Saudi Journal of Medicine and Public Health

https://saudijmph.com/index.php/pub

https://doi.org/10.64483/202412460

The Quintuple-Aim Attack on Hospital-Associated Pneumonia: An Interdisciplinary, Informatics-Driven Review of Prevention, Diagnosis, and Stewardship

Fayed Faleh Alharbi [(1)], Abdullah Ahmed Mohammed Alhazmi [(2)], Sultan Marzouq Albeladi [(3)], Ibrahim Salem Owaydhah Alessi [(4)], Narjes Mousa Taher Alabdullah[(5)], Owaidh Mathkar Owaidh Almutairi [(6)], Mohammed Ibrahim Mohsen Gomer [(7)], Abdullah Essa Magbool Oraybi , Khalid Hamoud Najea Somaily[(7)], Ahlam Mohammed Ahmed Arishi[(7)] , Essa Ali Ali Oraybi , Abdullah Zain Abdullah Abbas[(7)]

(1) Imam Abdulrahman Al-Faisal Hospital, First Riyadh Health Cluster, Riyadh,Ministry of Health, Saudi Arabia,
(2) Chest Diseases Hospital in Jazan Health Cluster, Jazan,Ministry of Health, Saudi Arabia,
(3) Al Noor Specialised Hospital,Ministry of Health, Saudi Arabia,
(4) King Abdulaziz Hospital, Jeddah,Ministry of Health, Saudi Arabia,
(5) Wathilan general hospital, Third Health Cluster in Riyadh, Ministry of Health, Saudi Arabia,
(6) Primary Healthcare Center in Al-Fawaz, Riyadh,Ministry of Health, Saudi Arabia,
(7) Jazan health cluster, Ministry of Health, Saudi Arabia

Abstract

Background: Hospital-acquired pneumonia (HAP) and ventilator-associated pneumonia (VAP) represent devastating, costly, and often preventable complications of modern critical care. Their persistence despite decades of study underscores the inadequacy of siloed, reactive approaches. A new paradigm is required—one that unites data science, clinical expertise, and systems engineering in a preemptive, collaborative defense. **Aim:** This narrative review aims to synthesize contemporary evidence for an integrated, informatics-powered model of HAP/VAP management. **Methods:** A systematic search of peer-reviewed literature (2010-2024) was conducted across PubMed, CINAHL, Scopus, and IEEE Xplore. **Results:** The review demonstrates that effective HAP/VAP control is a function of system-wide integration. Key findings highlight: 1) Electronic health record-embedded bundles with feedback loops drastically improve compliance; 2) Predictive analytics identify high-risk patients for targeted prevention; 3) Rapid microbiological diagnostics, when coupled with proactive pharmacy stewardship, shorten time to optimal therapy; and 4) Continuous epidemiological surveillance is vital for outbreak detection and protocol refinement. Persistent challenges include alert fatigue, data interoperability, and workforce sustainability. **Conclusion:** Eliminating preventable HAP/VAP is an archetypal interdisciplinary challenge. Success demands moving beyond checklist compliance to creating intelligent, learning health systems where data flows seamlessly to empower each discipline in real-time. The future lies in co-designed protocols, closed-loop analytics, and a shared culture of safety that treats every case as a system failure to be analyzed and prevented.

Keywords: pneumonia, ventilator-associated; cross-infection; clinical decision support systems; antimicrobial stewardship; interdisciplinary communication

Introduction

Hospital-acquired pneumonia (HAP) and its subset, ventilator-associated pneumonia (VAP), remain formidable adversaries in intensive care units (ICUs) worldwide. As leading causes of morbidity, mortality, prolonged mechanical ventilation, and excess healthcare costs, they represent a critical failure of system safeguards (Kalil et al., 2016). Despite the well-established efficacy of preventive bundles—such as elevation of the head of bed, daily sedation interruption, and oral care—sustained, high-level compliance and subsequent dramatic reductions in incidence have proven elusive in many settings (Klompas et al., 2022). This gap between evidence and execution signals a fundamental flaw in traditional implementation strategies, which often rely on manual auditing, passive education, and disciplinary silos. The complexity of modern critical care, characterized by overwhelming data streams, high clinician cognitive load, and multidrug-resistant pathogens, has outstripped the capacity of manual, retrospective quality improvement (Alecrim et al., 2019).

A paradigm shift is urgently needed. Contemporary management of HAP/VAP must be reconceptualized not as a series of discrete clinical tasks but as a continuous, data-driven cycle of prediction, prevention, rapid diagnosis, precise treatment, and systematic learning (Martinez-Reviejo et al., 2023). This approach demands the seamless integration of five core disciplines, each contributing

*Corresponding author e-mail: FayedFA@moh.gov.sa (Fayed Faleh Alharbi).
Receive Date: 18 December 2024, Revise Date: 30 December 2024, Accept Date: 31 December 2024

unique expertise: Health Informatics provides the digital infrastructure and intelligence; Epidemiology offers the population-level lens and surveillance framework; Pharmacy drives antimicrobial precision and stewardship; Nursing executes and evolves frontline preventive care; and the Laboratory accelerates the diagnostic timeline. Together, they form an interdependent defense network. This narrative review synthesizes literature from 2010-2024 to articulate this integrated model, examining how an informatics-powered, interdisciplinary system can transform the fight against HAP/VAP from a reactive battle to a proactive, learning campaign aligned with the quintuple aim of healthcare improvement.

The Interdisciplinary Framework for a Learning Health System Response

Engineering the Digital Backbone for Prevention and Insight

The informatics platform is the central nervous system of the modern HAP/VAP response. Its role extends far beyond documentation to active system orchestration. First, it operationalizes prevention through embedded clinical decision support (CDS) (Song & Wu, 2022). By hard-coding evidence-based bundles (the IHI Ventilator Bundle) into the electronic health record (EHR) as mandatory order sets or nursing checklists with real-time compliance dashboards, informatics moves protocols from paper to practice (Goletti et al., 2022). These systems can provide "nudges"—reminders for oral care every 12 hours or alerts for suboptimal head-of-bed elevation—directly at the point of care. Second, informatics enables predictive risk stratification (Feng et al., 2023).

Machine learning models can analyze real-time EHR data—including vital signs, laboratory values, medication administration, and respiratory parameters—to generate dynamic risk scores identifying patients at the highest imminent risk for VAP, allowing for targeted, resource-intensive preventive interventions (Sendak et al., 2020; Wardi et al., 2023). Finally, by integrating data streams from microbiology, pharmacy, and nursing flowsheets, informatics creates a unified patient story, facilitating root-cause analysis of every HAP/VAP case to identify systemic, rather than individual, failures (Holmgren et al., 2022).

Epidemiology and Chest Disease: The Sentinel and Strategist

The epidemiologist, often embedded within infection prevention or pulmonary critical care, serves as the sentinel and strategist for the ICU ecosystem. Their primary function is robust, real-time surveillance. Moving beyond traditional, retrospective manual chart review, modern surveillance leverages informatics to automate case-finding using validated definitions (CDC/NHSN criteria), providing near-real-time incidence rates and standardized infection ratios (SIRs) (Monegro et al., 2023). This data is critical for benchmarking and detecting outbreaks. Epidemiologists also conduct microbiological cartography, tracking the unit-specific and hospital-wide prevalence and susceptibility patterns of causative pathogens (*Pseudomonas aeruginosa*, MRSA, *Acinetobacter baumannii*). This intelligence directly informs empirical antibiotic guidelines developed with pharmacy and pulmonary teams (Goh et al., 2023). Furthermore, they lead interdisciplinary root-cause analyses of every HAP/VAP case, employing tools like fishbone diagrams to dissect contributions from device management, staffing levels, protocol compliance, and environmental factors, translating single events into system-level learning (Abdalla et al., 2023; Porto et al., 2023).

The Conductor of Antimicrobial Precision and Stewardship

In the context of HAP/VAP, the pharmacist's role is that of a precision conductor, ensuring the right antibiotic reaches the right pathogen at the right dose and for the right duration. This is achieved through proactive, data-driven antimicrobial stewardship (ASP). ICU pharmacists, ideally present on daily rounds, use informatics dashboards to identify patients on broad-spectrum antibiotics and collaborate with the laboratory to interpret rapid diagnostic results (Bauer et al., 2010). Upon receipt of a rapid molecular panel from bronchial alveolar lavage (BAL) fluid, the pharmacist can immediately recommend de-escalation from a carbapenem to a narrower-spectrum agent or addition of targeted coverage for a resistant gram-negative rod, often within hours instead of days (Bork & Heil, 2023; Echavarría et al., 2018). This "actionable stewardship" dramatically reduces time to optimal therapy, a key determinant of mortality in sepsis. Additionally, pharmacists ensure optimized pharmacokinetics/pharmacodynamics (PK/PD) in critically ill patients, adjusting doses for renal/hepatic function, fluid shifts, and the need for penetration into lung tissue, thereby maximizing efficacy and minimizing toxicity (Roberts et al., 2021).

The Foundation of Execution and Continuous Protocol Evolution

Nurses are the indispensable engine of prevention and the crucial link in the diagnostic chain. Their work is transformed from a series of tasks to a data-informed practice. Bundle execution is guided and documented via the EHR, with prompts ensuring adherence to evidence-based sequences (Roggeveen et al., 2022). More importantly, nurses provide contextual intelligence; they are first to observe subtle clinical changes—an increase in tracheal secretions, a change in ventilator waveforms, or a new fever—that may signal early pneumonia (Kiekkas, 2013). They are also responsible for high-quality diagnostic specimen collection. Proper technique in obtaining endotracheal aspirates or assisting with BAL, including minimizing oral contamination, is paramount for accurate laboratory results (Abell et al., 2023). Finally, through their

continuous presence, nurses are vital partners in protocol co-design and refinement. Their feedback on the usability of informatics tools (e.g., alert fatigue from excessive reminders) and the practicality of bundle elements in complex patients is essential for creating sustainable, effective systems (Fernando et al., 2023).

The Accelerator of the Diagnostic Timeline

The modern microbiology laboratory is the accelerator, collapsing the traditional 48-72 hour diagnostic window into a matter of hours. This revolution is powered by rapid diagnostic technologies (RDTs) (Kamel et al., 2022). Rapid Gram staining of respiratory specimens provides immediate morphological clues. Multiplex polymerase chain reaction (PCR) panels (e.g., BioFire® FilmArray Pneumonia Panel) can identify a broad array of bacterial pathogens and key resistance genes (e.g., *mecA*, *blaKPC*) directly from BAL fluid in about 1.5 hours, bypassing the lengthy culture step (Buchan et al., 2020; Everson & Adler-Milstein, 2018). The laboratory's critical second function is aggressive, multi-modal communication. Critical results are not merely posted to the EHR; they are actively pushed via secure text pages or phone calls to the treating team and the ASP pharmacist, triggering immediate therapeutic action. Furthermore, the lab maintains antibiogram and molecular epidemiology data, crucial for informing empirical therapy choices and detecting clonal outbreaks in tandem with the epidemiology team (Bouza et al., 2018). Figure 1 illustrates a learning health system model for the prevention of hospital-acquired pneumonia (HAP) and ventilator-associated pneumonia (VAP).

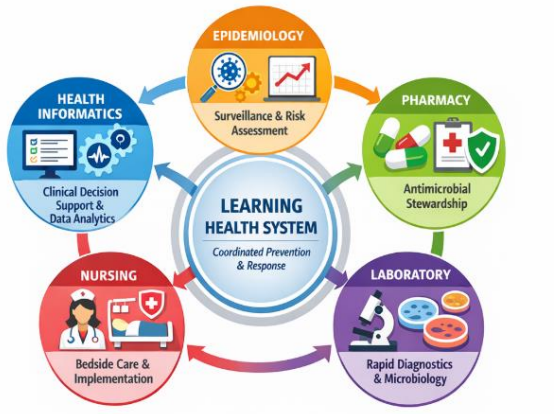

Figure 1. Integrated Interdisciplinary Framework for Preventing Hospital-Acquired and Ventilator-Associated Pneumonia

Table 1: The Interdisciplinary HAP/VAP Management Cycle: Roles and Interactions

Phase of Cycle	Health Informatics	Epidemiology	Pharmacy	Nursing	Laboratory
Prediction & Prevention	Generates predictive risk scores; Embeds & monitors bundle compliance via EHR dashboards.	Defines at-risk populations; analyzes risk factor trends from surveillance data.	Reviews medication profiles for acid-suppression overuse (a VAP risk); advises on sedation minimization.	Executes real-time bundle components (oral care, HOB elevation) triggered by EHR prompts.	N/A
Suspicion & Diagnosis	Flags clinical triggers (new fever, WBC rise) in EHR for clinician review.	Validates clinical case definitions for surveillance.	Recommends appropriate empirical therapy based on local antibiogram displayed in EHR.	Identifies early clinical signs; collects high-quality respiratory specimen per protocol.	Performs rapid Gram stain & multiplex PCR; ACTIVELY COMMUNICATES results (<2 hrs).
Treatment & Stewardship	Integrates RDT results into patient summary; CDS for antibiotic dose adjustment.	Monitors for changes in pathogen/resistance patterns post-protocol change.	**Leads:** Interprets RDT, recommends de-escalation/optimization within hours; manages PK/PD.	Monitors patient response; administers timed antibiotics; assesses for adverse	Confirms ID & susceptibilities via traditional culture; refines antibiogram.

				drug reactions.	
Learning & Adaptation	Provides data for root-cause analysis dashboards; facilitates protocol updates in EHR.	**Leads:** Root-cause analysis of every case; recommends systemic interventions.	Analyzes antibiotic use patterns and outcomes; refines empirical guidelines.	Provides frontline feedback on protocol feasibility and barriers.	Tracks test performance & turnaround time; alerts to novel resistance mechanisms.

From Friction to Flow in a High-Stakes System

The HAP/VAP pathway exemplifies a high-reliability clinical microsystem (Table 2). Its optimal function is not merely the absence of infection but the presence of a fluid, information-rich feedback loop where each discipline's output becomes another's input (French et al., 2022). A nursing observation triggers a diagnostic order; the lab's rapid result triggers a pharmacist's stewardship intervention; the outcome of that intervention is captured by informatics and analyzed by epidemiology to refine the unit's prevention strategy. This creates a virtuous cycle of learning and adaptation (Senek et al., 2022).

However, significant system friction persists. Alert fatigue from poorly designed CDS can lead to clinician burnout and ignored alerts (Baysari et al., 2019). Data silos between standalone microbiology systems and the EHR can delay result integration. Workforce challenges, particularly nursing shortages, can strain the consistent execution of labor-intensive bundles (Lasater et al., 2021). Furthermore, the implementation gap between acquiring advanced RDTs and establishing effective, interdisciplinary workflows to act on them remains a major barrier to realizing their value (Timbrook et al., 2016). Figure 2 depicts the cyclical, informatics-enabled management pathway for HAP and VAP.

Table 2: Critical Barriers and Integrated Solutions for an Optimal HAP/VAP Defense System

System Barrier	Consequence	Interdisciplinary Solution
CDS-Generated Alert Fatigue	Critical alerts are ignored; clinician burnout.	**Informatics/Nursing/Pharmacy:** Co-design "smart" alerts that are risk-stratified, actionable, and infrequent. Use tiered notifications (dashboard vs. pop-up). Regularly refine based on feedback.
Disconnected Data Systems	Delayed access to critical lab/imaging results; fragmented patient picture.	**Informatics/Lab/Management:** Invest in interoperable systems with bidirectional interfaces. Implement middleware or single-platform solutions to ensure RDT results flow instantly into the EHR and stewardship dashboards.
Variable Bundle Compliance	Persistent preventable infections; inequitable care.	**Nursing/Informatics/Epidemiology:** Embed bundles into mandatory EHR workflows with auto-documentation. Use compliance data not for blame but for system diagnosis—e.g., low oral care compliance may indicate supply access issues.
Delayed Stewardship Action	Prolonged broad-spectrum antibiotic use, driving resistance and toxicity.	**Pharmacy/Lab/Informatics:** Establish a formal "Rapid Diagnostic Result & Response" protocol with defined roles. Mandate pharmacist review of all positive RDTs within 2 hours, supported by secure communication channels.
Insufficient Feedback Loops	Static protocols; missed learning opportunities from each case.	**Epidemiology/All Disciplines:** Institute mandatory, blameless, interdisciplinary case reviews for all HAP/VAP occurrences. Use data from informatics to map the care pathway and identify systematic breakdowns.

Saudi Journal of Medicine and Public Health

https://saudijr
https://doi.org

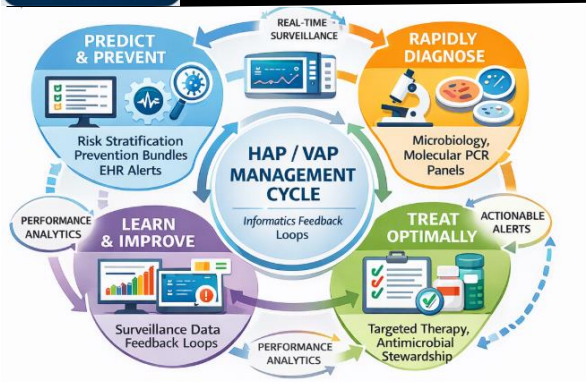

Figure 2. The HAP/VAP Management Cycle: An Informatics-Driven, Interdisciplinary Workflow

Conclusion and Future Directions

The fight against HAP/VAP is a defining test of a healthcare system's ability to integrate, learn, and adapt. This review demonstrates that sustainable success is unattainable through any single discipline's excellence. It is an interdisciplinary imperative. The future of HAP/VAP prevention and management lies in the deliberate engineering of resilient, learning health systems within the ICU.

Key trajectories for advancement are clear. First, the move from predictive analytics to prescriptive analytics, where the system not only identifies risk but also suggests specific, personalized preventive interventions. Second, the expansion of automation and ambient intelligence, such as continuous monitoring of head-of-bed angle via sensors or automated oral care delivery systems, to reduce nursing cognitive load and human error. Third, a deeper integration of molecular epidemiology, using whole-genome sequencing to trace transmission pathways with precision, closing the loop between infection control and clinical management (Mustapha et al., 2022). Finally, achieving this vision requires cultural and financial investment in interdisciplinary teams, valuing the time spent on collaborative rounds, protocol design, and system analysis as essential, non-discretionary work.

Ultimately, eliminating preventable harm from HAP/VAP is a moral and operational necessity. By forging a truly integrated, informatics-powered alliance across health informatics, epidemiology, pharmacy, nursing, and laboratory science, healthcare systems can transform the ICU from a place where pneumonia is a common complication to a high-reliability environment where it is a rare system failure—a testament to the power of collaborative, intelligent care.

References

1. Abdalla, J. S., Albarrak, M., Alhasawi, A., Al-Musawi, T., Alraddadi, B. M., Al Wali, W., ... & Kurdi, A. (2023). Narrative review of the epidemiology of hospital-acquired pneumonia and ventilator-associated pneumonia in Gulf Cooperation Council countries. *Infectious diseases and therapy*, *12*(7), 1741-1773. https://doi.org/10.1007/s40121-023-00834-w
2. Abell, B., Naicker, S., Rodwell, D., Donovan, T., Tariq, A., Baysari, M., ... & McPhail, S. M. (2023). Identifying barriers and facilitators to successful implementation of computerized clinical decision support systems in hospitals: a NASSS framework-informed scoping review. *Implementation Science*, *18*(1), 32. https://doi.org/10.1186/s13012-023-01287-y
3. Alecrim, R. X., Taminato, M., Belasco, A., Longo, M. C. B., Kusahara, D. M., & Fram, D. (2019). Strategies for preventing ventilator-associated pneumonia: an integrative review. *Revista brasileira de enfermagem*, *72*, 521-530. https://doi.org/10.1590/0034-7167-2018-0473
4. Bauer, K. A., West, J. E., Balada-Llasat, J. M., Pancholi, P., Stevenson, K. B., & Goff, D. A. (2010). An antimicrobial stewardship program's impact. *Clinical Infectious Diseases*, *51*(9), 1074-1080. https://doi.org/10.1086/656623
5. Baysari, M. T., Zheng, W. Y., Li, L., Westbrook, J., Day, R. O., Hilmer, S., ... & Samson, R. (2019). Optimising computerised decision support to transform medication safety and reduce prescriber burden: study protocol for a mixed-methods evaluation of drug–drug interaction alerts. *BMJ open*, *9*(8), e026034. https://doi.org/10.1136/bmjopen-2018-026034
6. Bork, J. T., & Heil, E. L. (2023). What Is Left to Tackle in Inpatient Antimicrobial Stewardship Practice and Research. *Infectious Disease Clinics*, *37*(4), 901-915. https://doi.org/10.1016/j.idc.2023.07.003
7. Bouza, E., Muñoz, P., & Burillo, A. (2018). Role of the clinical microbiology laboratory in antimicrobial stewardship. *Medical Clinics*, *102*(5), 883-898. https://doi.org/10.1016/j.mcna.2018.05.003
8. Buchan, B. W., Windham, S., Balada-Llasat, J. M., Leber, A., Harrington, A., Relich, R., ... & Huang, A. (2020). Practical comparison of the BioFire FilmArray pneumonia panel to routine diagnostic methods and potential impact on antimicrobial stewardship in adult hospitalized patients with lower respiratory tract infections. *Journal of clinical microbiology*, *58*(7), 10-1128. https://doi.org/10.1128/jcm.00135-20
9. Echavarría, M., Marcone, D. N., Querci, M., Seoane, A., Ypas, M., Videla, C., ... & Carballal, G. (2018). Clinical impact of rapid molecular detection of respiratory pathogens in patients with acute respiratory infection. *Journal of Clinical*

*Corresponding author e-mail: FayedFA@moh.gov.sa (Fayed Faleh Alharbi).
Receive Date: 18 December 2024, Revise Date: 30 December 2024, Accept Date: 31 December 2024

Virology, *108*, 90-95. https://doi.org/10.1016/j.jcv.2018.09.009
10. Everson, J., & Adler-Milstein, J. (2018). Gaps in health information exchange between hospitals that treat many shared patients. *Journal of the American Medical Informatics Association*, *25*(9), 1114-1121. https://doi.org/10.1093/jamia/ocy089
11. Feng, T., Noren, D. P., Kulkarni, C., Mariani, S., Zhao, C., Ghosh, E., ... & Conroy, B. (2023). Machine learning-based clinical decision support for infection risk prediction. *Frontiers in medicine*, *10*, 1213411. https://doi.org/10.3389/fmed.2023.1213411
12. Fernando, M., Abell, B., Tyack, Z., Donovan, T., Mcphail, S. M., & Naicker, S. (2023). Using theories, models, and frameworks to inform implementation cycles of computerized clinical decision support systems in tertiary health care settings: scoping review. *Journal of Medical Internet Research*, *25*, e45163. https://doi.org/10.2196/45163
13. French, R., Aiken, L. H., Rosenbaum, K. E. F., & Lasater, K. B. (2022). Conditions of nursing practice in hospitals and nursing homes before COVID-19: Implications for policy action. *Journal of Nursing Regulation*, *13*(1), 45-53. https://doi.org/10.1016/S2155-8256(22)00033-3
14. Goletti, D., Delogu, G., Matteelli, A., & Migliori, G. B. (2022). The role of IGRA in the diagnosis of tuberculosis infection, differentiating from active tuberculosis, and decision making for initiating treatment or preventive therapy of tuberculosis infection. *International Journal of Infectious Diseases*, *124*, S12-S19. https://doi.org/10.1016/j.ijid.2022.02.047
15. Goh, L. P. W., Marbawi, H., Goh, S. M., bin Abdul Asis, A. K., & Gansau, J. A. (2023). The prevalence of hospital-acquired infections in Southeast Asia (1990-2022). *The Journal of Infection in Developing Countries*, *17*(02), 139-146. doi: 10.3855/jidc.17135
16. Holmgren, A. J., Everson, J., & Adler-Milstein, J. (2022, February). Association of hospital interoperable data sharing with alternative payment model participation. In *JAMA Health Forum* (Vol. 3, No. 2, pp. e215199-e215199). American Medical Association. doi:10.1001/jamahealthforum.2021.5199
17. Kalil, A. C., Metersky, M. L., Klompas, M., Muscedere, J., Sweeney, D. A., Palmer, L. B., ... & Brozek, J. L. (2016). Management of adults with hospital-acquired and ventilator-associated pneumonia: 2016 clinical practice guidelines by the Infectious Diseases Society of America and the American Thoracic Society. *Clinical infectious diseases*, *63*(5), e61-e111. https://doi.org/10.1093/cid/ciw353
18. Kamel, N. A., Alshahrani, M. Y., Aboshanab, K. M., & El Borhamy, M. I. (2022). Evaluation of the BioFire FilmArray pneumonia panel plus to the conventional diagnostic methods in determining the microbiological etiology of hospital-acquired pneumonia. *Biology*, *11*(3), 377. https://doi.org/10.3390/biology11030377
19. Kiekkas, P. (2013). Nurse understaffing and infection risk: current evidence, future research and health policy. *Nursing in Critical Care*, *18*(2). DOI: 10.1111/nicc.12014
20. Klompas, M., Branson, R., Cawcutt, K., Crist, M., Eichenwald, E. C., Greene, L. R., ... & Berenholtz, S. M. (2022). Strategies to prevent ventilator-associated pneumonia, ventilator-associated events, and nonventilator hospital-acquired pneumonia in acute-care hospitals: 2022 Update. *Infection Control & Hospital Epidemiology*, *43*(6), 687-713. doi:10.1017/ice.2022.88
21. Lasater, K. B., Aiken, L. H., Sloane, D. M., French, R., Martin, B., Reneau, K., ... & McHugh, M. D. (2021). Chronic hospital nurse understaffing meets COVID-19: an observational study. *BMJ quality & safety*, *30*(8), 639-647. https://doi.org/10.1136/bmjqs-2020-011512
22. Martinez-Reviejo, R., Tejada, S., Jansson, M., Ruiz-Spinelli, A., Ramirez-Estrada, S., Ege, D., ... & Rello, J. (2023). Prevention of ventilator-associated pneumonia through care bundles: A systematic review and meta-analysis. *Journal of Intensive Medicine*, *3*(04), 352-364. https://doi.org/10.1016/j.jointm.2023.04.004
23. Mustapha, M. M., Srinivasa, V. R., Griffith, M. P., Cho, S. T., Evans, D. R., Waggle, K., ... & Van Tyne, D. (2022). Genomic diversity of hospital-acquired infections revealed through prospective whole-genome sequencing-based surveillance. *Msystems*, *7*(3), e01384-21. https://doi.org/10.1128/msystems.01384-21
24. Porto, A. P. M., Borges, I. C., Buss, L., Machado, A., Bassetti, B. R., Cocentino, B., ... & Costa, S. F. (2023). Healthcare-associated infections on the intensive care unit in 21 Brazilian hospitals during the early months of the coronavirus disease 2019 (COVID-19) pandemic: An ecological study. *Infection Control & Hospital Epidemiology*, *44*(2), 284-290. doi:10.1017/ice.2022.65
25. Roberts, J. A., Joynt, G. M., Lee, A., Choi, G., Bellomo, R., Kanji, S., ... & Lipman, J. (2021). The effect of renal replacement therapy and antibiotic dose on antibiotic concentrations in critically ill patients: data from the multinational sampling antibiotics in renal replacement therapy study. *Clinical Infectious Diseases*, *72*(8), 1369-1378. https://doi.org/10.1093/cid/ciaa224
26. Roggeveen, L. F., Guo, T., Fleuren, L. M., Driessen, R., Thoral, P., Van Hest, R. M., ... & Elbers, P. W. (2022). Right dose, right now:

bedside, real-time, data-driven, and personalised antibiotic dosing in critically ill patients with sepsis or septic shock—a two-centre randomised clinical trial. *Critical care*, *26*(1), 265. https://doi.org/10.1186/s13054-022-04098-7

27. Sendak, M. P., Ratliff, W., Sarro, D., Alderton, E., Futoma, J., Gao, M., ... & O'Brien, C. (2020). Real-world integration of a sepsis deep learning technology into routine clinical care: implementation study. *JMIR medical informatics*, *8*(7), e15182. https://doi.org/10.2196/15182
28. Senek, M., Robertson, S., Taylor, B., Wood, E., King, R., & Ryan, T. (2022). Consequences of understaffing on type of missed community care-a cross-sectional study. *International journal of nursing studies advances*, *4*, 100075. https://doi.org/10.1016/j.ijnsa.2022.100075
29. Song, K., & Wu, D. (2022). Shared decision-making in the management of patients with inflammatory bowel disease. *World journal of gastroenterology*, *28*(26), 3092. https://doi.org/10.3748/wjg.v28.i26.3092
30. Timbrook, T. T., Morton, J. B., McConeghy, K. W., Caffrey, A. R., Mylonakis, E., & LaPlante, K. L. (2016). The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. *Clinical Infectious Diseases*, ciw649. https://doi.org/10.1093/cid/ciw649
31. Wardi, G., Owens, R., Josef, C., Malhotra, A., Longhurst, C., & Nemati, S. (2023). Bringing the promise of artificial intelligence to critical care: what the experience with sepsis analytics can teach us. *Critical care medicine*, *51*(8), 985-991. *DOI:* 10.1097/CCM.0000000000005894.