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ORIGINAL RESEARCH

A Hospital Infection Management Department-Led Intervention to Improve the Pathogen Submission Rate Before Antimicrobial Therapy Using a FOCUS-PDCA Model

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Background: Antimicrobial resistance (AMR) is a growing global public health threat, which is primarily driven by the irrational use of antibiotics. Enhancing the pathogen submission rate before antimicrobial therapy is crucial for effective antimicrobial management in healthcare institutions. This study aimed to improve this rate using the FOCUS-PDCA (Find, Orgnize, Clarify, Understand, Select, Plan, Do, Check, Act) model in a tertiary hospital.

Methods: The present study was conducted from 2021 to 2024, applying the FOCUS-PDCA model. Led by the Hospital Infection Management Department, a multi-disciplinary collaboration team was set up, with indicators and problems as the guide. The interventions included improving information monitoring technology, optimizing specimen collection and delivery processes, strengthening regulatory efforts, and establishing a diversified training system. Data were collected from 56 clinical departments and compared before and after intervention.

Results: The pathogen submission rate before antimicrobial therapy was notably increased from 64.99% in 2021 to 76.40% in 2024 ($p < 0.001$), with a similar increase in the targeted pathogen submission rate from 55.51% to 69.48% ($p < 0.001$). The pathogen submission rate related to hospital-acquired infections (HAIs) and the pathogen submission rate before the combined use of key antibiotics were also improved. Specimen quality was enhanced, with the proportion of sterile specimens increasing from 38.07% to 43.24% ($p < 0.001$). Detection rates of multidrug- resistant organisms (MDRO) were decreased overall, with notable declines in MRSA, CRPA, and CRKP.

Conclusion: The FOCUS-PDCA model effectively improved pathogen submission rates and specimen quality, reduced the detection rate of MDRO, and promoted rational antimicrobial use. This approach provides valuable experience for other clinical institutions aiming to enhance antimicrobial stewardship.

Keywords: antimicrobial stewardship, pathogen submission, plan-do-check-act, detection rate, information technology

Introduction

Antimicrobial resistance (AMR) has emerged as a global public health threat, and infections caused by resistant bacteria increase patient mortality and treatment costs.[1–4] It is estimated that in 2021, the burden of bacterial AMR has led to approximately 1.14 million attributable deaths and about 4.71 million associated deaths. Without intervention, deaths are projected to increase substantially by 2050.[5] Consequently, the World Health Organization(WHO) has developed a global action plan against AMR, and 178 countries (including China) have formulated national action plans to curb AMR.[6–8] Studies have shown that the irrational use of antibiotics is the primary cause of AMR, a problem prevalent in developing countries. Additionally, data from the Global Antimicrobial Resistance and Use Surveillance System (GLASS) in 2022 have also indicated that reducing antibiotics consumption can lower AMR.[9,10] It has been confirmed and widely

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used in international countries that implementing antimicrobial stewardship programs (ASPs) can improve patient outcomes, reduce AMR, and lower healthcare costs.[11,12] Microbiological diagnostic testing is a core component of ASPs, and using antibiotics based on microbiological testing and antibiotic susceptibility results can provide a basis for precise clinical treatment, as well as reduce the occurrence of multidrug-resistant organisms (MDRO).[13,14] Despite the widespread recognition of the importance of microbiological testing, its application in clinical practice remains insufficient. During the COVID-19 pandemic, physicians still used a large number of antimicrobial agents empirically. Multiple studies have emphasized the need to strengthen antimicrobial stewardship through microbiological testing and the use of biomarkers to aid decision-making.[12,15,16]

Pathogen submission before antimicrobial therapy refers to the initiation of pathogen testing and completion of relevant specimen collection before the administration of antimicrobial therapy. Specifically, pathogen testing includes microbiological culture and biomarkers such as procalcitonin. The pathogen submission rate before antimicrobial therapy has been proven to be a key indicator for the rational use of antibiotics and the containment of AMR.[13,14] From 2009 to 2010, the pathogen submission rate in 6 emergency care hospitals in the United States reached 79.10% (the highest reported rate in the literature, but specimens collected on the same day as the initiation of antimicrobial therapy were also included).[17] Moreover, accumulating studies have shown that comprehensive intervention measures (such as information systems, training and education, performance assessment, and feedback follow-up) can effectively improve the pathogen submission rate before antimicrobial therapy and guide rational clinical medication use.[18–22] China has included "improving the pathogen submission rate before antimicrobial therapy" in hospital infection management quality control objectives and national medical quality and safety improvement objectives. Since 2021, a special improvement action (hereinafter referred to as the special action) has been launched to "increase the pathogen submission rate before antimicrobial therapy", proposing that the pathogen submission rate before antimicrobial therapy should not be less than 50%, the pathogen submission rate related to hospital-acquired infections (HAIs) should not be less than 90%, and the pathogen submission rate before the combined use of key antibiotics should be 100%. With the government as the leading force, the rational use of antibiotics and the AMR control system have been continuously optimized, and some achievements have been made in curbing bacterial resistance.[23] However, the irrational use of antibiotics still exists in medical institutions at all levels, and the increase in bacterial resistance has not been effectively controlled.[24,25] The situation remains severe, and the management of submission rates requires not only national policy support but also administrative intervention from hospitals.[26] Therefore, from the perspective of hospital management, It is of great significance to adopt a scientific quality improvement method to enhance the pathogen submission rate before antimicrobial therapy.

The Find-Organize-Clarify-Understand-Select (FOCUS)-Plan-Do-Check-Act (PDCA) model is a comprehensive quality management tool, which is divided into 9 steps: Find, Organize, Clarify, Understand, Select, Plan, Do, Check, and Act. Originating in the United States, it has been widely used at national and international levels in recent years. This model emphasizes data-driven decision-making and multi-department collaboration to break down departmental barriers, as well as continuous quality improvement targeting the root causes of problems to adapt to the ever-changing medical environment and patient needs. Huang et al have applied the FOCUS-PDCA model to the management of sterile packages in the disinfection supply center, effectively reducing the occurrence rate of distribution defects and lowering the risk of hospital infections.[27] Xu et al have applied the FOCUS-PDCA model to central venous catheter management, significantly reducing the incidence of catheter-related bloodstream infections (CR-BSI).[28] Therefore, the FOCUS-PDCA model has been successfully used in the medical industry, especially in medical quality management, patient safety, and optimization of medical processes.

Currently, there is research on the application of the FOCUS-PDCA model in hospital infection management, and there are few reports on its application in antimicrobial stewardship. This study innovatively applied the FOCUS-PDCA model to the management of pathogen submission before antimicrobial therapy from the perspective of hospital management. Using fishbone diagrams and Pareto analysis, we identified the weak links in the management of pathogen submission before antimicrobial therapy. Through information technology and multi-department collaboration, we significantly improved the pathogen submission rate and specimen quality before antimicrobial therapy, thereby reducing the detection rate of MDRO and providing new ideas and methods for antimicrobial stewardship.

Materials and Methods

Study Setting and Patient Population

This study was conducted in a tertiary general hospital in Zhejiang Province, China, with 2560 open beds, nearly 140,000 patient admissions, and more than 50,000 surgeries performed annually. The study population included hospitalized patients who received antimicrobial therapy from January 1, 2021, to December 31, 2024. Based on whether the FOCUS-PDCA model was implemented for pathogen submission management before antimicrobial therapy, patients were assigned to the control group (admitted from January 1, 2021 to December 31, 2021) and intervention group (admitted from January 1, 2022, to December 31, 2024). The pathogen submission rates before antimicrobial therapy from 2022 to 2024 were continuously tracked to evaluate the improvement effects of the FOCUS-PDCA model. The inclusion criteria were: hospitalized patients receiving systemic antimicrobial therapy. The exclusion criteria were: (1) Patients receiving prophylactic antimicrobial drugs. (2) patients receiving topical antimicrobial treatment.

Study Design and Intervention

In 2021, the state introduced new benchmarks and target values for the pathogen submission rate before antimicrobial therapy. According to data analysis, our hospital achieved a pathogen submission rate before antimicrobial therapy of 55.51% for inpatients. However, 26 departments (47% of all departments, mainly surgical wards) had submission rates below 50%. Moreover, these departments had a high number of patients receiving antimicrobial drugs, with large amounts of usage and significant irrational use. Neurosurgery, Hepatobiliary and Pancreatic Surgery, General Surgery, Orthopedics, Colorectal and Anal Surgery, Cardiothoracic Surgery, Vascular Surgery, and Trauma Surgery were selected as key departments for improvement. Meanwhile, we continued to improve the pathogen submission rate before antimicrobial therapy for all hospitalized patients.

At the end of 2021, a special improvement team was established, coordinated by the vice president, led by the Hospital Infection Management Department, and supported by multiple departments (including the Medical Affairs Office, Laboratory Department, Pharmacy Department, Information Center, Nursing Department, and General Affairs Department). Quarterly meetings were held.

A form was designed to retrospectively analyze data from hospitalized patients in the fourth quarter of 2021, focusing on those with low pathogen submission rates before antimicrobial therapy. The reasons were categorized as follows: (1) failure to order pathogen tests: physicians did not issue order pathogen tests when prescribing antimicrobials simultaneously; (2) post-antimicrobial specimen collection: the time of pathogen specimen collection occurred after the time of antibiotic administration; (3) failure to collect available specimens: physicians ordered the pathogen tests, and patients receiving antimicrobial therapy had pathogen specimens available for collection, but medical staff did not collect them; (4) incorrect ONCE medical order: the ONCE order did not have correct frequency designation; (5) no specimen available for collection: patients had indications for antimicrobial use, but no pathogen specimen was available for collection (eg patients with cholecystitis and appendicitis); (6) other reasons: patients receiving antimicrobial therapy did not have pathogen specimens submitted due to reasons such as transfer to another department or emergency surgery.

Pareto analysis was performed on the non-compliant data. According to the 80/20 rule, failure to order pathogen tests and post-antimicrobial specimen collection accounted for 48.73% and 33.21%, respectively, which was the primary reason for the low pathogen submission rate before antimicrobial therapy (Figure 1). The fishbone diagram was employed to analyze the primary reasons. During the verification of true causes, the team analyzed the reasons from 4 aspects (personnel, equipment, work procedure, and environment). Finally, 4 specific causes were determined, including incomplete information system construction, inefficient specimen submission processes, insufficient supervision and assessment efforts by administrative departments, and insufficient training (Figures 2 and 3).

Specific improvement measures were listed as follows:

Establishing a Diversified Training System

A hospital-wide survey on the knowledge of pathogen submission before antimicrobial therapy was conducted to develop a targeted training plan. The whole hospital was organized to study the relevant specifications of antimicrobial drug management, interpret national policy documents, and hold training courses on a standardized collection of microbiological

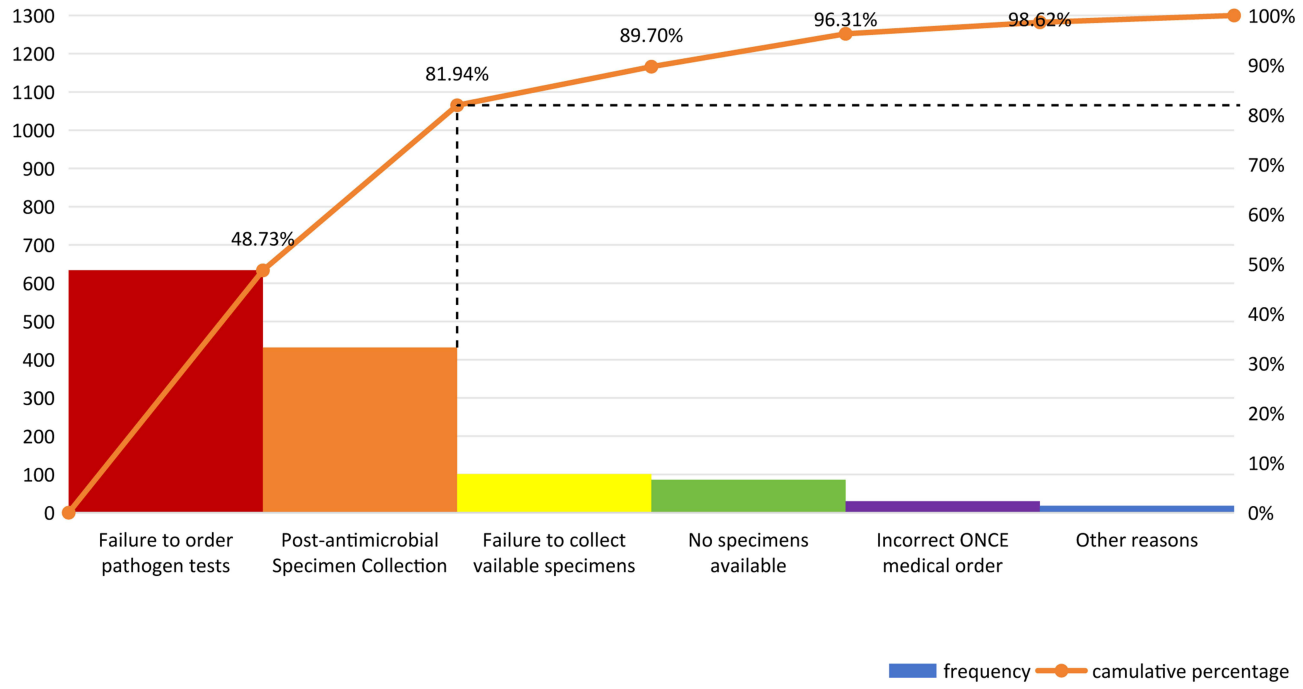

Figure 1 Classification of Non-Compliance Items for Pathogen Detection before antimicrobial Therapy.

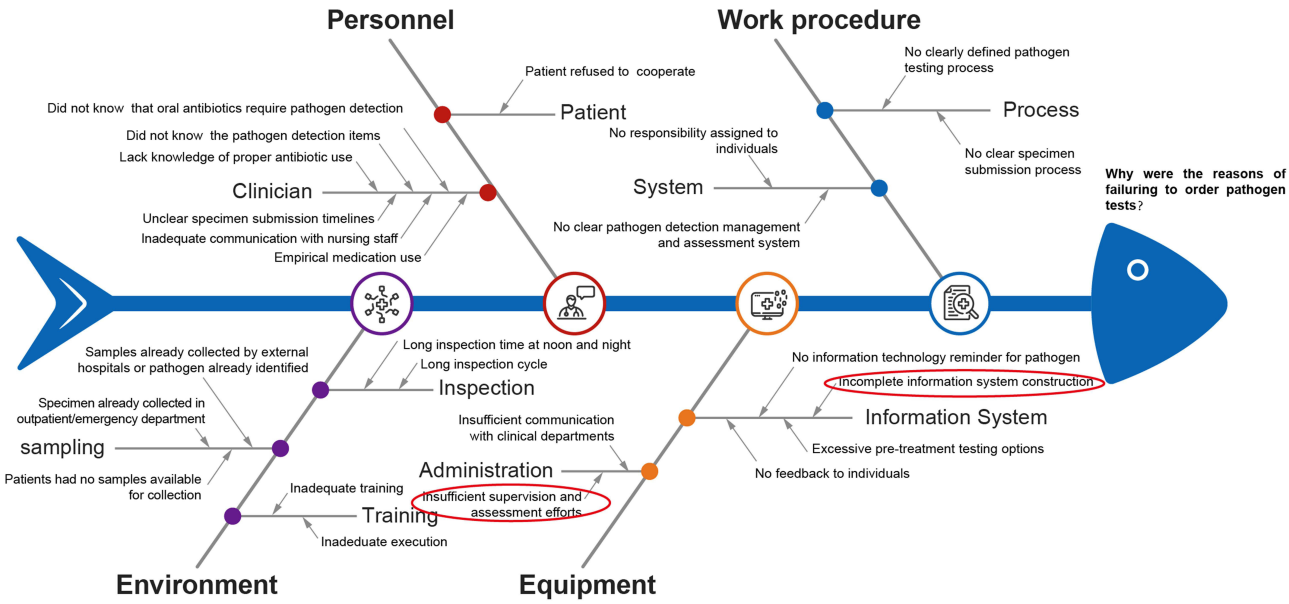

Figure 2 Roots cause of failuring to order pathogen tests.

specimens (eg video recordings on correct blood, urine, and sputum culture collection) with assessments. Joint training at both hospital and department levels was conducted to reinforce physicians' awareness of active and standardized specimen submission. Hospital infection specialists provided specialized lectures for key monitoring departments, analyzed reasons for failure to conduct pathogen tests before antimicrobial therapy, and assisted with departmental improvements.

Improving Information Technology Monitoring

An information monitoring module was established within the real-time hospital infection surveillance system to clearly define the capture points for antimicrobial administration and pathogen specimen collection times. It required that

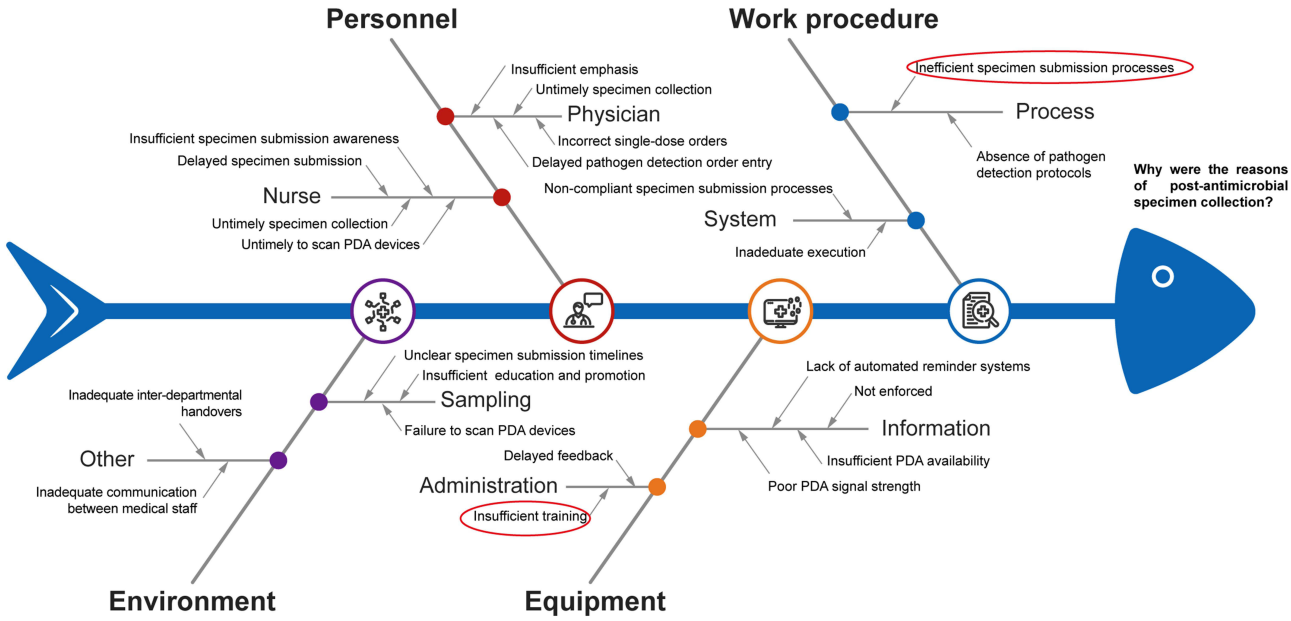

Figure 3 Roots cause of post-antimicrobial specimen collection.

specimens should be collected before the initiation of therapeutic antimicrobial therapy, enabling real-time monitoring and querying of submission rate indicators by both administrative departments and clinical departments. A pop-up reminder for pathogen testing was added when physicians ordered antimicrobial agents, with medication options for preventive or therapeutic use. For therapeutic use, physicians could choose empirical or sensitivity-guided treatment, with reminders to conduct pathogen testing before treatment and options for pathogen tests. Specimens that have already been submitted could be linked to sensitivity results. Moreover, as some specimens (such as cerebrospinal fluid and blood cultures) are difficult to obtain, specimens submitted within 72 hours before admission for outpatients and emergency patients were included in the statistics. The information department increased the number of PDAs available for clinical use and ensured full network coverage in all departments.

Optimizing Specimen Collection and Submission Processes

To reduce delays and errors in specimen collection, transport, and testing, multiple departments (including the Medical Affairs Office, General Affairs Office, Nursing Department, and Laboratory Department) collaborated to optimize the specimen submission process. The Medical Affairs Office coordinated with the microbiology laboratory to operate 24 hours for microbiological specimen receipt, with night shifts covered by the emergency laboratory and specimen inoculation performed by qualified physicians. The specimen submission processes for microbiological specimens collected during surgery and endoscopy were optimized. Instead, specimens were directly transported by logistics workers to the laboratory to shorten transport times. Meanwhile, the Nursing Department led efforts to improve the quality of specimen collection for sputum, blood, and urine cultures. The General Affairs Office focused on shortening specimen transport times.

Increasing Regulatory and Assessment Efforts

A supervision plan was developed, linking performance to clinical department evaluations. The pathogen submission rate was included as a hospital-level quality assessment indicator; clinical departments were assessed monthly, which was integrated into the annual performance assessment of department heads. Monthly statistical analyses of antimicrobial use and pathogen submission rates were published in the Medical Quality and Safety Newsletter, with department rankings. The top 10 departments with substandard submission rates were publicly notified at the Hospital Infection Management Committee and Antimicrobial Management meetings. Monthly drug newsletters published antimicrobial use data and conducted antimicrobial prescription reviews. The use of special-use antimicrobial agents was strictly regulated,

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requiring prescriptions by physicians with appropriate prescription rights and online consultation approval from infectious disease specialists. The Antimicrobial Management Team developed a "penalty plan for typical irrational antimicrobial use cases", which listed cases of combined key antimicrobial use without prior pathogen testing as typical irrational cases, with penalties applied to both the department head and the responsible physician (with double penalties for department heads).

Definitions of Terms

HAIs were diagnosed by the Hospital Infection Management Department according to the diagnostic criteria issued by the National Health Commission of China in 2001. The pathogen submission rate before antimicrobial therapy in inpatients is defined according to the document issued by China's National Health Commission (Guiding Opinions on the Special Action to Improve the Pathogen submission Rate Before Antimicrobial Therapy in Hospitalized Patients).

Targeted pathogen submission rate before antimicrobial therapy (%) = the number of cases with targeted pathogen submission before antimicrobial therapy/total number of cases receiving antimicrobial therapy × 100% (Note: targeted pathogen submission includes microbiological culture and sensitivity testing, microscopic examination, immunological submission, and molecular rapid diagnostic tests).

Pathogen submission rate before antimicrobial therapy (%) = the number of cases with pathogen submission before antimicrobial therapy/total number of cases receiving antimicrobial therapy × 100% (Note: including both targeted and non-targeted pathogen submission; non-targeted pathogen submission refers to related biomarkers such as procalcitonin, interleukin-6, fungus(1-3)-β-D-glucantests, and galactomannan antigen submission).

Pathogen submission rate related to HAIs (%) = the number of cases with pathogen submission related to HAIs/total number of cases with HAIs × 100% (Note: related biomarkers are excluded).

Pathogen submission rate before the combined use of key antibiotics (%) = the number of cases with pathogen submission before combined use of two or more key antibiotics/total number of cases receiving combined therapy with two or more key antibiotics × 100% [Note: key drugs include carbapenems (imipenem, meropenem, panipenem, biapenem, and ertapenem), glycopeptides (vancomycin and teicoplanin), tigecycline, linezolid, polymyxin, cefoperazone sulbactam, and antifungals (voriconazole, itraconazole, and caspofungin)].

The proportion of sterile specimens (%) = the number of sterile specimens for microbiological culture/total number of microbiological specimens × 100% [Note: sterile specimens include blood, cerebrospinal fluid, synovial fluid (joint fluid), pleural effusion (pleural fluid), peritoneal fluid (peritoneal fluid), pericardial effusion, blind tube fluid (pelvic effusion), amniotic fluid, bone marrow, and tissues].

The proportion of microbiological specimens (%) = the number of specific microbiological specimens/total number of all microbiological specimens × 100%.

The detection rate of MDRO (%) = the number of cases with specific multidrug-resistant bacteria detected in hospitalized patients/total number of cases with specific bacteria detected in hospitalized patients×100%. [Note: target multidrug-resistant bacteria include methicillin-resistant *Staphylococcus aureus* (MRSA), carbapenem-resistant P*seudomonas aeruginosa* (CRPA), carbapenem-resistant *Klebsiella pneumoniae* (CRKP), carbapenem-resistant *Acinetobacter baumannii* (CRAB), and carbapenem-resistant *Escherichia coli* (CREC)].

Microbial Identification

Bacteria were cultured and isolated according to the standard microbiological procedures, the strain identification was carried out using the matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDITOF/MS, Bruker, America), and the quality control strains were provided by the Clinical Laboratory Center of the Ministry of Health. The antibiotic sensitivity testing was performed using the Kirby-Bauer disk diffusion technique, E-test or Minimum inhibitory concentrations (MICs), and the MICS was tested via the VITEK2-Compact system (bioMérieux, France). The interpretation criteria and quality control followed the 2023 recommendations of the Clinical and Laboratory Standards Institute (CLSI).

Data Collection and Analysis

Relevant data were collected via the Xingling Real-Time Hospital Infection Surveillance System and the Laboratory Information Management System (LIS). Data on bacterial isolation and antimicrobial susceptibility test results from the microbiology laboratory were collected, excluding duplicate strains from the same patient and the same site. These data were collected by microbiology laboratory staff, while other data were collected by hospital infection management specialists. Data analysis was performed using R software (version 4.4.2). The count data were expressed as percentages, and trend analysis over different years was conducted using the Cochran-Armitage trend test, with a statistical significance level set at $p < 0.05$.

Results

Antibiotics-Related Pathogen Submission

The pathogen submission rate before antimicrobial therapy increased from 64.99% in 2021 to 76.40% in 2024 ($Z = 31.992$, $p < 0.001$), and the targeted pathogen submission rate before antimicrobial therapy increased from 55.51% in 2021 to 69.48% in 2024 ($Z = 36.727$, $p < 0.001$). Additionally, the pathogen submission rates in key departments also showed significant improvement, with an increasing trend year by year. The increase was primarily driven by targeted pathogen submission projects. In the pathogen submission rate before antimicrobial therapy, the Hepatobiliary and Pancreatic Surgery Ward 1 and the Vascular Surgery Ward showed the most substantial improvements in the pathogen submission rate before antimicrobial therapy, as evidenced by an increase of 171.11% and 117.00%, respectively. Moreover, the targeted pathogen submission rate before antimicrobial therapy also increased significantly by 144.34% and 142.16% in these wards, respectively ($p < 0.001$) (Tables 1 and 2).

The pathogen submission rate related to HAIs increased from 95.16% in 2021 to 99.62% in 2024, consistently remaining above 95% and reaching the national requirement ($Z = 8.877$, $p < 0.001$) (Table 3).

The pathogen submission rate before the combined use of key antibiotics increased from 94.38% in 2021 to 99.44% in 2024, showing statistically significant differences ($Z = 7.742$, $p < 0.001$) (Table 3).

Microbiological Specimen Structure

The total number of microbiological specimens submitted for testing increased yearly from 2021 to 2024. The proportion of sterile specimens increased from 38.07% in 2021 to 43.24% in 2024 ($Z = 27.497$, $p < 0.001$). The proportion of blood

Table 1 The Pathogen Submission Rate Before Antimicrobial Therapy From 2021 to 2024 (%)

Department	2021	2022	2023	2024	Z	P
Hepatobiliary Pancreatic Surgery Ward 1	24.48(282/1152)	41.51(479/1154)	56.08(641/1143)	66.12 (884/1337)	21.787	<0.001
Hepatobiliary Pancreatic Surgery Ward 2	38.58(419/1086)	48.83(624/1278)	47.49(700/1474)	49.25 (789/1602)	4.619	<0.001
Vascular Surgery	31.06(132/425)	46.23(196/424)	46.25(185/400)	67.42 (267/396)	9.874	<0.001
General Surgery	34.13(300/879)	44.95(418/930)	47.42(487/1027)	60.02 (722/1203)	11.561	<0.001
Cardiothoracic Surgery	35.77(220/615)	44.88(351/782)	46.17(452/979)	64.00 (773/1206)	11.823	<0.001
Orthopedic Ward 3	37.69(150/398)	46.89(196/418)	50.28(177/352)	69.11 (179/259)	7.571	<0.001
Orthopedic Ward 1	42.82(161/376)	56.16(228/406)	71.00(377/531)	69.85 (475/680)	9.232	<0.001
Colorectal and Anal Surgery	42.47(285/671)	49.78(333/669)	58.77(429/730)	65.00 (520/800)	9.259	<0.001
Trauma Surgery	46.17(175/379)	58.54(257/439)	68.26(314/460)	81.43 (377/463)	11.080	<0.001
Neurosurgery	53.59(851/1588)	79.20(1013/1279)	84.50(1325/1568)	91.58(1479/1615)	25.579	<0.001
Other word	74.93(14,663/19,569)	73.22(15,875/21,680)	74.60(18,196/24,391)	79.76 (19,961/25,026)	13.168	<0.001
Total	64.99(17,638/27,138)	67.79(19,970/29,459)	70.44(23,283/33,055)	76.40 (26,426/34,587)	31.992	<0.001

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Table 2 The Targeted Pathogen Submission Rate Before Antimicrobial Therapy From 2021 to 2024 (%)

Department	2021	2022	2023	2024	Z	P
Hepatobiliary Pancreatic Surgery Ward 1	19.10(220/1152)	37.69(435/1154)	45.41(519/1143)	46.67 (624/1337)	14.361	<0.001
Hepatobiliary Pancreatic Surgery Ward 2	30.85(335/1086)	46.79(598/1278)	46.00(678/1474)	46.50 (745/1602)	6.892	<0.001
Vascular Surgery	26.59(113/425)	42.69(181/424)	42.50(170/400)	64.39 (255/396)	10.316	<0.001
General Surgery	33.11(291/879)	40.54(377/930)	45.08(463/1027)	59.10 (711/1203)	12.064	<0.001
Cardiothoracic Surgery	31.06(191/615)	41.56(325/782)	41.47(406/979)	49.17 (593/1206)	7.031	<0.001
Orthopedic Ward 3	36.43(145/398)	42.11(176/418)	43.75(154/352)	62.16 (161/259)	6.012	<0.001
Orthopedic Ward 1	30.32(114/376)	34.73(141/406)	55.74(296/531)	61.18 (416/680)	11.217	<0.001
Colorectal and Anal Surgery	25.63(172/671)	35.72(239/669)	42.60(311/730)	55.25 (442/800)	11.817	<0.001
Trauma Surgery	36.41(138/379)	51.25(225/439)	63.04(290/460)	76.89 (356/463)	12.370	<0.001
Neurosurgery	33.44(531/1588)	50.66(648/1279)	66.07(1036/1568)	72.63 (1173/1615)	23.856	<0.001
Other word	65.49(12,815/19,569)	65.79(14,264/21,680)	67.64(16,498/24,391)	74.15 (18,556/25,026)	20.632	<0.001
Total	55.51(15,065/27,138)	59.77(17,609/29,459)	62.99(20,821/33,055)	69.48 (24,032/34,587)	36.727	<0.001

Table 3 Therapy-Related Pathogen Submission Rates Before Antimicrobial Therapy From 2021 to 2024 (%)

Index	2021	2022	2023	2024	Z	P
Pathogen submission rate related to HAIs	95.16(1220/1282)	96.49(1266/1312)	99.54(1307/1313)	99.62 (1316/1321)	8.877	<0.001
Pathogen submission rate before the combined use of key antibiotics	94.38(772/818)	96.54(1284/1330)	99.07(1071/1081)	99.44 (1060/1066)	7.742	<0.001

cultures increased from 35.13% in 2021 to 38.49% in 2024 ($Z = 15.863$, $p < 0.001$). However, the proportion of sputum cultures decreased from 31.99% to 29.90% ($Z = -10.848$, $p < 0.001$), and that of urine cultures decreased from 10.74% to 9.63% ($Z = -8.535$, $p < 0.001$) (Table 4).

Detection Rate of MDRO

The overall detection rate of MDRO showed a downward trend from 17.19% in 2021 to 15.36% in 2024 ($Z = -2.733$, $p < 0.05$). Specifically, from 2021 to 2024, the detection rates of MRSA, CRPA, and CRKP decreased from 32.42%, 20.57%, and 14.19% to 27.50%, 12.66%, and 12.23%, respectively. However, the detection rate of CRAB showed an increasing trend (30.96% in 2021 to 41.78% in 2023) before dropping to 33.04% in 2024. The detection rate of CREC showed an upward trend, which increased from 1.40% in 2021 to 2.09% in 2024 ($Z = 3.161$, $p < 0.05$) (Table 5).

Table 4 Analysis of Microbiological Specimen Composition Proportions From 2021 to 2024 (%)

Type of Culture	2021	2022	2023	2024	Z	P
Sterile specimen	38.07(35,821/94,086)	39.26(42,473/108,172)	41.59(54,406/130,829)	43.24(58,993/136,421)	27.497	<0.001
Blood	35.13(33,050/94,086)	37.04(40,063/108,172)	37.34(48,851/130,829)	38.49(52,505/136,421)	15.863	<0.001
Sputum	31.99(30,102/94,086)	33.01(35,707/108,172)	33.66(44,034/130,829)	29.90(40,791/136,421)	−10.848	<0.001
Urine	10.74(10,104/94,086)	9.78(10,577/108,172)	9.45(12,369/130,829)	9.63(13,139/136,421)	−8.535	<0.001

Table 5 The Detection Rate of MDRO From 2021 to 2024 (%)

MDRO	2021	2022	2023	2024	Z	P
CRKP	14.19(383/2699)	13.68(420/3070)	11.74(470/4005)	12.23(389/3182)	−2.914	0.004
CREC	1.14(23/2013)	1.26(33/2624)	2.07(67/3242)	2.09(58/2775)	3.161	0.002
CRAB	30.96(431/1392)	34.93(618/1769)	41.78(973/2329)	33.04(639/1934)	2.231	0.026
CRPA	20.57(244/1186)	18.47(219/1186)	16.61(232/1397)	12.66(146/1153)	−5.187	<0.001
MRSA	32.42(366/1129)	30.54(393/1287)	31.40(470/1497)	27.50(355/1291)	−2.332	0.020
Total	17.19(1447/8419)	16.94(1683/9936)	17.74(2212/12,470)	15.36(1587/10,335)	−2.733	0.006

Notes: Satistically significant results is $p<0.05$.
Abbreviations: MRSA, methicillin-resistant *Staphylococcus aureus*; CRPA, carbapenem-resistant P*seudomonas aeruginosa*; CRKP, carbapenem-resistant *Klebsiella pneumoniae*; CRAB, carbapenem-resistant *Acinetobacter baumannii*; CREC, carbapenem-resistant *Escherichia coli.*

Discussion

The management of pathogen submission before antimicrobial therapy involves multiple aspects, including enhancing the professional capabilities of medical staff, optimizing the specimen submission process, and improving information system construction. Specifically, the process includes the clinical physician's specimen submission request, patient specimen collection, specimen transportation, and feedback from the microbiology laboratory, involving clinical physicians, nurses, specimen transporters, and laboratory personnel. From the perspective of hospital management, this study applied the FOCUS-PDCA model to effectively improve the pathogen submission rate and specimen quality before antimicrobial therapy and reduce the detection rate of MDRO, providing a sustainable management mechanism.

FOCUS-PDCA Model-Driven Continuous Quality Improvement Promotes Special Action

Compared with traditional management methods, the FOCUS-PDCA model has the following advantages. It is data-driven, allowing for precise problem identification through the collection and analysis of large amounts of data, avoiding the shortcomings of relying on experience-based judgments. It promotes multi-department collaboration, enhancing management efficiency and effectiveness. It emphasizes continuous improvement through the PDCA cycle, continuously enhances antimicrobial management levels.

This study applied the FOCUS-PDCA model and kept the pathogen submission process efficient and rational by integrating quality management concepts into improving pathogen submission rates. After the improvement, the pathogen submission rate before antimicrobial therapy for hospitalized patients increased from 64.99% to 76.40%, and the targeted pathogen submission rate increased from 55.51% to 69.48%, with significant growth in surgical departments. These data are higher than the results reported by Lao et al and Zheng et al.[18,21] Measures such as training, performance assessment, and information technology can effectively improve the pathogen submission rate before antimicrobial therapy and enhance physicians' willingness to submit specimens. Zheng et al have reported consistent results.[29] From a hospital management perspective, this study proved that applying the FOCUS-PDCA model is beneficial for the advancement of special action measures.

FOCUS-PDCA Model-Driven Information Management Significantly Improves Submission Rates

Currently, hospital infection information management has become an essential tool for reducing hospital infection rates and antimicrobial usage. Information technology helps increase microbiological testing submission rates and facilitates timely communication between departments.[20,22,29–31] Physicians play a central role in antimicrobial use, as they are the ones who order pathogen tests. Studies have shown that information system decision-making is a key factor influencing physicians' intentions to conduct pathogen testing, especially for special-use antibiotics.[29] Antimicrobial drugs have high usage rates in surgical departments. This is because surgeons often use antimicrobial agents for the long term to prevent surgical site

infections. They may have insufficient awareness of the importance of pathogen diagnosis and may prefer empirical treatment due to the long turnaround time for antimicrobial susceptibility testing (AST).[32–34] In this study, rigid rules were designed based on information technology. When physicians ordered antimicrobial agents, a pop-up reminder for pathogen testing was displayed, with pathogen test options provided for selection. Additionally, Personal Digital Assistants (PDAs) were used to scan and match antimicrobial administration times with pathogen specimen collection times, which directly intervened in physicians' diagnostic behaviors and improved their compliance with pathogen testing before therapeutic antimicrobial use. The combined use of key antibiotics is mostly used for patients with severe conditions and long hospital stays. In this study, the pathogen submission rate before the combined use of key antibiotics was slightly lower than the 100% target set by the National Health Commission, which will be a key area for improvement in the next phase.

High-quality monitoring is the foundation for controlling drug-resistant bacteria. Inaccurate or erroneous monitoring results can mislead clinical practice and are not conducive to resistance control. This study showed that the submission rate and quality were increased. The proportion of sterile specimens in microbiological specimens increased by 5.17%, and the proportion of blood cultures increased by 3.36%. However, the proportion of sputum and urine cultures decreased by 2.09% and 1.11%, respectively. In foreign countries, blood and urine cultures are the most common microbiological specimens, while sputum is the most frequently collected specimen in China. Although sputum and urine cultures are easily obtained in clinical practice, they are also more prone to contamination. Blood and other sterile specimens should be preferred.[35,36] In this study, it was found through PDA specimen collection times that many departments still collected morning sputum and urine, which violated the principle of specimen submission before antimicrobial therapy. The awareness of medical staff was gradually changed through a cycle of training, inspection feedback, retraining, and re-inspection feedback. The increase in sterile specimens (such as blood cultures) reduced the risk of specimen contamination, improved the reliability of antimicrobial susceptibility results, shortened the duration of empirical treatment, and thus encouraged clinical physicians to shift from empirical to evidence-based treatment, curbing the development of multidrug resistance.

FOCUS-PDCA Model-Driven Antimicrobial Management Contributes to Lowering MDRO Detection Rates

The 2022 Global Burden of Disease study identified 6 major pathogens responsible for AMR-related deaths in 2019, including *Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus pneumoniae, Acinetobacter baumannii, and Pseudomonas aeruginosa*, accounting for 73.4% of attributable deaths.[37,38] The management of antibiotics is crucial to curb the trend of MDRO.[39,40] After improvements, the detection rate of MRSA, CRPA, and CRKP decreased from 32.42% to 27.50%, from 20.57% to 12.66%, and from 14.19% to 12.23%, respectively. The analysis suggests that submitting relevant biomarkers and targeted pathogen specimens can maximize the use of empirical antibiotics without indication and prevent prolonged antimicrobial courses.[15,16] For patients with confirmed pathogen diagnoses, physicians can select antimicrobial agents to which the pathogens are susceptible for targeted treatment, avoiding the use of broad-spectrum or combination therapy to reduce the selective pressure of resistance. Timely adjustment of treatment regimens based on AST results could improve treatment efficacy and reduce the development of resistance. Therefore, it's believed that the decline in MRSA/CRPA/CRKP detection rates is directly related to the reduction of antimicrobial selective pressure due to precise medication use.

However, in this study, CRAB and CREC showed a fluctuating upward trend, which requires attention. The detection rate of CRAB increased from 30.96% in 2021 to 41.78% in 2023, and then dropped to 33.04% in 2024. The detection rate of CREC slowly rose from 1.40% in 2021 to 2.09% in 2024, which is consistent with global data.[10] The analysis indicates that MDRO mainly originate from the ICU, where carbapenem antimicrobial agents are used at a high rate for treating severe bacterial infections or MDRO infections, leading to an increasing trend in the detection rate of carbapenem-resistant Enterobacteriaceae. Moreover, the medical environment is conducive to the growth of resistant bacteria. CRAB can survive for a long time on dry and inanimate surfaces, and *E.coli* is ubiquitous in the environment,[41] making them unresponsive to single antimicrobial management strategies. This suggests that controlling multidrug-resistant bacteria requires joint environmental cleaning and disinfection, hand hygiene, and active surveillance, in addition to rational antimicrobial use.[42,43] Although the detection rate of CREC is still relatively low, its upward trend

is concerning and warrants continued monitoring. In the next phase, we will strengthen bacterial resistance surveillance and promote multi-disciplinary collaboration.

This study has some limitations. First, some patients may have used antimicrobial agents before admission, and it is currently impossible to screen out patients who have already used antimicrobial agents in other hospitals or outpatient clinics through information technology. Therefore, the impact of pre-hospital antimicrobial use on pathogen specimens cannot be completely ruled out. Second, the detection rate of CREC shows an overall upward trend in this study, which requires further improvement. Third, this study fails to further investigate whether the specimen collection sites match the infection sites for HAIs. In future research, we will focus on matching the infection sites with the submitted specimens.

Conclusion

In summary, this study implemented the FOCUS-PDCA model, adopting a metrics-driven and problem-oriented approach to enhance multi-disciplinary team collaboration and communication. Strengthening intelligent regulatory systems using information technology reinforced the awareness of clinical medical staff in pathogen submission before antimicrobial therapy. These measures effectively promoted rational clinical antimicrobial use and reduced the detection rate of MDRO. Furthermore, through multiple measures (including establishing a diversified training system, analyzing representative cases of inappropriate antimicrobial use, implementing departmental and individual performance evaluations, and ensuring follow-up by dedicated infection control personnel), the study strictly monitored every step of antimicrobial prescribing and specimen submission management. This approach not only increased the pathogen submission rate but also improved the submission quality, providing practical experience for clinical healthcare institutions seeking to enhance the pathogen submission rate before antimicrobial therapy. In the future, we aim to accelerate information system development, promote clinical rapid diagnostic technologies, and uphold the principle of "collecting specimens whenever necessary; performing pathogen testing before administering therapeutic antimicrobials for infections", thereby better supporting clinical practice.

Ethics Statement

This study was conducted in accordance with the Declaration of Helsinki. The research design was reviewed and approved by the Ethics Committee of Affiliated Jinhua Hospital, Zhejiang University School of Medicine. The hospital's Ethics Committee approved the waiver of informed consent. We guarantee the privacy, confidentiality, or anonymity of the participants at any stage of this study. The anonymous indirect data of the participants will be collected, analyzed, and presented in the research.

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Disclosure

The authors have declared that no competing interests exist in this work.

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