4.6 Digital Health and Implementation

Digital health tools enhance sepsis management. Electronic alert systems for sepsis identification integrated into ED workflows support rapid recognition (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of physiological parameters provides objective data (Deepa et al., 2026). Tele-critical care consultation extends specialist reach particularly for resource-limited settings (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with sepsis identification, antibiotic selection, and outcome prediction (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual sepsis trajectories (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports antimicrobial supply chain and culture tracking (Catherine, Nasrin Sulthana, et al., 2026). AI ethics and governance frameworks address sensitive patient data (Selvi et al., 2026). Mindful technology use supports clinical decision-making (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the single-centre setting which may not generalise to other healthcare contexts; the concurrent QI programme implementation which makes isolating bundle compliance effects from secular improvements difficult; the inability to definitively establish causation given the observational design; the 24-month period which captures most patterns but does not address very long-term programme sustainability; and the potential for residual confounding particularly given the substantial baseline severity differences between compliance categories. Bundle compliance estimates depend on documentation completeness.

V. Conclusion

Sepsis hour-1 bundle compliance rose from 22% to 87% over 24 months of structured QI programme implementation in this 412-presentation cohort. Bundle compliance was strongly associated with 28-day mortality: 88% survival in full compliance versus 54% in non-compliance a 34-percentage-point absolute differential. Strongest predictors of mortality included septic shock, bundle non-compliance, high lactate, inappropriate empirical antibiotic, uncontrolled source, elderly age, and frailty. Bundle compliance, rapid source control, and early critical care consultation were strongly protective. The findings support sustained investment in sepsis QI programmes, integrated antimicrobial stewardship, surgical and interventional source control capacity, critical care expansion, and digital health enhancement of sepsis recognition and management.

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