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From Evidence to Practice: A Behaviourally Informed Multidisciplinary Strategy to Increase Cefazolin Prophylaxis in Joint Arthroplasty Patients with Penicillin Allergy Labels

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Abstract

Background: Cefazolin is recommended for surgical prophylaxis in most patients with penicillin allergy labels (PALs) but concerns over beta-lactam cross-reactivity often limit use. We evaluated a behaviourally informed, multidisciplinary antimicrobial stewardship strategy on cefazolin utilisation among patients with PALs undergoing joint arthroplasty. **Methods:** Behavioural change frameworks identified determinants influencing perioperative antibiotic prescribing, which guided multidisciplinary antimicrobial stewardship strategy implementation over two phases: (1) department-level advocacy within Orthopaedics and then (2) hospital-wide advocacy. We retrospectively evaluated the strategies among adults with PALs undergoing primary total knee or hip arthroplasty. The primary outcome was cefazolin utilisation over time. Secondary outcomes included perioperative hypersensitivity reactions, surgical site infections (SSIs), and prosthetic joint infections (PJIs). **Results:** The proportion of patients receiving perioperative cefazolin increased significantly and sustainably over time ($p < 0.001$), rising from approximately 20% (baseline) to 92.9% (peak). Among 606 patients, 356 and 250 received cefazolin and alternative antibiotics, respectively. Suspected perioperative hypersensitivity reactions were uncommon, mild, and self-limiting (0.8% vs. 2.0%, cefazolin vs. alternative). SSIs and PJIs were similar between groups. **Conclusions:** A behaviourally informed, multidisciplinary stewardship strategy successfully increased cefazolin use in joint arthroplasty patients with PALs. Similar behavioural frameworks may be adopted to guide the design of other antimicrobial stewardship interventions to drive sustainable practice change.

Keywords: penicillin; drug allergy; implementation science

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1. Introduction

Surgical site infections (SSIs) are important postoperative complications associated with increased morbidity, mortality, and healthcare costs, and they reflect negatively on the performance of surgical units [1–3]. In elective joint arthroplasty, prosthetic joint infections (PJIs) following total knee arthroplasty (TKA) or total hip arthroplasty (THA), though rare (1–2.4%), are associated with five-year mortality rates as high as 21% along with substantial

economic burden [4–8]. Hence, the use of surgical antimicrobial prophylaxis remains a critical element of perioperative care bundles to prevent PJIs [1,2,5,9].

Cefazolin, a narrow-spectrum first-generation cephalosporin, is the preferred first-line prophylactic drug for joint arthroplasty as it is safe, inexpensive, effective against common skin bacteria, and has favourable pharmacokinetic properties [5,9–15]. It has lower rates of SSIs and fewer antibiotic-related adverse events compared with alternative agents such as clindamycin and vancomycin [5,16,17]. Furthermore, there is growing evidence supporting the safe use of cefazolin in patients with penicillin allergy labels (PALs), including those with a prior history of IgE-mediated hypersensitivity, when guided by appropriate risk stratification and clinical safeguards [5,14,16,18–21].

Nonetheless, we noticed that in our hospital, similar to other academic hospitals investigated by Prasad et al., patients with PALs frequently receive non-cefazolin surgical prophylaxis due to concerns of beta-lactam cross-reactivity [21]. This highlighted an important evidence–practice gap in perioperative care. Based on an analysis in 2021, only approximately 20% of patients with PALs received cefazolin prophylaxis for elective joint arthroplasty. In response, a multidisciplinary team comprising the Antimicrobial Stewardship Unit (ASU), allergists, and clinicians from the Departments of Orthopaedics and Anaesthesia was convened to improve the use of cefazolin prophylaxis for eligible patients with PALs.

We adopted a holistic, higher-impact behavioural change strategy by applying the Capability–Opportunity–Motivation–Behaviour (COM-B) model and the Theoretical Domains Framework (TDF) to identify behavioural determinants and guide the design of targeted antimicrobial stewardship interventions [22–24]. These interventions were implemented over approximately 3 years; initial interventions were first directed to the Orthopaedics team, and subsequently, rolled out hospital-wide.

The primary objective of this study was to evaluate temporal changes in cefazolin use among patients with PALs undergoing primary TKA or THA using a behavioural change strategy driven by a multidisciplinary team. For secondary objectives, we compared the incidence of perioperative hypersensitivity reactions, SSIs, PJIs, and *Clostridioides difficile* infections (CDIs) between patients receiving cefazolin and those receiving alternative surgical prophylaxis.

2. Materials and Methods

2.1. Development and Implementation of Our Phased Implementation Strategy

Based on our multidisciplinary discussions, clinician feedback, and direct observations of prescribing practices, we identified 6 critical behavioural determinants that influenced perioperative antibiotic prescribing in the Orthopaedics Department (Table 1), which were subsequently mapped to the COM-B model and TDF. They include (i) a lack of champion and organisational support to address antibiotic use in patients with PALs, (ii) a hierarchical prescribing culture, (iii) deeply entrenched beliefs about the high rates of cross-reactivity between penicillin and cefazolin, (iv) a fear of perioperative allergic complications and potential litigation arising, (v) uncertainty about interpreting allergic reactions to penicillin, and (vi) time burden and cognitive pressure associated with perioperative practice. These determinants informed the design of targeted antimicrobial stewardship strategies, which were implemented over 3 years: (i) Phase 1—department-level advocacy within Orthopaedics from January 2023 to March 2025, and (ii) Phase 2—hospital-wide advocacy from April 2025 onwards (Figure 1).

Table 1. Mapping of behavioural determinants identified using COM-B model and TDF and corresponding stewardship strategies.

Behavioural Determinants	COM-B Source of Behaviour [23]	Primary and Secondary TDF Domains [24]	Antimicrobial Stewardship Strategies Implemented
Lack of antimicrobial stewardship champions and organisational support ASU alone was unlikely to drive sustained practice change	Opportunity	Social influence	1. **Multidisciplinary collaboration [Strategic planning phase]** Collaboration among ASU, allergists, the Department of Orthopaedics and Anaesthesia was established to align practice and strengthen shared ownership. 2. **Senior clinician antibiotic stewardship champions [Phase 1 and 2]** Respected senior clinicians within the Department of Orthopaedics and Anaesthesia enabled practice change through peer advocacy and departmental leadership. 3. **Senior leadership endorsed institution-guideline [Phase 2]** Hospital Medical Board and clinical heads' approval of new guidelines for the use of beta-lactams in patients with PALs. Allergist led the development of the guideline, with inputs from ASU and anaesthetists (Supplementary Figure S1); guideline incorporated allergy risk-stratification algorithms and protocols for managing allergic reactions.
Hierarchical prescribing culture Junior doctors are strongly influenced by the antibiotic prescribing patterns of senior clinicians	Opportunity	Social Influence	1. **Orthopaedic antibiotic stewardship champion [Phase 1]** A senior orthopaedic surgeon provided peer advocacy to promote the use of cefazolin among patients with PALs. 2. **Anaesthesia antibiotic stewardship champion [Phase 2]** A senior anaesthetist led a quality improvement programme, comprising the introduction of a series of educational videos, placing laminated reminder cards in operating-theatre medication trolleys, and revised allergy assessment and counselling workflows in preoperative anaesthesia clinics.
Deeply entrenched "legacy beliefs" on the high rates of cross-reactivity between penicillin and cefazolin	Capability	Knowledge	1. **Reinforcing confidence through clinician champions and sharing of local safety data [Phase 1 and 2]** Early local data on the safety and efficacy of cefazolin use within the TKA/THA population were shared with clinicians in various educational campaigns to build confidence and support wider adoption. 2. **Multidisciplinary education campaigns [Phase 2]** Education sessions were conducted for anaesthetists, pharmacists, and 13 major surgical departments beyond the Department of Orthopaedics.
	Motivation	Beliefs about consequences	
Fear of perioperative allergic complications and potential litigation Clinicians would generally prioritise uneventful surgery and prefer avoidance of perioperative disruptions.	Motivation	Beliefs about consequences	1. **Senior leadership endorsed institution-guideline [Phase 2]** Assures clinicians that cefazolin can be used safely through an institution-approved, risk-stratified approach. 2. **Revised allergy assessment and counselling workflows [Phase 2]** Led by a senior anaesthetist champion, revised allergy assessment and counselling workflows were implemented at preoperative anaesthesia clinics. 3. **Real-time specialist support made available to the Department of Anaesthesia [Phase 2]** Our allergist and ASU physicians provided real-time review and feedback for suspected perioperative allergic reactions, including guidance on whether to proceed with or abort surgery and selection of alternative antibiotics, where required. This acts as a safety net to ensure smooth and safe procedures.
	Motivation	Social/professional role and identity	
Uncertainty regarding interpretation of penicillin allergy histories Allergy histories are often poorly documented or unclear.	Motivation	Beliefs about consequences	
	Capability	Knowledge	

Table 1. *Cont.*

Behavioural Determinants	COM-B Source of Behaviour [23]	Primary and Secondary TDF Domains [24]	Antimicrobial Stewardship Strategies Implemented
Time pressure and cognitive burden within perioperative practice High workload in the perioperative setting contributes to decision fatigue, leading clinicians to favour alternative antibiotics perceived to be "safer" in an effort to minimise disruption to surgical workflows	Opportunity	Environmental context and resources	1. **Guidelines made readily accessible [Phase 2]** The institution-endorsed beta-lactam guideline and updated surgical prophylaxis recommendations for major surgeries were made readily accessible through the hospital intranet and antibiotic mobile application (ABxSG) to reduce cognitive burden during prescribing.
	Capability	Memory, attention, and decision processes	2. **Physical prompts and reminders [Phase 2]** Posters and laminated reminder cards were positioned within various locations in the operating theatres (e.g., induction and changing rooms and near medication trolleys).

COM-B model: Capability, Opportunity, Motivation–Behaviour model; TDF: Theoretical Domains Framework. Behavioural barriers were identified locally but categorised using predefined domains from the COM-B model and TDF in columns 2 and 3 [23,24].

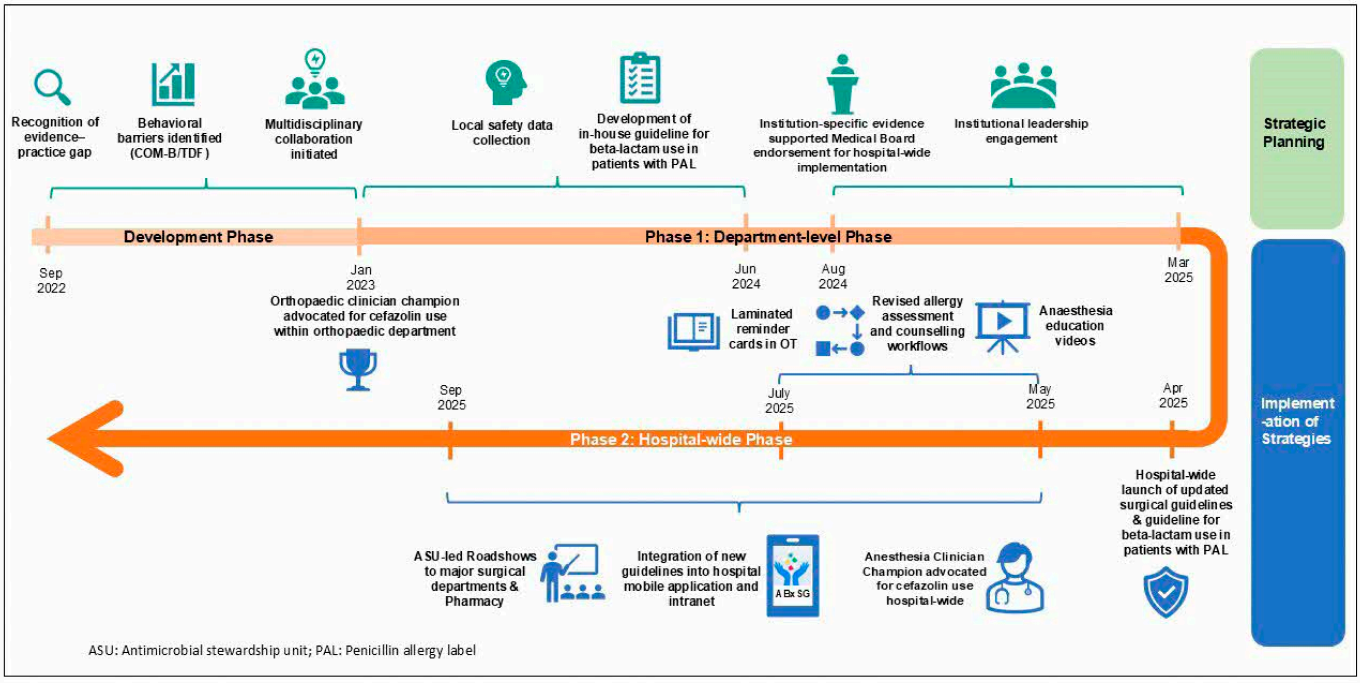


Figure 1. Timeline of key antimicrobial stewardship events from September 2022 onwards.

This was a retrospective, single-centre observational study conducted to evaluate a series of quality-improvement interventions at Singapore General Hospital (SGH), a 1800-bed tertiary academic hospital in Singapore.

2.2. Patient Selection

2.2.1. Inclusion Criteria

All adult patients (≥21 years old) with a documented preoperative PALs who underwent primary TKA or THA in SGH between 1 January 2023 and 31 December 2025 and received perioperative antimicrobial prophylaxis with either cefazolin or an alternative antibiotic were included.

2.2.2. Exclusion Criteria

Patients were excluded if they were (i) treated for a concurrent infection, (ii) had a documented history of severe cutaneous adverse reactions (SCAR) to penicillins, or (iii) received antihistamines within 72 h of surgery for documented indications unrelated to a suspected perioperative hypersensitivity reaction (e.g., eczema, chronic pruritus, or other non-allergic conditions).

2.3. Study Outcomes

The primary outcome of this study was the temporal changes in cefazolin utilisation among patients with penicillin allergy labels (PALs) undergoing primary TKA or THA. This serves as a measure of uptake following implementation of the multidisciplinary, behaviourally informed implementation strategy described in Figure 1.

For the secondary outcomes, we compared the incidence of (1) perioperative hypersensitivity reactions occurring within 72 h of antimicrobial prophylaxis administration, (2) 90-day SSIs, (3) 90-day PJIs, and (4) 90-day CDIs between patients who received cefazolin and those who received alternative surgical antimicrobial prophylaxis.

2.4. Definitions

2.4.1. Penicillin Allergy Risk Stratification

Building on prior institutional experience with protocolised drug allergy evaluation and given clinicians' familiarity with our existing local approach, we chose to refine and formalise a guideline for use of beta-lactams in patients with PALs rather than adopt an external penicillin allergy risk stratification tool [25,26]. In our institutional guidelines, patients with PALs (and without SCAR) are categorised into low-, medium-, and high-risk for true penicillin allergy according to their reported allergy history (Supplementary Figure S1). The low-risk category comprised mainly non-allergic symptoms without features of immediate or severe delayed hypersensitivity. The medium-risk category included urticaria, angioedema without cardiorespiratory compromise, or reactions with insufficient information for confident classification. The high-risk category comprised severe immediate reactions with cardiorespiratory involvement. Patients across all categories are eligible for cefazolin use. However, patients in the higher-risk categories undergo additional administration precautions and more stringent monitoring, as specified by the institutional guidelines (Supplementary Figure S1).

2.4.2. Characterisation of Monthly Cefazolin Utilisation Rate

Monthly cefazolin utilisation was measured as the percentage of patients with PALs who received cefazolin among all patients with PALs who underwent TKA or THA during the same month.

2.4.3. Hypersensitivity Reaction

Patients with documented clinical features suggestive of immune-mediated hypersensitivity reactions occurring within 72 h of the first dose of perioperative antimicrobial prophylaxis were identified by reviewing clinical notes and medication administration records. Causality between antibiotic use and the suspected reaction was assessed using the Naranjo adverse drug reaction probability scale (Supplementary Table S1).

2.4.4. Surgical Site Infection

Cases of SSIs and PJIs occurring within 90 days of surgery were identified by reviewing electronic medical records and classified according to the National Healthcare Safety Network (NHSN) SSI criteria [1].

2.4.5. *Clostridioides difficile* Infection

CDI was defined as the presence of compatible clinical symptoms occurring within 90 days of surgery together with either (i) positive stool testing for both *C. difficile* glutamate dehydrogenase (GDH) antigen and toxins or (ii) a positive polymerase chain reaction (PCR) test for *C. difficile* when GDH or toxin testing was indeterminate.

2.5. Statistical Analysis

Continuous variables were presented as median (interquartile range [IQR]) and compared using the Mann–Whitney U test. Categorical variables were presented as frequency (percentage) and compared using the chi-square or Fisher's exact test, as appropriate. Linear regression was performed to evaluate trends in the proportion of patients receiving cefazolin as perioperative antimicrobial prophylaxis over time, coded in calendar months from January 2023 to December 2025. Linear regression was used as an exploratory analysis to quantify the overall temporal trend in monthly cefazolin utilisation across the study period; it was not intended to estimate the effect of individual interventions or characterise phase-specific changes. A two-sided *p*-value of <0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA).

3. Results

There were 606 patients included in this study; 356 (58.7%) and 250 (41.3%) patients received IV cefazolin and alternative agents, respectively.

3.1. Patient Demographics and Clinical Characteristics

The baseline patient characteristics are detailed in Table 2. According to the institutional beta-lactam risk stratification guidelines (Supplementary Figure S1), most patients were classified as medium-risk based on their reported penicillin allergy [564/606 (93.1%)], of whom 255/564 (45.2%) had an unknown penicillin reaction. Only 21/606 (3.5%) were classified as high-risk because of reported severe immediate penicillin hypersensitivity with cardiorespiratory involvement.

Table 2. Patient demographics and clinical characteristics.

Baseline Characteristics	Cefazolin (*n* = 356)	Alternative Prophylaxis (*n* = 250)	*p*-Value
Age in years	70 (65–75)	71 (64–76)	0.861
Male, *n* (%)	92 (25.8%)	47 (18.8%)	**0.042**
Weight (kg)	66.1 (57.8–75.6) (*n* = 243)	66.1 (58.2–75.8) (*n* = 175)	0.777
Obesity (BMI $\geq$ 30 kg/m^2), *n* (%)	60 (24.9%) (*n* = 241)	55 (31.6%) (*n* = 174)	0.132
Type 2 diabetes mellitus, *n* (%)	40 (11.2%)	16 (6.4%)	**0.043**
MRSA colonisation within 90 days prior to operation, *n* (%)	0 (0.0%)	1 (0.4%)	0.413
Procedure			
TKA, *n* (%)	315 (88.5%)	220 (88.0%)	0.856
THA, *n* (%)	41 (11.5%)	30 (12.0%)	
Allergy risk category *			
Low, *n* (%)	18 (5.1%)	3 (1.2%)	**0.011**
Medium, *n* (%)	329 (92.4%)	235 (94.0%)	0.450
High, *n* (%)	9 (2.5%)	12 (4.8%)	0.132

Table 2. *Cont.*

Baseline Characteristics	Cefazolin (*n* = 356)	Alternative Prophylaxis (*n* = 250)	*p*-Value
Perioperative antibiotic prophylaxis			
IV cefazolin, *n* (%)	356 (100%)	0	N.A.
IV clindamycin, *n* (%)	0	222 (88.8%)	
IV vancomycin, *n* (%)	0	28 (11.2%)	
Adjunctive intra-articular vancomycin, *n* (%)	173 (48.6%)	143 (57.2%)	**0.037**

Data are presented as median (interquartile range [IQR]) or *n* (%), unless otherwise stated. Percentages were calculated using available data where applicable. Weight was available for 418 patients and BMI for 415 patients; analyses for these variables were performed using available-case analysis. Abbreviations: BMI, body mass index; IV, intravenous; IQR, interquartile range; MRSA, methicillin-resistant *Staphylococcus aureus*; N.A., not applicable; TKA, total knee arthroplasty; THA, total hip arthroplasty. * Patients are classified into low, medium or high risk based on risk stratification as per institutional guidelines for the use of beta-lactams in patients with penicillin allergy (Supplementary Figure S1).

A significantly higher proportion of male patients (25.8% vs. 18.8%, $p < 0.05$) and patients with diabetes mellitus (11.2% vs. 6.4%, $p < 0.05$) received cefazolin prophylaxis as compared to those receiving alternative agents. Significantly fewer patients in the cefazolin group received adjunctive intra-articular vancomycin (48.6% vs. 57.2%, $p < 0.05$) (Table 2).

3.2. Primary Outcome

Overall, the linear regression on the proportion of patients with PALs receiving cefazolin for perioperative prophylaxis in primary arthroplasty showed a significant positive temporal trend (β = 1.156; 95% CI 0.722–1.590; $p < 0.001$; $R^2 = 0.46$) (Figure 2). As illustrated in Figure 2, the magnitude and rate of increase differed across the different intervention phases rather than following a uniform linear pattern throughout the study period.

Historically, a 2021 institutional audit estimated that approximately 20% of patients with PALs undergoing arthroplasty received cefazolin. Following targeted advocacy within the Department of Orthopaedics in Phase 1, cefazolin use had possibly increased slightly to 27% within the first month of intervention in January 2023, and continued to increase gradually to a mean of 58.4%, which was largely sustained from January 2024 to July 2024 (Figure 2). Although a slight decline was observed thereafter, cefazolin utilisation rose sharply to 92.9% in April 2025, following the launch of hospital guidelines for beta-lactam use and updated surgical prophylaxis in Phase 2. High cefazolin utilisation was subsequently maintained with continued implementation of stewardship strategies targeting hospital-wide perioperative cefazolin use.

3.3. Secondary Outcomes

3.3.1. Suspected Perioperative Hypersensitivity Reaction

Naranjo causality assessment revealed that the overall incidence of suspected perioperative hypersensitivity reactions was low at 1.3% (8/606) (Supplementary Table S1). All reactions were mild and self-limiting, with no cases of anaphylaxis or severe cutaneous adverse reactions. There was also no significant difference in the rate of suspected hypersensitivity reactions between the cefazolin arm and the alternative prophylaxis arm (Table 3).

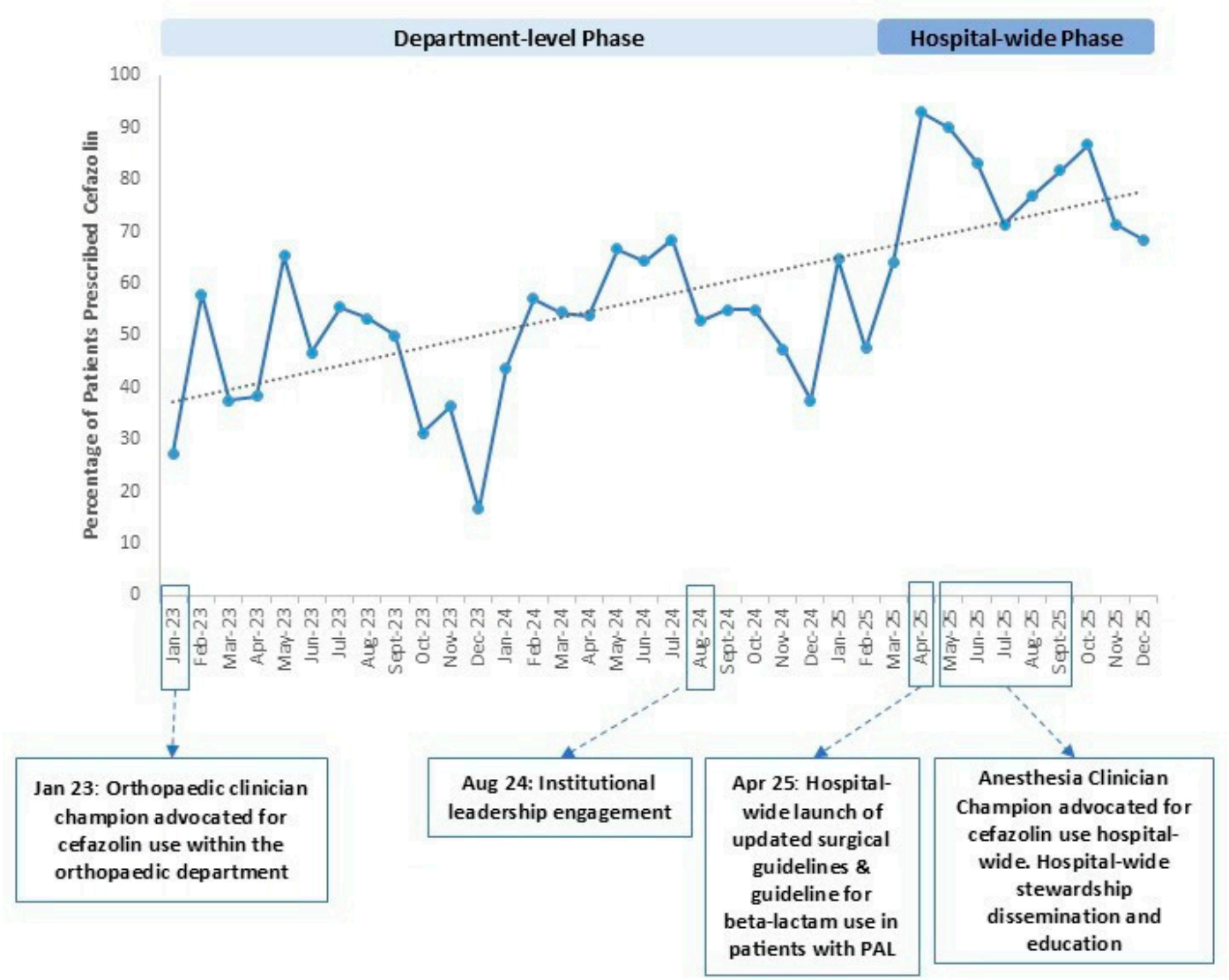


Figure 2. Trend of monthly cefazolin utilisation among patients with PALs undergoing primary TKA or THA following sequential implementation of various antimicrobial stewardship interventions (January 2023–December 2025); black dotted line represents linear regression demonstrating an overall increase in monthly cefazolin utilisation throughout the study period.

Table 3. Secondary clinical outcomes.

	Cefazolin (*n* = 356)	Alternative Prophylaxis (*n* = 250)	*p*-Value
Perioperative hypersensitivity reactions, *n* (%)	3 (0.8%)	5 (2.0%)	0.285
SSIs, *n* (%)	5 (1.4%)	2 (0.8%)	0.706
Incisional SSIs, *n* (%)	3 (0.8%)	2 (0.8%)	1.00
Organ space SSIs (PJIs), *n* (%)	2 (0.6%)	0 (0.0%)	0.510
CDIs, *n* (%)	0 (0.0%)	0 (0.0%)	-

Data are presented as *n* (%). Surgical site infections (SSIs) were classified according to the National Healthcare Safety Network (NHSN). Prosthetic joint infection (PJI) was classified as an organ/space SSI.

3.3.2. Incidence of Surgical Site Infection

At 90 days following surgery, the overall incidence of SSIs was low at 1.2% (7/606), and there was no significant difference in SSI rates between cefazolin and alternative prophylaxis (Table 3).

3.3.3. Incidence of *Clostridioides difficile* Infection

No cases of CDI were observed in either group within 90 days of surgery (Table 3).

4. Discussion

In this study, we evaluated a real-world multidisciplinary antimicrobial stewardship initiative implemented over approximately 3 years to promote cefazolin surgical prophylaxis in patients with PALs undergoing joint arthroplasty. Behavioural science-informed multidisciplinary stewardship interventions led to a significant and sustained increase in the uptake of cefazolin prophylaxis in patients with PALs, with low but comparable rates of hypersensitivity reactions, SSIs, PJIs, and CDIs between groups, concordant with international studies [4,5,7,13,14,16–19].

Behavioural science frameworks are increasingly used to strengthen antimicrobial stewardship interventions by identifying context-specific barriers and aligning strategies to behavioural determinants. Previous studies have demonstrated the value of leveraging behavioural science approaches to improve perioperative penicillin allergy management and penicillin allergy de-labelling processes [27,28]. Similarly, using the COM-B model and TDF, we systematically identified the behavioural determinants that influenced antibiotic prescribing [22–24]. The key determinants centred on the following three themes: (i) social influences, (ii) beliefs about consequences, and (iii) the need for an enabling environment with accessible point-of-care resources. These insights guided the design and implementation of our targeted antimicrobial stewardship strategies in the two phases (Table 1).

Among the identified categories of behavioural determinants, we observed that social influences appeared to play the greatest role in shaping the observed implementation trajectory in our institution. For many senior clinicians, the reluctance to prescribe cefazolin for patients with PALs reflects a long-standing belief that penicillin and cephalosporins shared approximately 10% cross-reactivity [19–21]. Although this belief has since been refuted by contemporary evidence, it remained entrenched, perpetuated and reinforced through hierarchical clinical structures, whereby junior clinicians adopted the prescribing behaviours of their senior colleagues [22]. Therefore, engaging a respected senior orthopaedic clinician champion became a pivotal component of our implementation strategy [29]. The orthopaedic champion promoted and practised cefazolin prophylaxis for patients with PALs and facilitated gradual changes in established prescribing practices. Similar experiences are also reported by Carter et al., who demonstrated that interventions targeting social influences facilitated implementation of perioperative penicillin allergy stewardship [27]. Following engagement of the orthopaedic clinician champion, cefazolin prophylaxis utilisation increased from a baseline of approximately 20% to a mean of 58.4% during the initial implementation of Phase 1 (Figure 2).

However, cefazolin utilisation began to decrease following July 2024 in Phase 1 (Figure 2), perhaps suggesting that prescribers continued to harbour concerns regarding the consequences of perioperative allergic reactions, including potential disruption of surgery, patient dissatisfaction, and adverse clinical outcomes. This also highlighted the limits of relying primarily on a single departmental clinician champion to drive sustained practice change. A strategic pivot was therefore needed, from department-level advocacy to broader organisational support, including senior leadership and anaesthesia support [30].

To secure senior leadership buy-in, we presented to the Institutional Medical Board a multidisciplinary guideline on beta-lactam use in patients with PALs, supported by 18 months of local cefazolin safety data from the Department of Orthopaedics. Surgical and medical leads were engaged, and the guideline recommendations were subsequently endorsed. Guideline development was led by a senior allergist and the ASU, while perioperative adoption was supported by an anaesthetist champion. The guideline outlined suitable patients for de-labelling or cefazolin challenge, provided risk-stratification recommendations, and specified measures for managing potential allergic reactions (Supplementary Figure S1). In parallel, based on practice culture and workflows, the anaesthesia champion further revised the allergy assessment, patient counselling, and allergist referral pathways within preoperative anaesthesia clinics, reducing uncertainty around allergy evaluation and further alleviating clinicians' concerns. The availability of real-time specialist support from ASU physicians and allergists for suspected perioperative allergic reactions provided additional reassurance to clinicians, and this was also integral to ensuring a successful implementation of the programme.

To advance hospital-wide adoption of the new guidelines, we improved accessibility and embedded the revised guidelines within routine clinical workflows. The institutional beta-lactam guidelines for patients with PALs, together with updated surgical antimicrobial prophylaxis recommendations, were integrated into the hospital intranet and ABxSG, a widely used in-house developed institutional antimicrobial mobile application providing clinicians with rapid access to local guidelines, policies, and antimicrobial information [31]. In doing so, we created an enabling prescribing environment by ensuring that practical guidance and decision-support resources were available at the point of care.

The initiation of Phase 2 coincided with the steepest increase in cefazolin utilisation observed across the study period, reaching a peak of 92.9% (Figure 2). This demonstrates that a sustainable practice change required not only robust evidence but also coordinated system-level support to implement change consistently [32,33].

Interestingly, there was a slight decline in cefazolin utilisation after November 2025 (Figure 2). Although the reasons for this decline are likely multifactorial, its timing coincided with a reduction in implementation intensity. This observation highlights that stewardship initiative implementation should not be regarded as a one-time event. Rather, it is an ongoing process requiring continued reinforcement and iterative refinement, particularly with rotation of junior clinicians. Ongoing follow-up will therefore be important to determine whether efforts to increase cefazolin utilisation are sustained beyond the study period. Future antimicrobial stewardship initiatives could further strengthen implementation by incorporating upstream ASU pharmacist-led identification of suitable patients for penicillin allergy assessment and de-labelling, thereby reducing the number of patients requiring risk stratification at the point of surgery [16,28].

As expected, the increased utilisation of cefazolin was not associated with higher rates of suspected perioperative hypersensitivity reactions, SSIs, PJIs, or CDIs, consistent with previous studies [5,7,8,14,16,19,20]. It was important for the generation of local data to reassure local prescribers. Although there was a higher number of SSIs in the cefazolin group, the difference was not statistically significant and should be interpreted with caution in the context of baseline differences between the cohorts. There was a significantly higher number of male patients and patients with diabetes mellitus (Table 2), both recognised risk factors for SSIs following arthroplasty [4]. Furthermore, patients in the cefazolin group were significantly less likely to receive adjunctive intra-articular vancomycin, an intervention for which some studies have reported reductions in SSIs and PJIs, though the overall evidence remains inconclusive [7,8,34].

A major strength of this study is the longitudinal evaluation of a multidisciplinary antimicrobial stewardship implementation across successive phases, rather than relying solely on pre- and post-intervention comparisons, as reported in previous implementation studies (Figure 2) [27,28]. This approach enabled us to demonstrate how prescribing behaviour evolved over time while highlighting the importance of continued multidisciplinary review and iterative refinement of implementation strategies throughout the study period, guided by behavioural change frameworks [22–24].

Our study has several limitations. First, we evaluated a pragmatic, multifaceted implementation strategy comprising several complementary interventions introduced over time. Consequently, the individual contribution of each implementation component could not be disentangled. However, this reflects real-world implementation practice, where multiple complementary strategies are often rolled out successively to achieve a sustainable organisational change. Second, this was a retrospective single-centre study, which may limit the generalisability of our findings to institutions with different patient populations, antimicrobial stewardship programmes, and perioperative workflows. Third, reliable institutional perioperative antimicrobial prescribing data immediately before January 2023 were limited, restricting evaluation of surgical prophylaxis in the pre-implementation period. This also precluded the use of an interrupted time series analysis to formally evaluate the impact of the implementation strategy. However, our 2021 institutional audit demonstrated that cefazolin utilisation was approximately 20% among patients with PALs undergoing arthroplasty, consistent with the baseline observed at study commencement and supporting the presence of a persistent evidence–practice gap. Fourthly, food allergy status was not routinely documented in our electronic medical records and was therefore not evaluated. Its potential influence on clinicians' antibiotic selection could not be assessed. Finally, the low incidence of perioperative hypersensitivity reactions limited statistical power to detect small differences between prophylactic regimens, making adequately powered comparative studies inherently challenging [5,18–20].

5. Conclusions

Implementation of multidisciplinary antimicrobial stewardship strategies, guided by behavioural change models, was associated with a sustained increase in cefazolin utilisation among patients with PALs undergoing joint arthroplasty, without compromising perioperative safety. Our findings demonstrate that translating established international evidence into routine clinical practice requires more than awareness of evidence-based best practices. Rather, sustained advocacy was achieved by systematically identifying and addressing behavioural determinants, supported by institution-specific safety data and multidisciplinary collaboration. COM-B model and TDF provided a practical implementation approach that may inform similar antimicrobial stewardship initiatives in other healthcare settings.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/allergies6040040/s1, Supplementary Figure S1: SGH Guidelines for the Use of Beta-lactams in Penicillin Allergic Inpatients; Supplementary Table S1: Clinical characteristics and causality assessment of patients with suspected perioperative hypersensitivity reactions.

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Institutional Review Board Statement: This study was exempted from our Institutional Ethics Board review (SingHealth Institutional Review Board Reference 2022/2560, date: 17 November 2022). It was deemed that the activities conducted by the ASP do not require further ethical deliberation because they mainly involve a series of quality improvement initiatives.

Informed Consent Statement: Patient consent was not required as deemed by the Institutional Ethics Board.

Data Availability Statement: The original contributions presented in this study are included in the article.

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