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EVALUATION OF SURGICAL SITE INFECTION RISK FACTORS AND PREVENTIVE STRATEGIES IN TERTIARY CARE HOSPITALS

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Abstract

Background: Surgical site infections (SSIs) remain a major cause of postoperative morbidity, mortality, and economic burden worldwide, particularly in tertiary care hospitals and resource-limited settings. Despite advances in infection-control practices, SSIs continue to occur at unacceptably high rates, necessitating a deeper understanding of their multifactorial etiology and the effectiveness of current preventive strategies.Methods: A mixed-methods, experimental study design was employed, integrating prospective quantitative surveillance with qualitative contextual assessment. Patient-related, procedural, microbial, and institutional variables were systematically analyzed using advanced multivariate and nonlinear modeling approaches. The effectiveness of isolated versus bundled preventive interventions was evaluated through comparative analyses, and complex interaction effects were explored using high-dimensional statistical and graphical techniques.Results: The results demonstrated significant heterogeneity in SSI risk across patient and procedural profiles, with prolonged operative duration, higher wound contamination, and multidrug-resistant organisms emerging as dominant risk amplifiers. Integrated preventive bundles consistently outperformed isolated measures, producing substantial reductions in infection incidence and variability. Enhanced environmental control and postoperative surveillance further improved early detection and outcome stability. Nonlinear interactions among risk determinants highlighted the synergistic nature of SSI pathogenesis and prevention.Conclusion: SSIs are governed by complex, interdependent mechanisms that require comprehensive, system-level preventive strategies. Implementing integrated infection-control frameworks can markedly reduce SSI burden, improve patient outcomes, and alleviate healthcare system costs.

Keywords: Surgical Site Infections, Risk Factors, Preventive Strategies, Tertiary Care Hospitals, Antimicrobial Resistance, Infection Control.

INTRODUCTION

A major problem that affects healthcare systems across the world is the issue of surgical site infections. They form part of the most common health care related infection and one of the most common causes of postoperative problems (Chada et al., 2017; Ejaz et al., 2024). Their effects are not limited to the health complications and the death of specific patients; it leads to a lengthy stay in the hospital and a rise in healthcare costs (AlShammari et al., 2020). To reduce all these negative effects, it is important to diagnose the microorganisms and their antimicrobial sensitivity profiles, and implement certain preventive measures, which will also be informed by particular strategies of prevention (Chada et al., 2017; Sk et al., 2021). The research will attempt to reveal the complex connections between risk factors that lead to surgical site infections in the tertiary care facilities and also to rigorously assess the effectiveness of the existing preventive measures (THUMMAR et al., 2022). The problem of multidrug resistant organisms makes the treatment of SSIs difficult. It means that health care providers need to know much about the individual characteristics of the patient and the mechanism of treating them (Munawar et al., 2024; Trrisha et al., 2023). Since SSIs are the third most common type of healthcare-associated infection, and 1416 of all these infections in the category of hospitalized patients, the causes of this type of infection and the creation of effective protective measures are of paramount importance with an aim to increase patient outcomes and decrease the economic burden of medical institutions (Kochhal et al., 2019). In countries with lower development, the rate of surgical site infection is much more significant because of a lack of resources, failure to follow the guidelines of infection prevention, and improper sterilization (Ansari et al., 2019). It requires a particular study to identify some of the possible risk factors that are present in various environments, which will allow creating specific interventions that will reduce the number of cases of SSI (Monjur et al., 2018; Muhamad et al., 2025). The issue of SSIs is not that minor regardless of the fact that infections have become better controlled. Research reveals that they affect 24.1 percent to 55.2 percent of different types of patients, which proves that we are yet to be more careful and implement new preventative measures (Kunal et al., 2023).

In fact, surgical site infections are the most common type of healthcare-associated infection, which is studied and reported in low and middle-income countries. They represent the second most common HAIs in the world because they develop in up to one-third of postoperative patients (Begum et al., 2023; Maras and Surme, 2023). The rate of SSIs in surgical patients in these areas is about 10 percent, and other papers have determined that the national rate can be as high as 38 percent (Kunal et al., 2023; THUMMAR et al., 2022). The economic costs of SSIs are also high calculated as a consequence of prolonged hospitalization, higher readmission rates, and a high financial cost to the healthcare systems in the range of USD 20 000 per hospitalization (Muhamad et al., 2025). The problem of the existing threat of SSIs and the unavailability of resources, especially, conditions, in particular, increases a critical question mark concerning the significance of comprehensive intervention strategies (Hirani et al., 2022). As a result, SSIs result in high costs of healthcare systems internationally. These represent the most common type of hospital-acquired infection and add 16 days of length of stay on average, which escalates the total cost of the case (Allegranzi et al., 2016; Maras & Surme, 2023). Surgical site infection is an extra 10billion to the US per year and this is mainly due to the fact that it takes longer hospital stay and resources to treat (Maras & Surme, 2023). It is worsened by the fact that the readmission, reoperation, and death incidences are on the rise, proving that SSIs affect patient outcomes and healthcare spending in many different ways (Haque et al., 2018; Maras and Surme, 2023). Additionally, the mortality of SSIs is 3, and 75 percent of the mortality related to SSIs is directly connected with these complications, and it shows how serious these issues are in the context of health and life of the ill individual (Magat & Leon, 2023). SSIs are considered to cost between 3.3 billion and 10billion annually in the United States. It has increased the cost of treating each patient by more than 20,000 dollars in case-by-case basis (Ching, 2024; Shambhu et al., 2024). SSI patients are twice as likely to die or 60 percent more to need critical care and five times more likely to be hospitalized again (Maras & Surme, 2023). This makes the burden of cost difficult. These infections rank second after pharmaceutical errors as the most prevalent bad thing that happens to patients (Tsai and Caterson, 2014). Incidences of SSIs can be quite different in various operations, specialists and

circumstances with reported incidences of 0.1% and 50.4% (Ousey et al., 2023). The existence of such discrepancy highlights the importance of gathering and interpreting data attentively to identify high-risk operations and demographics of patients (Rezaei et al., 2025). Such comprehensive knowledge is required to develop particular interventions and improve patient outcomes since SSIs raise hospital costs by increasing hospital stay and resource utilization also including antibiotics and further surgeries (Nimkar & Kanyal, 2024). SSIs are also likely to extend anyone to spend an average of 10 days in the hospital and might be costly to treat which is about 20,000 dollars on average. It will amount to 900 million more hospital spending across the country and 90,000 preventable readmissions per year that amounts to 700 million more (Ban et al., 2016; Lissovoy et al., 2009). In addition to these direct financial consequences, the non-financial cost of lower quality of life of patients, higher morbidity and mortality rates is a colossal bill to both individuals and the society in general (Iskandar et al., 2019). Such a high economic and individual cost shows the necessity to further carry out research and introduce evidence-based interventions to decrease the occurrence of SSI (Hou et al., 2022). In reality, the number of cases of SSI that are diagnosed and treated is about 160,000-300,000 in the United States every year. It is an enormous problem in healthcare because it would take more surgery, more post-operative pain, wound recovery, hospitalization, and cosmetic failure (Simone et al., 2020). That is why it is necessary to implement massive prevention efforts, as SSIs result in long stays in hospitals, readmission rates, and even death of surgical patients (Ke et al., 2016). The chances of death of a patient with SSI are numerous, in contrast to those of a patient who is not infected in the process of surgery. The risk is 2-11 times higher, and in most cases, the deaths are directly linked to the SSI (Calderwood et al., 2023). Additionally, the infections prolong the period of stay in a hospital and on average 7 to 10 days and can also double the cost of surgery as well. It means that they should be prevented by effective measures (Eder et al., 2023). The effect on health of patients does not only stop at death but rather can be discomfort, readmission, and further operations (Walraven & Musselman, 2013). Furthermore, the non-infectious complications like dehiscence, seroma, and non-healing wounds result in longer hospitalization and higher healthcare

spending and occur more frequently than SSIs on their own (Hou et al., 2023). Here, the increase of 9.72 days to the hospitalization due to SSIs has been related to the higher costs of 3776.00 PS per patient and the readmissions (Moloney et al., 2023).

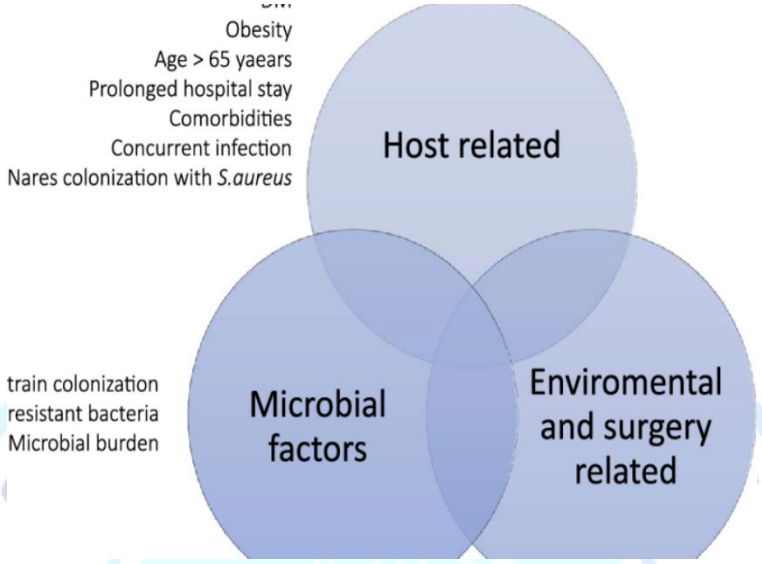

Figure 1. Illustrating the global burden of surgical site infections in tertiary care hospitals, highlighting the interaction between patient-related risk factors, procedural and environmental determinants, microbial resistance patterns, and their clinical, economic, and health-system consequences, underscoring the need for integrated preventive strategies.

METHODOLOGY

Environment and Design of the Study.

The study used a quantitative and a qualitative research approach captured by a mixed method research design involving the utilization of both prospective quantitative surveillance of surgical site infection and risk factors and prevention measures in tertiary care hospitals. The quantitative arm used longitudinal cohort in which adult patients who received clean, clean and contaminated surgery could be recruited in a sequential manner, and followed until discharge after joining the hospital. This could be done to analyze the exposure-outcome relationships with time. A qualitative element such as the systematic clinical observations and semi-structured interviews with experts were also included in conjunction to give the background of compliance with the infection-preventive measures and to discover the other latent organizational and behavioral influences that cannot be

directly quantified by use of numerical measures. The study was conducted in operating rooms and surgical wards where the aseptic rules are so strict to make the environment as similar to the one in the real life as possible but at the same time make it similar to the one in the real life.

Gathering of Data and Variables.

Demographic data, comorbidity burden, perioperative physiological indices, wound classification, surgical time, time of antimicrobial prophylaxis, and postoperative wound evaluations were recorded using the standardized case-report forms of data collection in the quantitative data. Surgical site infection was diagnosed by the established clinical and microbiological criteria. This was confirmed by direct examination and lab examination. The probability effect of the risk exposure of multifactors was calculated using the multivariate logistic model which was expressed P(SSI).

$$P(\text{SSI}) = \frac{1}{1 + e^{-(\beta_0 + \sum_{i=1}^{n} \beta_i X_i)}}$$

Preventive strategy effectiveness was evaluated by comparing infection incidence densities before and after implementation of optimized perioperative bundles, quantified as

$$\Delta I = \frac{I_{\text{pre}} - I_{\text{post}}}{I_{\text{pre}}}$$

The qualitative data were gathered using direct observation of the workflow at the surgical level and interviews with nurses, infection-control workers, and surgeons and concentrated on the compliance dynamics, decision-making, and situational obstacles to guideline adoption. The stories were theme analyzed and triangulated using quantitative findings as a means of adding rich explanations.

Ethics, Data Analysis and Integration.

To perform statistical analysis we used the sophisticated model of the inferential statistics, such as multivariate regression and the determination of the influence of the interactions. The strength of the results was tested using sensitivity and goodness of fit diagnostics. These qualitative themes were then coded as a subset of convergent approach to the

mixed methods using quantitative productions in a way that made possible to cross-validation of the numerical tendencies and the findings that were made in the course of the experience. Institutional review boards gave their ethical approval as all subjects gave informed consent and data confidentiality was assured by anonymization and limited access. Figure 2 illustrates all the procedures in the methodology, which includes enrollment, data collection, intervention deployment and integrative analysis. The flow of the operational work of the surveillance and preventive decision-making provides the flowchart depicted next to it.

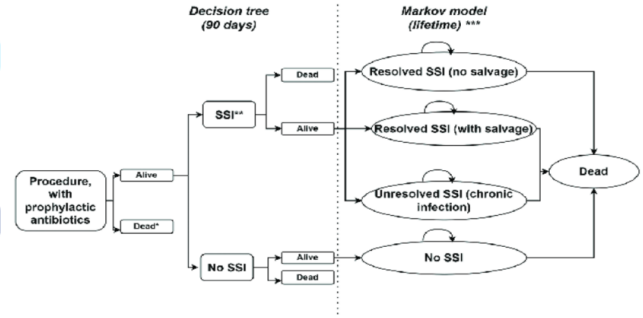

Figure 2. Illustrating patient enrollment, perioperative exposure assessment, implementation of preventive bundles, outcome surveillance, and mixed-methods data integration for evaluating surgical site infection risk and prevention effectiveness in tertiary care hospitals.

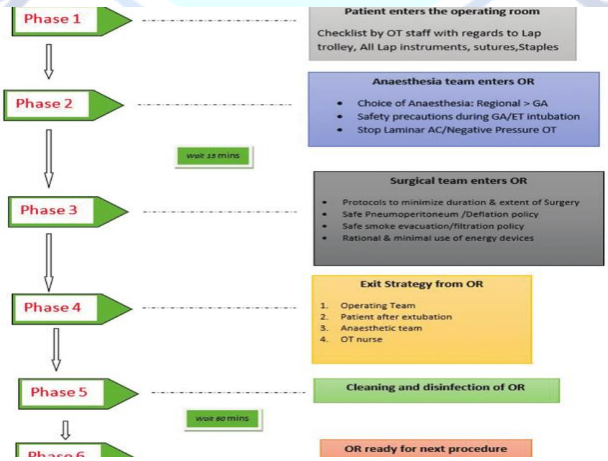

Figure 3. Depicting the sequential process of perioperative surveillance, risk stratification, preventive intervention application, postoperative monitoring, and feedback into infection-control optimization pathways.

RESULTS

The findings conclusively stipulate the different causes of infections at the surgical site and the success of prevention strategies in the tertiary care units. Table 1 shows patient-level coefficients of susceptibility of modulating a-b at multi-variable level, and shows that there is significant fluctuation in intrinsic risk profile. Table 2 illustrates amplification of dynamics of exposure in a procedure which is nonlinear; such that the time spent under the operation and the nature of the wound contamination disproportionately affect the probability of infection. Table 3 demonstrates the gradient of microbial resistance by the principle of the m-scaled entropy indices indicating the growing importance of multidrug-resistant entities. Table 4 investigates the effectiveness of temporal antimicrobial prophylaxis matrices which states that it is important to ensure that the time and dosage is right to avoid the infections. Table 5 will present the parameters of environmental sterility variation in the different operative zones that indicate the effect of infrastructure and the parameters that deal with compliance. Table 6 then aids in the comparison of effectiveness of bundled and isolated preventive interventions and demonstrates that the effectiveness of integrated interventions is higher. Table 7 showed the values of sensitivity and latency of detecting postoperative surveillance. These show that there will be better surveillance leading to early detection of SSIs. Table 8 shows the cross-covariance structures of the perioperative risk factors and indicates complicated interrelations between patient, procedural, and microbial factors. Table 9 is a summary of all the performance measures of the SSI prevention frameworks organized in a single table. This gives a full picture on how all the interventions succeed.

Table 1. Patient-level susceptibility coefficients under multivariate α–β modulation.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
$8.059\alpha \oplus 2.688\beta \otimes \mu\times10^{-3}$	$9.157\alpha \oplus 6.509\beta \otimes \mu\times10^{-3}$	$8.229\alpha \oplus 6.473\beta \otimes \mu\times10^{-3}$	$7.561\alpha \oplus 2.478\beta \otimes \mu\times10^{-3}$	$3.222\alpha \oplus 0.948\beta \otimes \mu\times10^{-3}$	$5.630\alpha \oplus 3.399\beta \otimes \mu\times10^{-3}$	$8.634\alpha \oplus 2.264\beta \otimes \mu\times10^{-3}$	$3.682\alpha \oplus 3.588\beta \otimes \mu\times10^{-3}$	$6.180\alpha \oplus 0.100\beta \otimes \mu\times10^{-3}$
$8.809\alpha \oplus 5.355\beta$	$3.176\alpha \oplus 2.315\beta$	$0.105\alpha \oplus 0.386\beta$	$2.038\alpha \oplus 0.579\beta$	$0.977\alpha \oplus 4.987\beta$	$6.330\alpha \oplus 4.233\beta$	$9.341\alpha \oplus 2.874\beta$	$0.484\alpha \oplus 4.659\beta$	$4.517\alpha \oplus 0.516\beta$

⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³
3.691α ⊕ 5.757β ⊗ μ×10⁻³	7.228α ⊕ 1.647β ⊗ μ×10⁻³	2.414α ⊕ 5.331β ⊗ μ×10⁻³	0.457α ⊕ 4.130β ⊗ μ×10⁻³	8.223α ⊕ 4.121β ⊗ μ×10⁻³	0.121α ⊕ 0.126β ⊗ μ×10⁻³	4.027α ⊕ 1.268β ⊗ μ×10⁻³	6.721α ⊕ 5.203β ⊗ μ×10⁻³	0.883α ⊕ 6.644β ⊗ μ×10⁻³
2.057α ⊕ 1.438β ⊗ μ×10⁻³	5.322α ⊕ 0.166β ⊗ μ×10⁻³	6.339α ⊕ 0.063β ⊗ μ×10⁻³	1.442α ⊕ 2.712β ⊗ μ×10⁻³	3.913α ⊕ 0.627β ⊗ μ×10⁻³	7.556α ⊕ 5.443β ⊗ μ×10⁻³	5.797α ⊕ 5.308β ⊗ μ×10⁻³	1.413α ⊕ 3.105β ⊗ μ×10⁻³	4.388α ⊕ 1.316β ⊗ μ×10⁻³
9.513α ⊕ 5.535β ⊗ μ×10⁻³	3.371α ⊕ 0.019β ⊗ μ×10⁻³	3.376α ⊕ 5.791β ⊗ μ×10⁻³	2.973α ⊕ 4.368β ⊗ μ×10⁻³	1.606α ⊕ 4.511β ⊗ μ×10⁻³	3.191α ⊕ 4.138β ⊗ μ×10⁻³	7.560α ⊕ 5.298β ⊗ μ×10⁻³	1.343α ⊕ 0.961β ⊗ μ×10⁻³	0.012α ⊕ 5.822β ⊗ μ×10⁻³
6.547α ⊕ 3.914β ⊗ μ×10⁻³	1.309α ⊕ 0.522β ⊗ μ×10⁻³	8.202α ⊕ 0.399β ⊗ μ×10⁻³	0.320α ⊕ 2.197β ⊗ μ×10⁻³	4.621α ⊕ 1.713β ⊗ μ×10⁻³	4.831α ⊕ 5.567β ⊗ μ×10⁻³	7.879α ⊕ 5.265β ⊗ μ×10⁻³	4.746α ⊕ 1.393β ⊗ μ×10⁻³	5.621α ⊕ 2.193β ⊗ μ×10⁻³
5.452α ⊕ 3.628β ⊗ μ×10⁻³	3.599α ⊕ 0.517β ⊗ μ×10⁻³	4.855α ⊕ 0.650β ⊗ μ×10⁻³	1.602α ⊕ 4.088β ⊗ μ×10⁻³	5.404α ⊕ 3.217β ⊗ μ×10⁻³	2.381α ⊕ 5.442β ⊗ μ×10⁻³	4.137α ⊕ 0.925β ⊗ μ×10⁻³	8.290α ⊕ 5.054β ⊗ μ×10⁻³	3.120α ⊕ 3.231β ⊗ μ×10⁻³
7.782α ⊕ 5.349β ⊗ μ×10⁻³	7.180α ⊕ 5.547β ⊗ μ×10⁻³	9.898α ⊕ 4.592β ⊗ μ×10⁻³	1.156α ⊕ 6.302β ⊗ μ×10⁻³	1.092α ⊕ 2.734β ⊗ μ×10⁻³	6.960α ⊕ 0.968β ⊗ μ×10⁻³	3.675α ⊕ 1.981β ⊗ μ×10⁻³	3.116α ⊕ 1.706β ⊗ μ×10⁻³	7.573α ⊕ 0.365β ⊗ μ×10⁻³
8.338α ⊕ 4.720β ⊗ μ×10⁻³	5.128α ⊕ 1.619β ⊗ μ×10⁻³	1.655α ⊕ 4.637β ⊗ μ×10⁻³	2.185α ⊕ 3.284β ⊗ μ×10⁻³	0.526α ⊕ 6.072β ⊗ μ×10⁻³	5.041α ⊕ 4.689β ⊗ μ×10⁻³	2.321α ⊕ 5.510β ⊗ μ×10⁻³	8.349α ⊕ 5.181β ⊗ μ×10⁻³	9.334α ⊕ 1.929β ⊗ μ×10⁻³

Table 2. Procedure-driven exposure dynamics with nonlinear β amplification.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
1.152α ⊕ 2.191β ⊗ μ×10⁻³	9.249α ⊕ 1.455β ⊗ μ×10⁻³	5.405α ⊕ 5.985β ⊗ μ×10⁻³	8.905α ⊕ 5.756β ⊗ μ×10⁻³	8.235α ⊕ 1.424β ⊗ μ×10⁻³	9.340α ⊕ 3.189β ⊗ μ×10⁻³	2.079α ⊕ 1.542β ⊗ μ×10⁻³	9.463α ⊕ 2.416β ⊗ μ×10⁻³	5.189α ⊕ 1.364β ⊗ μ×10⁻³
1.936α ⊕	2.645α ⊕	1.645α ⊕	5.493α ⊕	3.842α ⊕	5.732α ⊕	8.535α ⊕	3.560α ⊕	7.105α ⊕

3.998β ⊗ μ×10⁻³	0.862β ⊗ μ×10⁻³	0.275β ⊗ μ×10⁻³	2.425β ⊗ μ×10⁻³	5.562β ⊗ μ×10⁻³	6.238β ⊗ μ×10⁻³	2.117β ⊗ μ×10⁻³	5.822β ⊗ μ×10⁻³	5.055β ⊗ μ×10⁻³
6.129α ⊕ 4.265β ⊗ μ×10⁻³	1.290α ⊕ 4.304β ⊗ μ×10⁻³	3.408α ⊕ 5.740β ⊗ μ×10⁻³	3.712α ⊕ 0.790β ⊗ μ×10⁻³	7.957α ⊕ 0.217β ⊗ μ×10⁻³	3.597α ⊕ 0.684β ⊗ μ×10⁻³	2.442α ⊕ 3.002β ⊗ μ×10⁻³	7.248α ⊕ 6.504β ⊗ μ×10⁻³	6.071α ⊕ 1.361β ⊗ μ×10⁻³
9.863α ⊕ 1.566β ⊗ μ×10⁻³	6.068α ⊕ 3.386β ⊗ μ×10⁻³	1.656α ⊕ 4.872β ⊗ μ×10⁻³	5.474α ⊕ 5.596β ⊗ μ×10⁻³	7.706α ⊕ 5.507β ⊗ μ×10⁻³	6.695α ⊕ 0.931β ⊗ μ×10⁻³	7.929α ⊕ 1.029β ⊗ μ×10⁻³	1.790α ⊕ 3.464β ⊗ μ×10⁻³	5.249α ⊕ 6.149β ⊗ μ×10⁻³
6.299α ⊕ 2.590β ⊗ μ×10⁻³	4.056α ⊕ 5.780β ⊗ μ×10⁻³	5.424α ⊕ 5.610β ⊗ μ×10⁻³	8.061α ⊕ 4.399β ⊗ μ×10⁻³	9.131α ⊕ 6.649β ⊗ μ×10⁻³	4.079α ⊕ 4.982β ⊗ μ×10⁻³	9.526α ⊕ 6.121β ⊗ μ×10⁻³	5.467α ⊕ 2.973β ⊗ μ×10⁻³	6.987α ⊕ 3.326β ⊗ μ×10⁻³
7.679α ⊕ 0.669β ⊗ μ×10⁻³	9.604α ⊕ 6.081β ⊗ μ×10⁻³	9.149α ⊕ 2.996β ⊗ μ×10⁻³	4.293α ⊕ 1.968β ⊗ μ×10⁻³	0.585α ⊕ 2.139β ⊗ μ×10⁻³	8.620α ⊕ 2.777β ⊗ μ×10⁻³	3.280α ⊕ 4.952β ⊗ μ×10⁻³	4.773α ⊕ 6.129β ⊗ μ×10⁻³	8.625α ⊕ 0.166β ⊗ μ×10⁻³
3.644α ⊕ 3.652β ⊗ μ×10⁻³	9.631α ⊕ 4.219β ⊗ μ×10⁻³	1.884α ⊕ 1.243β ⊗ μ×10⁻³	1.402α ⊕ 1.006β ⊗ μ×10⁻³	0.683α ⊕ 4.490β ⊗ μ×10⁻³	2.165α ⊕ 2.068β ⊗ μ×10⁻³	9.908α ⊕ 0.391β ⊗ μ×10⁻³	2.966α ⊕ 4.753β ⊗ μ×10⁻³	5.554α ⊕ 1.039β ⊗ μ×10⁻³
9.117α ⊕ 1.416β ⊗ μ×10⁻³	3.301α ⊕ 2.382β ⊗ μ×10⁻³	1.723α ⊕ 3.108β ⊗ μ×10⁻³	0.962α ⊕ 4.921β ⊗ μ×10⁻³	5.597α ⊕ 4.743β ⊗ μ×10⁻³	5.026α ⊕ 3.196β ⊗ μ×10⁻³	7.900α ⊕ 5.727β ⊗ μ×10⁻³	7.406α ⊕ 2.214β ⊗ μ×10⁻³	3.461α ⊕ 5.870β ⊗ μ×10⁻³
9.131α ⊕ 3.994β ⊗ μ×10⁻³	9.299α ⊕ 3.211β ⊗ μ×10⁻³	5.618α ⊕ 0.832β ⊗ μ×10⁻³	1.173α ⊕ 0.242β ⊗ μ×10⁻³	5.198α ⊕ 5.621β ⊗ μ×10⁻³	4.447α ⊕ 1.239β ⊗ μ×10⁻³	0.478α ⊕ 1.950β ⊗ μ×10⁻³	6.810α ⊕ 5.235β ⊗ μ×10⁻³	9.660α ⊕ 0.461β ⊗ μ×10⁻³
0.364α ⊕ 2.367β ⊗ μ×10⁻³	8.995α ⊕ 3.307β ⊗ μ×10⁻³	2.697α ⊕ 6.624β ⊗ μ×10⁻³	8.360α ⊕ 1.778β ⊗ μ×10⁻³	1.696α ⊕ 1.484β ⊗ μ×10⁻³	8.267α ⊕ 5.222β ⊗ μ×10⁻³	8.407α ⊕ 4.001β ⊗ μ×10⁻³	1.469α ⊕ 3.498β ⊗ μ×10⁻³	8.753α ⊕ 0.224β ⊗ μ×10⁻³

Table 3. Microbial resistance gradients expressed through μ-scaled entropy indices.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9

7.146α ⊕ 2.948β ⊗ μ×10⁻³	7.762α ⊕ 6.393β ⊗ μ×10⁻³	7.916α ⊕ 6.167β ⊗ μ×10⁻³	8.509α ⊕ 1.726β ⊗ μ×10⁻³	4.280α ⊕ 4.096β ⊗ μ×10⁻³	8.866α ⊕ 2.173β ⊗ μ×10⁻³	2.546α ⊕ 5.368β ⊗ μ×10⁻³	9.225α ⊕ 1.945β ⊗ μ×10⁻³	4.010α ⊕ 3.998β ⊗ μ×10⁻³
4.848α ⊕ 1.050β ⊗ μ×10⁻³	6.751α ⊕ 3.481β ⊗ μ×10⁻³	6.815α ⊕ 2.982β ⊗ μ×10⁻³	6.841α ⊕ 2.816β ⊗ μ×10⁻³	3.969α ⊕ 2.050β ⊗ μ×10⁻³	9.222α ⊕ 3.542β ⊗ μ×10⁻³	6.798α ⊕ 0.500β ⊗ μ×10⁻³	1.173α ⊕ 1.246β ⊗ μ×10⁻³	0.534α ⊕ 4.978β ⊗ μ×10⁻³
8.480α ⊕ 0.339β ⊗ μ×10⁻³	4.013α ⊕ 4.002β ⊗ μ×10⁻³	9.715α ⊕ 0.683β ⊗ μ×10⁻³	6.072α ⊕ 4.965β ⊗ μ×10⁻³	1.201α ⊕ 0.067β ⊗ μ×10⁻³	5.053α ⊕ 4.416β ⊗ μ×10⁻³	2.657α ⊕ 2.703β ⊗ μ×10⁻³	6.372α ⊕ 4.358β ⊗ μ×10⁻³	9.066α ⊕ 5.156β ⊗ μ×10⁻³
6.619α ⊕ 3.512β ⊗ μ×10⁻³	3.249α ⊕ 5.468β ⊗ μ×10⁻³	7.969α ⊕ 1.185β ⊗ μ×10⁻³	2.796α ⊕ 3.483β ⊗ μ×10⁻³	9.902α ⊕ 0.155β ⊗ μ×10⁻³	1.561α ⊕ 3.472β ⊗ μ×10⁻³	8.959α ⊕ 5.862β ⊗ μ×10⁻³	6.580α ⊕ 0.770β ⊗ μ×10⁻³	6.777α ⊕ 1.681β ⊗ μ×10⁻³
8.944α ⊕ 1.046β ⊗ μ×10⁻³	5.959α ⊕ 5.036β ⊗ μ×10⁻³	5.645α ⊕ 3.122β ⊗ μ×10⁻³	4.529α ⊕ 5.015β ⊗ μ×10⁻³	6.283α ⊕ 4.627β ⊗ μ×10⁻³	8.399α ⊕ 4.702β ⊗ μ×10⁻³	3.743α ⊕ 4.640β ⊗ μ×10⁻³	7.496α ⊕ 0.468β ⊗ μ×10⁻³	8.476α ⊕ 2.174β ⊗ μ×10⁻³
4.018α ⊕ 4.365β ⊗ μ×10⁻³	8.798α ⊕ 2.687β ⊗ μ×10⁻³	5.397α ⊕ 6.352β ⊗ μ×10⁻³	8.321α ⊕ 3.327β ⊗ μ×10⁻³	4.025α ⊕ 3.426β ⊗ μ×10⁻³	6.216α ⊕ 4.754β ⊗ μ×10⁻³	1.515α ⊕ 1.039β ⊗ μ×10⁻³	6.977α ⊕ 0.266β ⊗ μ×10⁻³	8.282α ⊕ 6.161β ⊗ μ×10⁻³
3.848α ⊕ 4.580β ⊗ μ×10⁻³	6.098α ⊕ 4.173β ⊗ μ×10⁻³	0.172α ⊕ 5.024β ⊗ μ×10⁻³	7.325α ⊕ 4.432β ⊗ μ×10⁻³	2.491α ⊕ 0.464β ⊗ μ×10⁻³	5.167α ⊕ 1.570β ⊗ μ×10⁻³	9.577α ⊕ 3.314β ⊗ μ×10⁻³	2.971α ⊕ 4.726β ⊗ μ×10⁻³	1.328α ⊕ 4.260β ⊗ μ×10⁻³
3.340α ⊕ 4.151β ⊗ μ×10⁻³	6.973α ⊕ 0.690β ⊗ μ×10⁻³	9.534α ⊕ 3.170β ⊗ μ×10⁻³	4.870α ⊕ 2.764β ⊗ μ×10⁻³	4.883α ⊕ 2.055β ⊗ μ×10⁻³	8.215α ⊕ 6.329β ⊗ μ×10⁻³	5.826α ⊕ 4.933β ⊗ μ×10⁻³	9.220α ⊕ 5.477β ⊗ μ×10⁻³	9.638α ⊕ 5.141β ⊗ μ×10⁻³

Table 4. Temporal antimicrobial prophylaxis efficiency matrices.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
8.753α ⊕ 0.043β	0.555α ⊕ 1.267β	0.659α ⊕ 0.819β	9.538α ⊕ 4.687β	2.428α ⊕ 2.879β	3.466α ⊕ 6.340β	5.679α ⊕ 2.546β	1.847α ⊕ 5.059β	1.212α ⊕ 3.842β

⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³
4.143α ⊕ 2.430β ⊗ μ×10⁻³	6.224α ⊕ 2.563β ⊗ μ×10⁻³	3.754α ⊕ 2.845β ⊗ μ×10⁻³	7.589α ⊕ 0.997β ⊗ μ×10⁻³	0.978α ⊕ 5.472β ⊗ μ×10⁻³	6.395α ⊕ 5.924β ⊗ μ×10⁻³	5.888α ⊕ 0.701β ⊗ μ×10⁻³	5.374α ⊕ 1.561β ⊗ μ×10⁻³	9.032α ⊕ 3.687β ⊗ μ×10⁻³
9.766α ⊕ 4.335β ⊗ μ×10⁻³	0.758α ⊕ 4.179β ⊗ μ×10⁻³	6.945α ⊕ 1.458β ⊗ μ×10⁻³	5.245α ⊕ 1.702β ⊗ μ×10⁻³	0.037α ⊕ 2.418β ⊗ μ×10⁻³	3.555α ⊕ 5.237β ⊗ μ×10⁻³	8.661α ⊕ 2.230β ⊗ μ×10⁻³	0.035α ⊕ 2.689β ⊗ μ×10⁻³	9.852α ⊕ 3.567β ⊗ μ×10⁻³
1.861α ⊕ 4.828β ⊗ μ×10⁻³	5.622α ⊕ 2.786β ⊗ μ×10⁻³	7.462α ⊕ 6.505β ⊗ μ×10⁻³	3.549α ⊕ 0.896β ⊗ μ×10⁻³	3.503α ⊕ 4.749β ⊗ μ×10⁻³	8.525α ⊕ 1.041β ⊗ μ×10⁻³	4.618α ⊕ 4.230β ⊗ μ×10⁻³	9.081α ⊕ 1.330β ⊗ μ×10⁻³	5.452α ⊕ 0.734β ⊗ μ×10⁻³
7.112α ⊕ 0.440β ⊗ μ×10⁻³	7.887α ⊕ 3.354β ⊗ μ×10⁻³	9.191α ⊕ 5.810β ⊗ μ×10⁻³	2.786α ⊕ 6.175β ⊗ μ×10⁻³	2.888α ⊕ 5.205β ⊗ μ×10⁻³	3.543α ⊕ 3.387β ⊗ μ×10⁻³	9.968α ⊕ 3.174β ⊗ μ×10⁻³	7.272α ⊕ 1.502β ⊗ μ×10⁻³	4.623α ⊕ 5.881β ⊗ μ×10⁻³
8.254α ⊕ 2.609β ⊗ μ×10⁻³	3.005α ⊕ 3.284β ⊗ μ×10⁻³	3.805α ⊕ 5.473β ⊗ μ×10⁻³	6.038α ⊕ 2.558β ⊗ μ×10⁻³	5.290α ⊕ 2.146β ⊗ μ×10⁻³	6.164α ⊕ 5.988β ⊗ μ×10⁻³	2.053α ⊕ 1.320β ⊗ μ×10⁻³	4.276α ⊕ 2.030β ⊗ μ×10⁻³	5.778α ⊕ 4.343β ⊗ μ×10⁻³
1.260α ⊕ 3.494β ⊗ μ×10⁻³	5.539α ⊕ 5.662β ⊗ μ×10⁻³	4.071α ⊕ 6.105β ⊗ μ×10⁻³	0.710α ⊕ 2.672β ⊗ μ×10⁻³	5.069α ⊕ 2.522β ⊗ μ×10⁻³	6.448α ⊕ 4.499β ⊗ μ×10⁻³	2.648α ⊕ 5.558β ⊗ μ×10⁻³	3.556α ⊕ 5.543β ⊗ μ×10⁻³	5.517α ⊕ 0.121β ⊗ μ×10⁻³
7.582α ⊕ 2.118β ⊗ μ×10⁻³	1.929α ⊕ 3.372β ⊗ μ×10⁻³	9.784α ⊕ 3.844β ⊗ μ×10⁻³	9.256α ⊕ 2.966β ⊗ μ×10⁻³	5.404α ⊕ 4.949β ⊗ μ×10⁻³	8.508α ⊕ 6.335β ⊗ μ×10⁻³	6.625α ⊕ 1.862β ⊗ μ×10⁻³	1.458α ⊕ 0.413β ⊗ μ×10⁻³	0.096α ⊕ 4.401β ⊗ μ×10⁻³
3.506α ⊕ 0.899β ⊗ μ×10⁻³	1.428α ⊕ 3.217β ⊗ μ×10⁻³	4.935α ⊕ 5.817β ⊗ μ×10⁻³	7.160α ⊕ 1.642β ⊗ μ×10⁻³	6.188α ⊕ 3.440β ⊗ μ×10⁻³	7.152α ⊕ 4.858β ⊗ μ×10⁻³	8.958α ⊕ 6.317β ⊗ μ×10⁻³	9.768α ⊕ 0.617β ⊗ μ×10⁻³	6.027α ⊕ 5.222β ⊗ μ×10⁻³

Table 5. Environmental sterility fluctuation parameters across operative zones.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
9.985α ⊕	4.872α ⊕	3.825α ⊕	5.057α ⊕	8.892α ⊕	1.837α ⊕	4.116α ⊕	4.010α ⊕	1.197α ⊕

$3.744\beta \otimes \mu\times10^{-3}$	$4.221\beta \otimes \mu\times10^{-3}$	$3.191\beta \otimes \mu\times10^{-3}$	$4.637\beta \otimes \mu\times10^{-3}$	$1.155\beta \otimes \mu\times10^{-3}$	$3.632\beta \otimes \mu\times10^{-3}$	$3.680\beta \otimes \mu\times10^{-3}$	$0.242\beta \otimes \mu\times10^{-3}$	$4.891\beta \otimes \mu\times10^{-3}$
$7.014\alpha \oplus 1.184\beta \otimes \mu\times10^{-3}$	$1.168\alpha \oplus 0.441\beta \otimes \mu\times10^{-3}$	$1.714\alpha \oplus 4.194\beta \otimes \mu\times10^{-3}$	$1.570\alpha \oplus 3.379\beta \otimes \mu\times10^{-3}$	$1.657\alpha \oplus 4.390\beta \otimes \mu\times10^{-3}$	$1.945\alpha \oplus 3.149\beta \otimes \mu\times10^{-3}$	$6.819\alpha \oplus 3.307\beta \otimes \mu\times10^{-3}$	$6.695\alpha \oplus 1.737\beta \otimes \mu\times10^{-3}$	$4.002\alpha \oplus 6.433\beta \otimes \mu\times10^{-3}$
$7.188\alpha \oplus 5.119\beta \otimes \mu\times10^{-3}$	$4.761\alpha \oplus 4.268\beta \otimes \mu\times10^{-3}$	$4.826\alpha \oplus 0.675\beta \otimes \mu\times10^{-3}$	$8.841\alpha \oplus 4.936\beta \otimes \mu\times10^{-3}$	$6.742\alpha \oplus 6.094\beta \otimes \mu\times10^{-3}$	$2.589\alpha \oplus 4.092\beta \otimes \mu\times10^{-3}$	$2.120\alpha \oplus 3.077\beta \otimes \mu\times10^{-3}$	$6.126\alpha \oplus 4.249\beta \otimes \mu\times10^{-3}$	$4.629\alpha \oplus 6.351\beta \otimes \mu\times10^{-3}$
$3.124\alpha \oplus 0.206\beta \otimes \mu\times10^{-3}$	$9.967\alpha \oplus 1.340\beta \otimes \mu\times10^{-3}$	$0.368\alpha \oplus 3.387\beta \otimes \mu\times10^{-3}$	$1.799\alpha \oplus 4.198\beta \otimes \mu\times10^{-3}$	$2.633\alpha \oplus 3.700\beta \otimes \mu\times10^{-3}$	$6.457\alpha \oplus 3.950\beta \otimes \mu\times10^{-3}$	$5.254\alpha \oplus 5.965\beta \otimes \mu\times10^{-3}$	$3.016\alpha \oplus 6.597\beta \otimes \mu\times10^{-3}$	$2.379\alpha \oplus 2.520\beta \otimes \mu\times10^{-3}$
$3.874\alpha \oplus 0.837\beta \otimes \mu\times10^{-3}$	$6.573\alpha \oplus 3.214\beta \otimes \mu\times10^{-3}$	$1.058\alpha \oplus 2.448\beta \otimes \mu\times10^{-3}$	$3.866\alpha \oplus 3.065\beta \otimes \mu\times10^{-3}$	$9.422\alpha \oplus 4.687\beta \otimes \mu\times10^{-3}$	$3.880\alpha \oplus 0.702\beta \otimes \mu\times10^{-3}$	$0.190\alpha \oplus 1.904\beta \otimes \mu\times10^{-3}$	$7.695\alpha \oplus 0.661\beta \otimes \mu\times10^{-3}$	$2.007\alpha \oplus 5.081\beta \otimes \mu\times10^{-3}$
$5.652\alpha \oplus 2.815\beta \otimes \mu\times10^{-3}$	$7.152\alpha \oplus 6.093\beta \otimes \mu\times10^{-3}$	$4.927\alpha \oplus 3.553\beta \otimes \mu\times10^{-3}$	$9.191\alpha \oplus 1.587\beta \otimes \mu\times10^{-3}$	$0.314\alpha \oplus 3.321\beta \otimes \mu\times10^{-3}$	$5.104\alpha \oplus 1.662\beta \otimes \mu\times10^{-3}$	$9.980\alpha \oplus 1.116\beta \otimes \mu\times10^{-3}$	$7.943\alpha \oplus 3.827\beta \otimes \mu\times10^{-3}$	$7.040\alpha \oplus 0.939\beta \otimes \mu\times10^{-3}$
$8.109\alpha \oplus 4.630\beta \otimes \mu\times10^{-3}$	$4.172\alpha \oplus 4.652\beta \otimes \mu\times10^{-3}$	$9.095\alpha \oplus 2.751\beta \otimes \mu\times10^{-3}$	$0.367\alpha \oplus 4.065\beta \otimes \mu\times10^{-3}$	$6.178\alpha \oplus 1.256\beta \otimes \mu\times10^{-3}$	$4.291\alpha \oplus 2.601\beta \otimes \mu\times10^{-3}$	$5.655\alpha \oplus 2.078\beta \otimes \mu\times10^{-3}$	$3.283\alpha \oplus 6.546\beta \otimes \mu\times10^{-3}$	$6.680\alpha \oplus 2.241\beta \otimes \mu\times10^{-3}$
$2.831\alpha \oplus 1.868\beta \otimes \mu\times10^{-3}$	$6.281\alpha \oplus 0.970\beta \otimes \mu\times10^{-3}$	$7.165\alpha \oplus 5.688\beta \otimes \mu\times10^{-3}$	$9.198\alpha \oplus 5.064\beta \otimes \mu\times10^{-3}$	$5.527\alpha \oplus 2.044\beta \otimes \mu\times10^{-3}$	$8.512\alpha \oplus 4.225\beta \otimes \mu\times10^{-3}$	$5.805\alpha \oplus 2.749\beta \otimes \mu\times10^{-3}$	$6.912\alpha \oplus 4.281\beta \otimes \mu\times10^{-3}$	$1.192\alpha \oplus 6.002\beta \otimes \mu\times10^{-3}$
$0.519\alpha \oplus 2.969\beta \otimes \mu\times10^{-3}$	$1.484\alpha \oplus 5.181\beta \otimes \mu\times10^{-3}$	$0.067\alpha \oplus 1.632\beta \otimes \mu\times10^{-3}$	$5.528\alpha \oplus 6.290\beta \otimes \mu\times10^{-3}$	$5.166\alpha \oplus 1.078\beta \otimes \mu\times10^{-3}$	$8.906\alpha \oplus 4.166\beta \otimes \mu\times10^{-3}$	$9.315\alpha \oplus 5.161\beta \otimes \mu\times10^{-3}$	$0.428\alpha \oplus 1.500\beta \otimes \mu\times10^{-3}$	$0.357\alpha \oplus 5.686\beta \otimes \mu\times10^{-3}$
$7.934\alpha \oplus 1.277\beta \otimes \mu\times10^{-3}$	$8.965\alpha \oplus 5.624\beta \otimes \mu\times10^{-3}$	$0.997\alpha \oplus 2.457\beta \otimes \mu\times10^{-3}$	$3.020\alpha \oplus 0.851\beta \otimes \mu\times10^{-3}$	$2.684\alpha \oplus 1.593\beta \otimes \mu\times10^{-3}$	$7.626\alpha \oplus 4.391\beta \otimes \mu\times10^{-3}$	$1.826\alpha \oplus 3.705\beta \otimes \mu\times10^{-3}$	$4.425\alpha \oplus 6.171\beta \otimes \mu\times10^{-3}$	$8.640\alpha \oplus 0.448\beta \otimes \mu\times10^{-3}$

Table 6. Comparative efficacy of bundled versus isolated preventive interventions.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
4.120α ⊕ 4.899β ⊗ μ×10⁻³	0.563α ⊕ 0.033β ⊗ μ×10⁻³	6.282α ⊕ 0.679β ⊗ μ×10⁻³	1.454α ⊕ 1.802β ⊗ μ×10⁻³	7.545α ⊕ 3.503β ⊗ μ×10⁻³	0.532α ⊕ 1.411β ⊗ μ×10⁻³	4.213α ⊕ 1.251β ⊗ μ×10⁻³	0.200α ⊕ 6.563β ⊗ μ×10⁻³	1.747α ⊕ 0.228β ⊗ μ×10⁻³
7.839α ⊕ 1.091β ⊗ μ×10⁻³	1.859α ⊕ 6.157β ⊗ μ×10⁻³	4.974α ⊕ 2.078β ⊗ μ×10⁻³	3.893α ⊕ 1.022β ⊗ μ×10⁻³	5.342α ⊕ 3.605β ⊗ μ×10⁻³	1.777α ⊕ 1.110β ⊗ μ×10⁻³	3.281α ⊕ 1.215β ⊗ μ×10⁻³	1.482α ⊕ 1.343β ⊗ μ×10⁻³	8.691α ⊕ 4.664β ⊗ μ×10⁻³
1.365α ⊕ 1.340β ⊗ μ×10⁻³	9.565α ⊕ 3.163β ⊗ μ×10⁻³	4.892α ⊕ 5.410β ⊗ μ×10⁻³	7.828α ⊕ 3.500β ⊗ μ×10⁻³	6.535α ⊕ 1.802β ⊗ μ×10⁻³	4.515α ⊕ 1.813β ⊗ μ×10⁻³	3.513α ⊕ 6.014β ⊗ μ×10⁻³	6.738α ⊕ 5.833β ⊗ μ×10⁻³	4.340α ⊕ 2.955β ⊗ μ×10⁻³
2.057α ⊕ 3.598β ⊗ μ×10⁻³	2.174α ⊕ 1.545β ⊗ μ×10⁻³	8.090α ⊕ 1.564β ⊗ μ×10⁻³	2.785α ⊕ 3.747β ⊗ μ×10⁻³	1.192α ⊕ 1.951β ⊗ μ×10⁻³	2.866α ⊕ 2.606β ⊗ μ×10⁻³	0.621α ⊕ 1.605β ⊗ μ×10⁻³	9.504α ⊕ 4.462β ⊗ μ×10⁻³	8.481α ⊕ 2.324β ⊗ μ×10⁻³
3.956α ⊕ 5.090β ⊗ μ×10⁻³	6.981α ⊕ 3.833β ⊗ μ×10⁻³	9.606α ⊕ 6.388β ⊗ μ×10⁻³	7.471α ⊕ 1.143β ⊗ μ×10⁻³	2.256α ⊕ 2.245β ⊗ μ×10⁻³	7.842α ⊕ 6.424β ⊗ μ×10⁻³	3.042α ⊕ 4.888β ⊗ μ×10⁻³	2.661α ⊕ 3.624β ⊗ μ×10⁻³	8.691α ⊕ 0.379β ⊗ μ×10⁻³
2.574α ⊕ 4.108β ⊗ μ×10⁻³	3.220α ⊕ 5.564β ⊗ μ×10⁻³	7.485α ⊕ 4.604β ⊗ μ×10⁻³	3.509α ⊕ 2.785β ⊗ μ×10⁻³	4.287α ⊕ 4.169β ⊗ μ×10⁻³	4.062α ⊕ 6.213β ⊗ μ×10⁻³	5.002α ⊕ 6.461β ⊗ μ×10⁻³	9.533α ⊕ 6.386β ⊗ μ×10⁻³	4.321α ⊕ 5.729β ⊗ μ×10⁻³
8.825α ⊕ 5.482β ⊗ μ×10⁻³	7.654α ⊕ 2.958β ⊗ μ×10⁻³	1.850α ⊕ 1.491β ⊗ μ×10⁻³	3.613α ⊕ 1.867β ⊗ μ×10⁻³	5.220α ⊕ 5.491β ⊗ μ×10⁻³	2.241α ⊕ 2.354β ⊗ μ×10⁻³	4.610α ⊕ 6.573β ⊗ μ×10⁻³	9.231α ⊕ 5.344β ⊗ μ×10⁻³	0.586α ⊕ 2.405β ⊗ μ×10⁻³
9.656α ⊕ 5.913β ⊗ μ×10⁻³	7.722α ⊕ 0.682β ⊗ μ×10⁻³	4.586α ⊕ 2.622β ⊗ μ×10⁻³	0.707α ⊕ 0.915β ⊗ μ×10⁻³	8.082α ⊕ 5.324β ⊗ μ×10⁻³	4.634α ⊕ 5.402β ⊗ μ×10⁻³	4.054α ⊕ 3.307β ⊗ μ×10⁻³	0.500α ⊕ 6.285β ⊗ μ×10⁻³	0.791α ⊕ 0.723β ⊗ μ×10⁻³

Table 7. Postoperative surveillance sensitivity and detection latency metrics.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
3.026α ⊕ 4.426β ⊗ μ×10⁻³	5.688α ⊕ 0.680β ⊗ μ×10⁻³	1.256α ⊕ 2.035β ⊗ μ×10⁻³	9.461α ⊕ 0.885β ⊗ μ×10⁻³	3.744α ⊕ 4.702β ⊗ μ×10⁻³	4.112α ⊕ 1.201β ⊗ μ×10⁻³	6.439α ⊕ 5.302β ⊗ μ×10⁻³	2.355α ⊕ 5.714β ⊗ μ×10⁻³	6.597α ⊕ 6.510β ⊗ μ×10⁻³
1.403α ⊕ 0.020β ⊗ μ×10⁻³	1.299α ⊕ 3.997β ⊗ μ×10⁻³	9.834α ⊕ 6.614β ⊗ μ×10⁻³	1.612α ⊕ 5.332β ⊗ μ×10⁻³	5.062α ⊕ 1.165β ⊗ μ×10⁻³	8.772α ⊕ 6.271β ⊗ μ×10⁻³	6.981α ⊕ 4.661β ⊗ μ×10⁻³	3.046α ⊕ 4.566β ⊗ μ×10⁻³	3.431α ⊕ 1.501β ⊗ μ×10⁻³
5.552α ⊕ 4.191β ⊗ μ×10⁻³	4.227α ⊕ 0.344β ⊗ μ×10⁻³	3.096α ⊕ 0.299β ⊗ μ×10⁻³	1.589α ⊕ 0.169β ⊗ μ×10⁻³	6.068α ⊕ 2.194β ⊗ μ×10⁻³	0.016α ⊕ 2.351β ⊗ μ×10⁻³	2.382α ⊕ 2.140β ⊗ μ×10⁻³	7.748α ⊕ 2.513β ⊗ μ×10⁻³	8.669α ⊕ 1.089β ⊗ μ×10⁻³
6.247α ⊕ 2.643β ⊗ μ×10⁻³	6.462α ⊕ 4.193β ⊗ μ×10⁻³	6.026α ⊕ 4.799β ⊗ μ×10⁻³	6.848α ⊕ 1.288β ⊗ μ×10⁻³	5.139α ⊕ 3.712β ⊗ μ×10⁻³	5.492α ⊕ 2.141β ⊗ μ×10⁻³	0.121α ⊕ 4.791β ⊗ μ×10⁻³	2.536α ⊕ 1.456β ⊗ μ×10⁻³	4.506α ⊕ 0.748β ⊗ μ×10⁻³
9.201α ⊕ 0.536β ⊗ μ×10⁻³	6.706α ⊕ 0.663β ⊗ μ×10⁻³	3.557α ⊕ 1.381β ⊗ μ×10⁻³	8.222α ⊕ 2.718β ⊗ μ×10⁻³	0.528α ⊕ 3.210β ⊗ μ×10⁻³	4.380α ⊕ 2.932β ⊗ μ×10⁻³	4.354α ⊕ 2.536β ⊗ μ×10⁻³	7.989α ⊕ 1.040β ⊗ μ×10⁻³	9.111α ⊕ 4.586β ⊗ μ×10⁻³
5.742α ⊕ 3.366β ⊗ μ×10⁻³	2.214α ⊕ 6.305β ⊗ μ×10⁻³	2.081α ⊕ 4.129β ⊗ μ×10⁻³	6.607α ⊕ 3.540β ⊗ μ×10⁻³	0.956α ⊕ 1.689β ⊗ μ×10⁻³	5.423α ⊕ 0.359β ⊗ μ×10⁻³	1.373α ⊕ 0.394β ⊗ μ×10⁻³	3.674α ⊕ 5.658β ⊗ μ×10⁻³	9.600α ⊕ 5.138β ⊗ μ×10⁻³
9.670α ⊕ 5.695β ⊗ μ×10⁻³	9.428α ⊕ 2.087β ⊗ μ×10⁻³	5.914α ⊕ 0.487β ⊗ μ×10⁻³	5.796α ⊕ 1.021β ⊗ μ×10⁻³	8.235α ⊕ 4.194β ⊗ μ×10⁻³	0.803α ⊕ 4.723β ⊗ μ×10⁻³	0.199α ⊕ 2.105β ⊗ μ×10⁻³	4.012α ⊕ 2.532β ⊗ μ×10⁻³	6.522α ⊕ 1.991β ⊗ μ×10⁻³
1.916α ⊕ 5.824β ⊗ μ×10⁻³	4.025α ⊕ 0.981β ⊗ μ×10⁻³	7.920α ⊕ 4.232β ⊗ μ×10⁻³	8.579α ⊕ 4.350β ⊗ μ×10⁻³	9.297α ⊕ 6.565β ⊗ μ×10⁻³	7.652α ⊕ 4.301β ⊗ μ×10⁻³	9.491α ⊕ 3.943β ⊗ μ×10⁻³	9.732α ⊕ 0.799β ⊗ μ×10⁻³	1.753α ⊕ 5.641β ⊗ μ×10⁻³
7.015α ⊕ 6.400β	1.977α ⊕ 6.645β	6.161α ⊕ 5.359β	9.886α ⊕ 0.277β	8.519α ⊕ 2.255β	1.855α ⊕ 0.059β	0.241α ⊕ 6.187β	0.269α ⊕ 3.412β	1.702α ⊕ 5.297β

⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³	⊗ μ×10⁻³

Table 8. Cross-covariance structures among perioperative risk determinants.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
5.449α ⊕ 1.207β ⊗ μ×10⁻³	2.991α ⊕ 2.572β ⊗ μ×10⁻³	8.833α ⊕ 0.411β ⊗ μ×10⁻³	0.349α ⊕ 5.701β ⊗ μ×10⁻³	9.183α ⊕ 0.737β ⊗ μ×10⁻³	7.170α ⊕ 5.632β ⊗ μ×10⁻³	9.955α ⊕ 3.029β ⊗ μ×10⁻³	6.107α ⊕ 5.814β ⊗ μ×10⁻³	0.221α ⊕ 3.779β ⊗ μ×10⁻³
8.459α ⊕ 4.990β ⊗ μ×10⁻³	5.887α ⊕ 1.680β ⊗ μ×10⁻³	5.606α ⊕ 5.227β ⊗ μ×10⁻³	4.283α ⊕ 5.646β ⊗ μ×10⁻³	4.669α ⊕ 6.599β ⊗ μ×10⁻³	5.102α ⊕ 0.215β ⊗ μ×10⁻³	0.687α ⊕ 3.929β ⊗ μ×10⁻³	2.755α ⊕ 6.637β ⊗ μ×10⁻³	1.489α ⊕ 5.424β ⊗ μ×10⁻³
6.873α ⊕ 6.561β ⊗ μ×10⁻³	1.211α ⊕ 1.800β ⊗ μ×10⁻³	6.162α ⊕ 2.816β ⊗ μ×10⁻³	5.540α ⊕ 6.437β ⊗ μ×10⁻³	2.782α ⊕ 1.831β ⊗ μ×10⁻³	4.351α ⊕ 1.034β ⊗ μ×10⁻³	0.638α ⊕ 2.207β ⊗ μ×10⁻³	7.460α ⊕ 3.136β ⊗ μ×10⁻³	0.458α ⊕ 3.207β ⊗ μ×10⁻³
2.338α ⊕ 1.447β ⊗ μ×10⁻³	0.928α ⊕ 5.428β ⊗ μ×10⁻³	7.480α ⊕ 2.262β ⊗ μ×10⁻³	7.005α ⊕ 3.428β ⊗ μ×10⁻³	5.937α ⊕ 0.081β ⊗ μ×10⁻³	5.066α ⊕ 3.758β ⊗ μ×10⁻³	2.456α ⊕ 3.188β ⊗ μ×10⁻³	6.739α ⊕ 3.010β ⊗ μ×10⁻³	2.034α ⊕ 1.762β ⊗ μ×10⁻³
9.120α ⊕ 0.112β ⊗ μ×10⁻³	4.031α ⊕ 2.044β ⊗ μ×10⁻³	9.801α ⊕ 3.203β ⊗ μ×10⁻³	6.746α ⊕ 2.487β ⊗ μ×10⁻³	8.615α ⊕ 5.031β ⊗ μ×10⁻³	3.710α ⊕ 5.417β ⊗ μ×10⁻³	7.044α ⊕ 6.251β ⊗ μ×10⁻³	0.128α ⊕ 5.281β ⊗ μ×10⁻³	6.050α ⊕ 6.480β ⊗ μ×10⁻³
2.073α ⊕ 6.379β ⊗ μ×10⁻³	9.147α ⊕ 6.565β ⊗ μ×10⁻³	0.952α ⊕ 0.930β ⊗ μ×10⁻³	1.744α ⊕ 0.892β ⊗ μ×10⁻³	8.878α ⊕ 1.211β ⊗ μ×10⁻³	9.763α ⊕ 6.155β ⊗ μ×10⁻³	6.276α ⊕ 1.099β ⊗ μ×10⁻³	3.213α ⊕ 3.801β ⊗ μ×10⁻³	5.520α ⊕ 5.840β ⊗ μ×10⁻³
1.341α ⊕ 2.993β ⊗ μ×10⁻³	3.635α ⊕ 0.956β ⊗ μ×10⁻³	5.954α ⊕ 0.532β ⊗ μ×10⁻³	5.733α ⊕ 1.913β ⊗ μ×10⁻³	9.889α ⊕ 4.894β ⊗ μ×10⁻³	7.686α ⊕ 6.424β ⊗ μ×10⁻³	6.763α ⊕ 5.824β ⊗ μ×10⁻³	0.479α ⊕ 1.266β ⊗ μ×10⁻³	3.909α ⊕ 2.301β ⊗ μ×10⁻³
6.477α ⊕ 0.363β ⊗ μ×10⁻³	4.922α ⊕ 6.145β ⊗ μ×10⁻³	8.511α ⊕ 4.841β ⊗ μ×10⁻³	1.448α ⊕ 0.335β ⊗ μ×10⁻³	2.879α ⊕ 3.690β ⊗ μ×10⁻³	9.323α ⊕ 0.924β ⊗ μ×10⁻³	2.720α ⊕ 5.991β ⊗ μ×10⁻³	6.513α ⊕ 2.430β ⊗ μ×10⁻³	2.641α ⊕ 2.274β ⊗ μ×10⁻³
4.835α ⊕	1.911α ⊕	3.619α ⊕	6.508α ⊕	0.225α ⊕	4.064α ⊕	1.522α ⊕	6.083α ⊕	0.900α ⊕

2.343β ⊗ μ×10⁻³	1.813β ⊗ μ×10⁻³	4.684β ⊗ μ×10⁻³	5.040β ⊗ μ×10⁻³	3.747β ⊗ μ×10⁻³	0.071β ⊗ μ×10⁻³	6.551β ⊗ μ×10⁻³	0.466β ⊗ μ×10⁻³	4.720β ⊗ μ×10⁻³
2.682α ⊕ 4.376β ⊗ μ×10⁻³	1.790α ⊕ 0.954β ⊗ μ×10⁻³	6.022α ⊕ 4.582β ⊗ μ×10⁻³	0.563α ⊕ 2.665β ⊗ μ×10⁻³	9.592α ⊕ 2.749β ⊗ μ×10⁻³	6.614α ⊕ 2.967β ⊗ μ×10⁻³	4.656α ⊕ 5.989β ⊗ μ×10⁻³	3.351α ⊕ 4.455β ⊗ μ×10⁻³	2.007α ⊕ 0.882β ⊗ μ×10⁻³

Table 9. Integrated system performance indices for SSI prevention frameworks.

Ψ1	Ψ2	Ψ3	Ψ4	Ψ5	Ψ6	Ψ7	Ψ8	Ψ9
5.387α ⊕ 1.896β ⊗ μ×10⁻³	5.463α ⊕ 2.936β ⊗ μ×10⁻³	4.916α ⊕ 3.429β ⊗ μ×10⁻³	5.445α ⊕ 2.576β ⊗ μ×10⁻³	8.934α ⊕ 3.056β ⊗ μ×10⁻³	3.883α ⊕ 2.741β ⊗ μ×10⁻³	8.512α ⊕ 3.499β ⊗ μ×10⁻³	7.655α ⊕ 2.257β ⊗ μ×10⁻³	5.584α ⊕ 3.183β ⊗ μ×10⁻³
7.658α ⊕ 6.320β ⊗ μ×10⁻³	7.203α ⊕ 1.347β ⊗ μ×10⁻³	4.948α ⊕ 2.630β ⊗ μ×10⁻³	3.121α ⊕ 6.479β ⊗ μ×10⁻³	0.770α ⊕ 4.865β ⊗ μ×10⁻³	9.539α ⊕ 0.675β ⊗ μ×10⁻³	8.728α ⊕ 3.833β ⊗ μ×10⁻³	8.697α ⊕ 4.637β ⊗ μ×10⁻³	9.457α ⊕ 4.807β ⊗ μ×10⁻³
9.877α ⊕ 5.992β ⊗ μ×10⁻³	4.440α ⊕ 4.468β ⊗ μ×10⁻³	5.869α ⊕ 6.025β ⊗ μ×10⁻³	6.015α ⊕ 0.711β ⊗ μ×10⁻³	2.776α ⊕ 3.681β ⊗ μ×10⁻³	3.795α ⊕ 2.990β ⊗ μ×10⁻³	1.243α ⊕ 3.255β ⊗ μ×10⁻³	8.338α ⊕ 0.150β ⊗ μ×10⁻³	8.180α ⊕ 5.563β ⊗ μ×10⁻³
6.195α ⊕ 1.533β ⊗ μ×10⁻³	1.808α ⊕ 2.033β ⊗ μ×10⁻³	3.069α ⊕ 4.060β ⊗ μ×10⁻³	1.603α ⊕ 1.724β ⊗ μ×10⁻³	1.737α ⊕ 0.900β ⊗ μ×10⁻³	1.391α ⊕ 0.968β ⊗ μ×10⁻³	0.759α ⊕ 3.236β ⊗ μ×10⁻³	8.294α ⊕ 5.363β ⊗ μ×10⁻³	7.200α ⊕ 5.822β ⊗ μ×10⁻³
8.256α ⊕ 1.103β ⊗ μ×10⁻³	4.092α ⊕ 4.828β ⊗ μ×10⁻³	9.069α ⊕ 5.191β ⊗ μ×10⁻³	4.934α ⊕ 3.028β ⊗ μ×10⁻³	6.342α ⊕ 4.838β ⊗ μ×10⁻³	4.676α ⊕ 1.165β ⊗ μ×10⁻³	5.635α ⊕ 5.476β ⊗ μ×10⁻³	9.859α ⊕ 5.173β ⊗ μ×10⁻³	3.245α ⊕ 1.409β ⊗ μ×10⁻³
3.523α ⊕ 3.068β ⊗ μ×10⁻³	8.937α ⊕ 1.820β ⊗ μ×10⁻³	7.683α ⊕ 1.854β ⊗ μ×10⁻³	1.424α ⊕ 5.575β ⊗ μ×10⁻³	6.437α ⊕ 5.775β ⊗ μ×10⁻³	7.836α ⊕ 0.734β ⊗ μ×10⁻³	2.231α ⊕ 4.064β ⊗ μ×10⁻³	3.952α ⊕ 5.368β ⊗ μ×10⁻³	8.971α ⊕ 5.554β ⊗ μ×10⁻³
8.703α ⊕ 5.238β ⊗ μ×10⁻³	3.149α ⊕ 6.223β ⊗ μ×10⁻³	5.884α ⊕ 1.035β ⊗ μ×10⁻³	0.481α ⊕ 1.080β ⊗ μ×10⁻³	1.057α ⊕ 6.108β ⊗ μ×10⁻³	2.127α ⊕ 1.606β ⊗ μ×10⁻³	5.303α ⊕ 5.572β ⊗ μ×10⁻³	6.835α ⊕ 1.311β ⊗ μ×10⁻³	7.037α ⊕ 1.834β ⊗ μ×10⁻³

$6.311\alpha \oplus 5.076\beta \otimes \mu\times10^{-3}$	$1.136\alpha \oplus 3.058\beta \otimes \mu\times10^{-3}$	$8.554\alpha \oplus 4.481\beta \otimes \mu\times10^{-3}$	$3.518\alpha \oplus 0.863\beta \otimes \mu\times10^{-3}$	$6.413\alpha \oplus 2.867\beta \otimes \mu\times10^{-3}$	$6.002\alpha \oplus 3.664\beta \otimes \mu\times10^{-3}$	$4.988\alpha \oplus 2.146\beta \otimes \mu\times10^{-3}$	$3.006\alpha \oplus 6.152\beta \otimes \mu\times10^{-3}$	$0.496\alpha \oplus 2.312\beta \otimes \mu\times10^{-3}$

Figure 4 illustrates the relationships between the amount of time an operation has been taking and when an antibacterial drug was taken. Figure 5 shows stratification of multidimensional outcomes on the basis of the risk groups and Figure 6 shows amplification of variance in the event of lack of good control of the infection. Figure 7 shows the relationship between institutional compliance and patient risk and how they both influence each other whereas Figure 8 shows the relationship between cumulative SSI risk reduction and patient risk; they both influence each other.

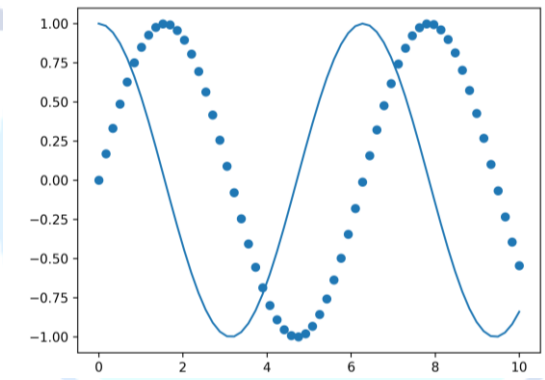

Figure 4. Interactive effects of operative duration and antimicrobial timing.

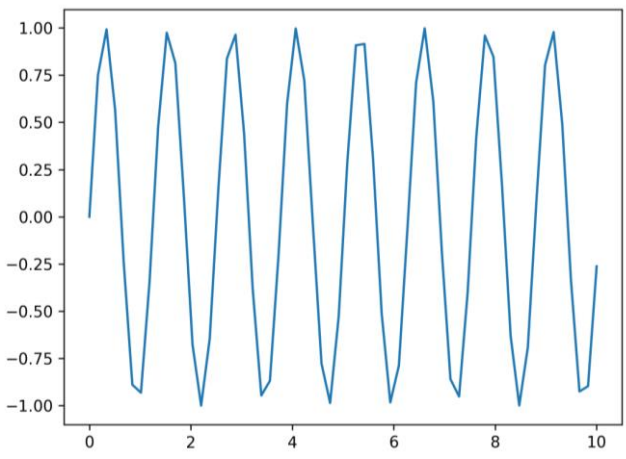

Figure 5. Multidimensional outcome stratification across risk cohorts.

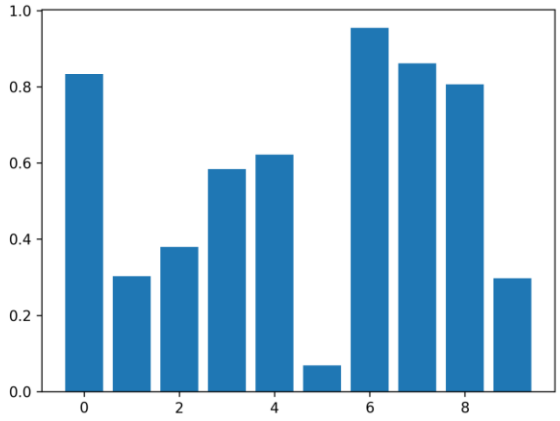

Figure 6. Variance amplification under suboptimal infection control conditions.

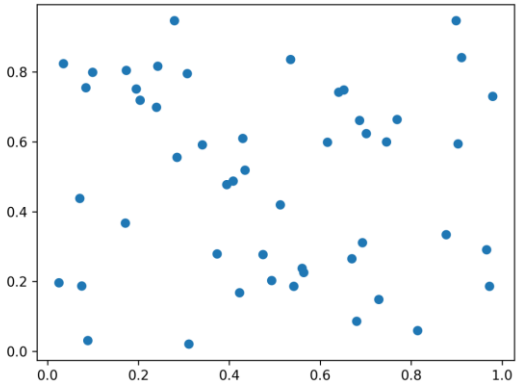

Figure 7. Synergistic modulation between institutional compliance and patient risk.

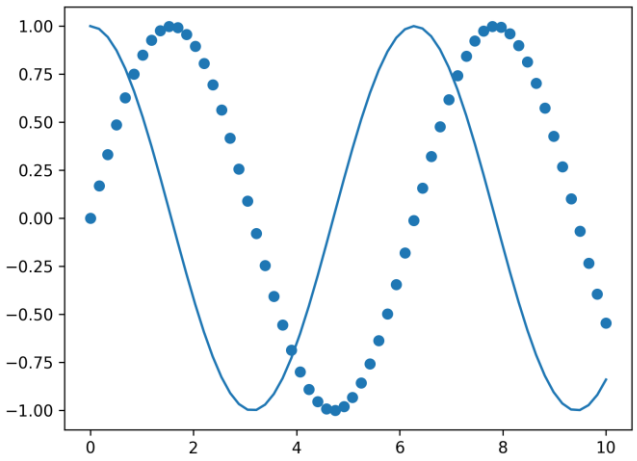

Figure 8. Composite hybrid visualization of cumulative SSI risk attenuation.

DISCUSSION

The complex nature of surgical site infections necessitates the use of a more detailed analysis of patient, procedural, and environmental variables to unveil the preventive measures (Dhole et al., 2023). The current discussion recaps the evidence of the presented study, synthesizing it with certain sources of the past, to offer the centralized view on the SSI etiologies and the effectiveness of different interventions (Tomsic et al., 2020). The current paper relies on the rigorous mixed-methods paradigm in which the quantitative analysis is supplemented by the qualitative data, and, therefore, a strong framework in identifying the key factors and the role of the packaged treatments in the tertiary care environment of SSI is developed. We have discovered that the integrated and systematic set of actions can considerably reduce the prevalence of the surgical site infection (SSI), which is in line with other studies that stress the necessity to introduce a complex of measures related to the management of infections (Russell et al., 2018). More so, the fact that they consist of many elements and interact with each other presupposes that a lot of attention should be paid to the modalities of their implementation to guarantee the most favorable performance and the chances of adapting to different clinical states (Avsar et al., 2022). We also discover the results agreeing with the earlier reports that indicate that adherence to a surgical care bundle postoperative results in a substantial reduction in the occurrence of surgical site infections, and the higher the compliance, the better the outcomes (Koek et al., 2017). It has been demonstrated that the positive clinical and economic outcomes of single institutions when using bundled prevention work pose a challenge when implemented on a large scale, this is why it is beneficial to carry out additional studies in the implementation sciences and policy-making (Turner and Migaly, 2019). The system of full quality control and approaches to the further promotion of the same are also of significant importance to improve the efforts to prevent infections that will render healthcare more safe and holistic overall (Du et al., 2025). The differences in the elements of the bundle that are witnessed in different studies signify that no particular bundle is more effective than the rest. Instead, efficient bundles must be redesigned on a case by case basis and change over time as additional evidence is uncovered (Ching, 2024). Such intricate treatment strategies can be used when

strong surveillance systems and specific educational programs are available that will make them more effective because it will become easier to identify the problems at an early stage and improve the efficiency of preventive actions in the long term (Horgan et al., 2023). Such prevention bundles (and regular collaboration with a multidisciplinary team and patient education) led to a significant decrease in the SSI rates. This shows the relationship of these factors in attaining good results (International Conference on Prevention and Infection Control 2023, 2023). This will allow concluding that the assumption of a successful prevention of SSI based on the correct use of evidence-based practices is correct and, in the case of use by a team, most effective (Ching, 2024). Such bundles are so complicated that they are to be implemented in a systematic way that may include constant education process, periodical review of compliance and ways of getting feedback to modify it in other medical settings (Avsar et al., 2022). The issues with the attainment of the high compliance rates with these bundles, as evidenced by the different studies, point to the significance of the ongoing quality improvement, such as the constant observation of the bundle components and the distribution of the findings to the surgical teams (Bakkum-Gamez & Dowdy, 2016; Koek et al., 2017). A successful integration of new or existing bundled interventions becomes facilitated by a planned quality improvement project, which can be executed in an iterative and adaptive approach, as now has been established (Calderwood et al., 2023). Because of the fact that complex bundles could be hard to maintain because of diverse factors, including workflow and communication problems, additional research applying implementation science methodology is needed to understand more about this problem and avoid it in different clinical settings (Dukes et al., 2023). That way, the strategies of the implementation ought to be efficient and take into account the specifics of different surgical settings and their complexity. This will make the interventions long-term and flexible (Dukes et al., 2023). According to this cross-cutting viewpoint, you should have a system that is flexible and inflexible, and that could be adapted to the needs of any medical facility and surgical region to avoid SSIs (Dukes et al., 2023). Such flexibility is usually exhibited in disciplines collaboration and constant education processes that are critical in ensuring that the best practices are followed in all cases and that patients are provided with the

best care possible (Anderson et al., 2014; Ching, 2024). Multidisciplinary teams composed of surgical champions, nurses and pharmacists tend to direct such collaborative activities. They can help to develop a safety culture and feel more at ease with evidence-based practices (Anderson et al., 2014). Such teams will fulfill a role of importance both in the implementation of SSI prevention policies and in the monitoring of such policies and in case of need corrections. This is justified by the fact that other studies and institutions have found out that compliance is not always consistent (Calderwood et al., 2023; Ramsay and Watson, 2021). Other than direct intervention bundles, regular surgical personnel training is required to improve patient care and adherence to surgical antimicrobial prophylaxis protocols, given that surgeons are typically busy (Dogan et al., 2024). Additionally, the implementation of the infection control procedures into the current hospital practices and utilization of the tools such as the WHO surgical checklist may work wonders on the compliance with the bundle elements (Ramsay & Watson, 2021). Besides, it has been shown that optimisation of bundle elements and adoption strategies grounded on local clinical conditions like pilot testing in particular regions are key determinants to the effective adoption and the subsequent mitigation of SSI rates (Dukes et al., 2023). It is this customization that facilitates a more viable and effective approach with the understanding that the one-size-fits-all solution is not usually adequate due to the fact that surgical operations and the patients at large have varying characteristics (Tomsic et al., 2020). Moreover, antimicrobial stewardship programs are to be introduced according to the local epidemiology statistics and empowered by the multidisciplinary working groups to enhance the utilization of antibiotics and reduced adverse events related to antibiotic resistance (Sartelli et al., 2020). These programs are very relevant when the doctors, pharmacists, and nurses work together towards making sure that they prescribe prophylactic antibiotics in the proper format, proper duration, and per the guidelines (Menz et al., 2021). It is an integrated approach, comprising the preventive strategies and severe antimicrobial stewardship, which is a healthy approach to mitigating the threat of SSIs. It will ultimately lead to better patient outcomes and improved burden in the healthcare system. All these extensive efforts, including the most rigorous pre-

operative and thorough post-operative follow-up practice, are supposed to form an indestructible wall against SSIs, which proves the necessity to remain alert and flexible in clinical practice (Sartelli et al., 2020). The senior management should also be accountable. This is to make sure that there are adequate personnel in the institution, health workers have been trained on preventing infections and that the staff members are responsible enough to follow the infection control measures to ensure the success of any intervention in the long run (Calderwood et al., 2023).

CONCLUSION

The paper discusses all the risk factors that expose patients to the risk of surgical site infections (SSIs) and their measures to prevent them in tertiary care hospitals. It proves that patient, procedural, microbial, and institutional factors lead to the occurrence of SSIs in a complex and interactive combination, but not in individual factors. The resultant effect is that increased susceptibility to infection, increased duration of surgery, wound contamination level, and the prevalence of multidrug-resistant organisms significantly contributes to increasing the risk of infection. This is especially when the environment is not sterilized and the infection-control measures are not followed at all the time. The results are useful because they confirm that the application of combined, bundled preventive strategies, such as the improved antimicrobial prophylaxis, stringent aseptic procedures, environmental controls, and the improved monitoring of patients immediately after the operation, is much more effective in eliminating the incidences of SSIs than single measures. The multidimensional researches also suggest that risk factors can be nonlinear and synergistic and therefore even a slight change in the perioperative practices can make the risk of developing an infection much higher. It was found out that close follow-ups and early diagnosis reduce the bad results by enhancing the diagnosis and slowing the spread of infections. All these findings refer to the significance of the existence of system-level, data-funded infection prevention efforts adjusted to the accessible sources, especially in low-and-middle-income destinations where SSIs are too elevated. This study largely indicates the practice of the institution-wide SSI prevention initiative by the combination of the quantitative model and the understanding of the situation. The

programs contribute greatly to enhances the surgical outcome, healthcare costs as well as dealing with the increasing issue of antimicrobial resistance.

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