REVIEW ARTICLE

# GLOBAL EXPERIENCE OF ANTIMICROBIAL STEWARDSHIP INTEGRATION IN ELECTRONIC MEDICAL RECORDS: A SCOPING REVIEW

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## ABSTRACT

*Antimicrobial resistance impedes the efficacy of currently available antimicrobial drugs for treating infectious diseases. Antimicrobial stewardship (AMS) practices contribute to in halting antimicrobial resistance by ensuring appropriate antimicrobial prescription. Consequently, many hospitals nowadays utilize electronic medical records (EMR) as a platform to enhance AMS practices among their healthcare professionals. The impact of EMR-based AMS modules needs to be ascertained. This scoping review aims to describe the impact of AMS Programs implemented through EMR on a global scale. A scoping review was conducted using the methodological framework of Arksey and O'Malley, in addition to the Joanna Briggs Institute. A comprehensive search was conducted on PubMed and Google Scholar databases for literature published between 2014 and 2021 using the keywords "antimicrobial", "stewardship", and "electronic medical records". Two reviewers independently screened the titles and abstracts of articles based on the "Population-Concept-Context" framework, using predefined inclusion and exclusion criteria. A total of 20 studies were included. Most of these studies were conducted in the United States (n=12) and the remaining studies were conducted in various countries, including the United Kingdom, Australia, Indonesia, Egypt, Canada, the Netherlands, Saudi Arabia, and South Korea. The studies demonstrated the global impact of integrating the AMS program in the EMR. The review declares that EMR adoption can provide healthcare providers with efficient processes given the availability of clinical data that guide appropriate antimicrobial use. Additionally, implementing information technologies for AMS facilitates adherence to national and international clinical practice guidelines and standardizes antimicrobial usage for optimal patient care.*

***Keywords:*** *Antimicrobial Stewardship, Electronic Medical Records, Integration, Global Experience, Information Technologies, Antimicrobial Usage.*

## INTRODUCTION

The discovery of antibiotics by Alexander Fleming in 1928 revolutionized modern medicine and extended the human life span[1]. Most antibiotics currently used in clinical practice were developed before 1987 [2], with only a few new antibiotic classes introduced afterwards[3]. Unfortunately, the rise of antimicrobial-resistant organisms and the failure to discover new antibiotics to combat these pathogens has led us toward a potential post antibiotic era[4]. Antimicrobial resistance is a serious problem in which microorganisms become resistant to medications, which can lead to severe illness and death[5]. Improper duration or ineffective dosing are among the most common clinical causes of the development of antimicrobial resistance[6]. The World Health Assembly urged member states to develop national action plans in 2015 to combat this threatening public health problem[5,7]. Antibiotic stewardship programs were introduced to estimate and optimize the appropriate utilization of antibiotics while reducing unintentional antimicrobial adverse effects and eventually halt additional development of resistance[8]. Antimicrobial stewardship (AMS) refers to the optimal selection, dosage, and duration of antimicrobial treatment that leads to the best clinical outcome for treating or preventing infection while minimizing toxicity to the patient and subsequent resistance [9-11].

The aim of AMS is threefold. The first goal is to ensure that healthcare providers prescribe the correct antimicrobial with an accurate dosage and duration for each patient. Secondly, it seeks to prevent the excessive, inappropriate, and abusive use of antimicrobials. Finally, it strives to minimize the development of resistant organisms on the long term [12-14]. To implement AMS in a hospital setting, there needs to be a program. These programs aim to enhance the use of antibiotics, optimize clinical practices for prescribing and dispensing, improve patient care and outcomes, reduce healthcare expenses, prevent the spread of new resistant pathogens, prolong the life of current antibiotics, mitigate the financial implications of antimicrobial resistance, and train healthcare professionals in the best practices for antibiotic use[15]. If AMS is performed correctly, antimicrobial resistance, healthcare-related infections, and healthcare expenses are estimated to be reduced[16]. There are generally cost savings because fewer doses of antibiotics are used, and less expensive

antibiotics are chosen. programs as part of national action plans are estimated to be able to save 1.6 million lives and 4.8 billion dollars by 2050 across 33 OECD countries[17]. A team with strategies (approaches and techniques) is needed to operate the AMS program. The AMS team typically includes an infectious disease physician or a pharmacist (with specialized training in infectious disease), as well as expert staff in the microbiology laboratory, hospital epidemiology, and administration[18-20]. Guidelines for creating an AMS program in acute care hospitals were first issued by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America in 2007 [21]. AMS programs utilize diverse methods or strategies to positively intervene in physicians' prescribing behavior and patterns to ensure appropriate antimicrobial use[22-23]. One crucial quality indicator is antimicrobial prescribing according to national or international guidelines, whichever is available[16].

There are two approaches to antimicrobial stewardship: one is at the front-end, and the other is at the back-end. The front-end approach involves restrictive prescriptive authority, where certain antimicrobials require prior authorization for use by everyone except a select group of clinicians. The back-end approach involves prospective review and feedback, where the antimicrobial stewards review active antibiotic orders and provide recommendations to clinicians based on the availability of microbiology results and clinical features of the case [12,24-26]. Many AMS programs implement both approaches; however, in resource limiting settings, the front-end approach seems to be the most implemented strategy. On a larger scale, various hospital-wide decisions can eventually promote the appropriate use of antibiotics. An example of such decisions includes formulary restriction, where hospitals selectively add antimicrobials to their formulary and refrain from adding others, which may lead to inappropriate antimicrobial utilization[27-28]. Another technique is implementing order sets and protocols, which are either paper-based or using a computerized physician order entry system to ensure that guideline-based, appropriate empiric antibiotic selection is followed at each time[29-30]. Clinical guidelines and national recommendations can also help minimize variation in practice at a local level and eventually increase the appropriate use of antibiotics [31-32]. Other system-based intervention includes the promotion of antibiotic dose optimization, which customizes the treatment based on the patient's clinical characteristics, the organism causing the infection, the location of the infection, and the pharmacokinetic and pharmacodynamic properties of the antimicrobial drug [33-34]. Clinicians also need to be educated on the proper use of antimicrobials in different situations. This education can be obtained through various methods, such as reading order sets, obtaining authorization for restricted antimicrobial use, conducting concurrent review and feedback, and attending formal didactic sessions or Grand Rounds-type lectures [35-36]. For the intravenous to Oral Switch process, these procedures may consider switching a patient's antimicrobial medication from intravenous to oral formulation if specific criteria are met [37-39]. Pharmacists can make dosing adjustments for specific antimicrobials, such as vancomycin and aminoglycosides, to achieve appropriate blood levels[40]. Last, computer-assisted decision support programs can identify allergies, inappropriate dosages, and mismatches between drugs and susceptibility.

As previously described, most of AMS interventions anchors around improving the prescribing of antibiotics which can be genuinely challenging in paper-based healthcare systems which used to be a perceived major setback to many programs. Nowadays, with the vast adoption of Electronic Medical Records (EMR) systems, it is presumed that it provided a critical opportunity for monitoring antimicrobial-prescribing practices and serves as an easy communication tool to provide opportunities for improvement and guidance to clinicians [41,30, 28].

**Antimicrobial Stewardship Program Application in Electronic Medical Records**

Institute of Medicine states that EMR can improve patient safety and enable effective care delivery [42]. While EMR usage has only recently become prevalent, third-party clinical decision support has aided AMS programs and clinicians in following current clinical practice guidelines for several years [43]. In recent years, the role of information technology in healthcare has significantly affected the delivery of healthcare services. One notable example is the Infectious Disease Society of America and the Society for Healthcare Epidemiology of America's advocacy for implementing information technology in AMS programs [22]. Electronic medical records are health-related records managed by authorized staff within a healthcare organization. Doctors can use computerized systems to enter orders and prescriptions and utilize decision support systems for healthcare decision-making[29]. Approximately 50% of hospital patients receive antimicrobial prescriptions from nonspecialized physicians, which can lead to less effective treatments against evolving pathogens. EMR-based AMS applications were able to improve prescription accuracy and support AMS programs [29]. Few studies explored the success of incorporating EMR functionalities to optimize AMS programs. EMR reminders have reduced prescription errors and encouraged adherence to antibiotic guidelines. This includes optimal treatment duration recommendations, resulting

in less use of certain antibiotics[31]. A study suggests implementing a mandatory protocol for prescribing antibiotics through electronic medical records to ensure accuracy and suitability due to disparities in prescription suitability among hospitals. Moreover, proper documentation helps with quick assessment and standardization of antimicrobial therapy by the AMS teams[32]. This scoping review aims to describe the impact of implementing the antimicrobial stewardship program interventions using EMR systems globally.

## METHODS

### Design

A scoping review was conducted using the methodological framework of Arksey and O'Malley and the Joanna Briggs Institute[44]. The scoping review included all study designs, editorials, commentaries, and grey literature.

### Search Strategy

The PubMed and Google Scholar databases were searched for literature published from 2014 to 2021. Two reviewers used inclusion and exclusion criteria based on the 'Population–Concept–Context' framework to independently screen titles and abstracts of articles considered for inclusion. Full-text screening of relevant eligible articles was carried out by two reviewers. The keywords and subject headings used were ["Antimicrobial Stewardship" or "AMS"] and ["Electronic Medical Records" or "Electronic Health Records", "Medical Records" or "Health Records" or "Electronic Medical Records" or "Clinical Decision Support (CDS)"] and ["effect" or "effectiveness" or "impact"].

### Eligibility Criteria and Selection Process

This scoping review involved all studies in the English language and published online between the years 2014 and 2021. The search process was conducted electronically in three phases: titles of various studies were evaluated during the first phase, searching the relevant studies was based on the prespecified inclusion criteria by assessing the study title and abstracts and filtering out duplicates and irrelevant studies in the second phase, and the complete retained articles were thoroughly reviewed in the third phase, as shown in the PRISMA-ScR diagram in **Figure 1**.

### Charting the data

A table for data extraction was created to align with the research objectives. it includes the article details, title, author(s), publication date, research/study region, and study outcomes. The findings were also analyzed using the Population, Context, and Content (PCC).

### Summarising and reporting findings

The selected studies detailing the impact of antimicrobial stewardship through electronic medical records were summarized and reported the findings and outcomes from the gathered studies.

## RESULTS

### Identification of potential studies

A total of 177 articles were found through the search strategy. After reviewing the article titles and abstracts, 86 articles were removed due to duplication, and an additional 71 articles were excluded as they did not meet inclusion criteria (Figure 1). Ultimately, 20 articles were included in this scoping review.

### Study characteristics

A total of 20 articles were included, comprising studies from countries in America, Asia, and Europe. The publication years ranged between 2014 and 2021, with 15 presented research in community settings, three in Academic Medical Hospital, one in a Pediatric hospital, and one in a Critical Care setting.

In terms of study design, there were five quasi-experimental studies, four single center cohort studies, three systematic/literature review studies, three review/ narrative studies, two analytical studies, two pre- and post-intervention studies, and one quality improvement study. The studies conducted in various countries worldwide were summarized in Table 1, which includes the following countries and their number of studies: United States (n=12), Australia (n=1), Indonesia (n=1), Egypt (n=1), Canada (n=1), United Kingdom (n=1), Netherlands (n=1), Kingdom of Saudi Arabia (n=1), and South Korea (n=1).

The results of the selected studies that described the impact of antimicrobial stewardship through electronic medical records were recorded and concisely summarized descriptively by illustrating the outcomes of the studies. A summary of the studies details, context, and impact of their AMS application within the EMR is presented in **Table 1.**

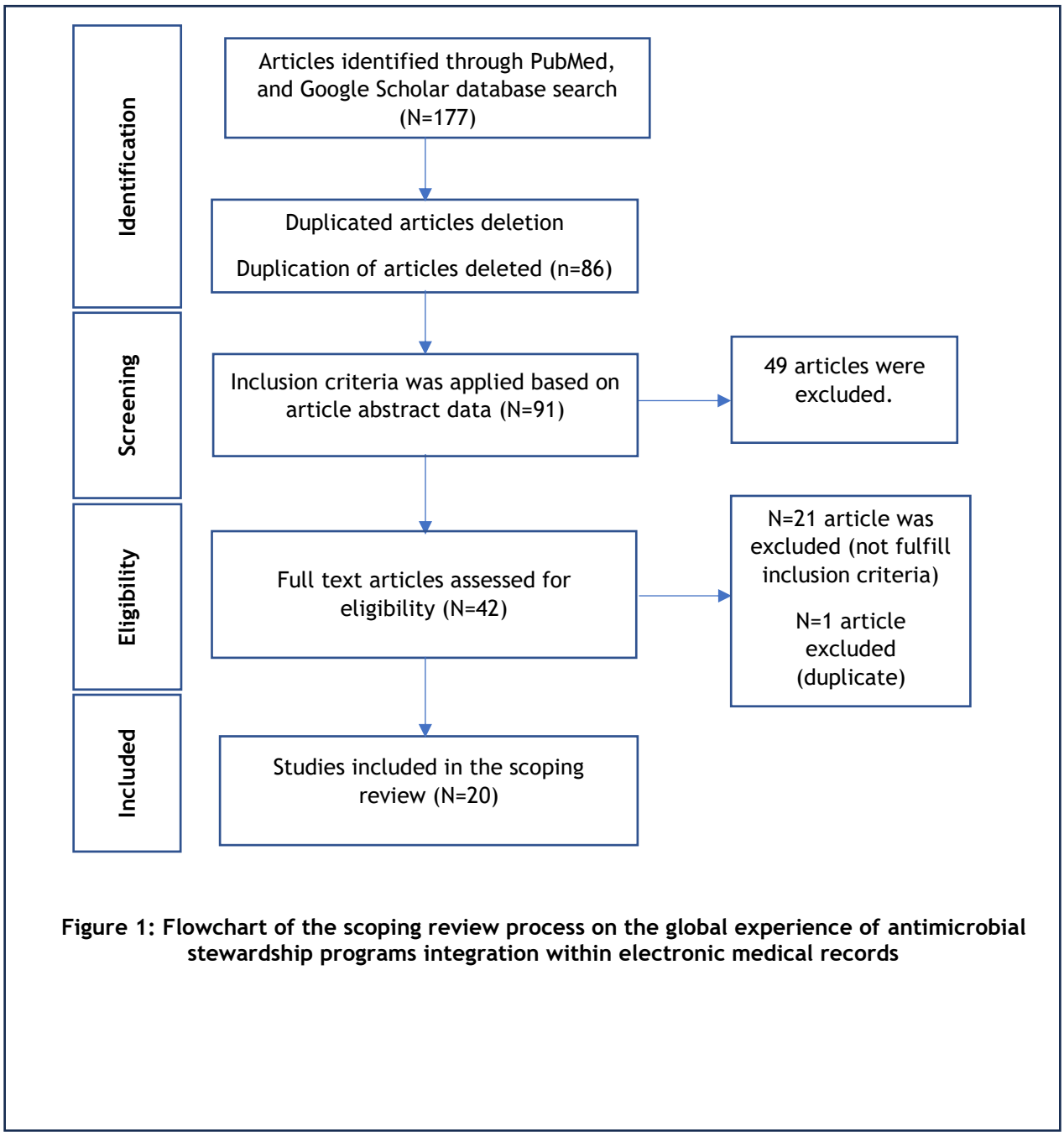


**Figure 1: Flowchart of the scoping review process on the global experience of antimicrobial stewardship programs integration within electronic medical records**

**Table 1: Main Findings from Research Articles**

| Authors | Year | Design | Country | Population | Context | Content/Impact |
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| Alotaibi & Federico | 2017 | Review article | Global | Acute care hospital & community setting | Review on selective health information technologies implementation within the EMR including electronic physician's orders, clinical decision support, E-prescribing, electronic sign-out and hand-off tools, bar code medication administration, smart pumps, automated medication dispensing cabinets, electronic medication administration record, patient data management systems, among others on improving patient safety outcome. | Implementing these EMR interventions had favourable results in reducing medication errors, reducing adverse drug reactions, and improving compliance with practice guidelines. |
| Cairns, Kelly A., et al. | 2021 | Narrative review | Australia | Acute care hospital setting | A narrative review of the Australian experience describing the factors that the AMS teams face during practice with paper-based prescribing followed by EMR implementation | Implementing an integrated AMS in EMR successfully improved workflows, expanded AMS team activities efficiently identified the appropriate antibiotics for patients in real-time, and reduced the time it takes for AMS rounds from 58 to 44 minutes. Specific |
| Kamaluddin & Adisasmito | 2023 | Systematic review | Indonesia | Acute care hospital setting | Systematically review the role of the electronic medical record in enhancing rational antibiotics prescription (number of articles included = 8) | Studies included show that implementing EMR in addition to electronic prescribing, daily AMS alerts, or application of antibiotic restriction system improved the rational use of antibiotics. Details in the EMR and the associated built in AMS systems allowed for more accurate patient information assessment, which along with other interventions (e.g., education, AMS team rounds, policies) facilitated decreased use of antibiotics and in some studies, in turn decreased hospital acquired infections. |

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| Weihs | 2020 | Single center application | United States | University Medical Center | Described antimicrobial stewardship program integration into EMR and how utilizing clinical decision support system (CDSS) and live alerts, along with building a patient worklist alert system at their center assisted in their AMS program. | EMR and alert systems help improve antimicrobial stewardship efforts by identifying patients who need review and de-escalation opportunities, positive cultures, rapid diagnostic results, and drug-bug mismatches. After implementing CDSS for ordering levofloxacin, the use of this antibiotics for inappropriate indication significantly decreased ($p<0.0001$) compared to prior implementation use. Additionally, levofloxacin days of therapy from 41.6 to 33.4 per 1000 patient days and the average duration of use from 3.3 days to 1.3 days. |
| Rittmann & Stevens | 2019 | Systematic review | United States | Acute care hospital setting | A systematic review of the role and effectiveness of clinical decision support systems (CDSSs) on antibiotic stewardship (number of articles included = 45) | The implementation of CDSS in EMR in various forms has significantly reduced antibiotic consumption rates in most settings and inconsistently improved compliance with treatment guidelines or recommendations. Using CDSS significantly improved the time to optimal therapy in bacteremia or sepsis. CDSS cost benefit was variable between studies reviewed. |
| Shawki, May A., et al. | 2021 | Analytical longitudinal study | Egypt | Acute care hospital setting | Evaluated the outcome of using mobile app to support the implementation of AMS program interventions. | The AMS mobile app has effectively reduced antimicrobial consumption from 75.1 defined daily doses to 64.65 per 100 bed days, resulting in significant cost savings of E£1,237,476. The app has also led to a significant decrease in the length of ICU stay by 1.63 days and a reduction in mortality rate from 1.17% to 0.83% comparing pre to post implementation phases. |

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| Nault, Vincent, et al. | 2017 | Quasi experimental retrospective study with interrupted time series | Canada | Acute care hospital setting | Studied the effects of implementing an AMS program that uses the Antimicrobial Prescription Surveillance System (a novel CDSS) on antimicrobial consumption, hospital stays, and the rate of inappropriate prescriptions. | Positive results were achieved by implementing computer-assisted AMS intervention, which is based on prospective audit and feedback done by a clinical pharmacist on triggered patients based on defined deviations from best practices. The system-based AMS intervention resulted in significant reduction in the average length of stay, antibiotic consumption rates, antibiotic cost, and non-adherence to local guidelines. |
| Parzen-Johnson, Simon, et al. | 2021 | Narrative review | United States | Acute care hospital setting | A narrative review identified how interventions in the EMR can influence antimicrobial prescribing behaviour. | Incorporating application of AMS clinical decision support tool into the electronic medical record can take various forms with variable impact and effort. Interventions using tailored education, alerts, prompts, time-limited orders, and antibiotic restriction systems demonstrated their ability to modify provider prescribing behaviour and improved unnecessary and prolonged use of antibiotics. |
| Simpao, Allan F., et al. | 2018 | Quality Improvement methodology | United States | Pediatric acute care hospital setting | Assessed the implemented Visual analytics and automated electronic antibiogram within the EHR system. Automating the process of creating electronic antibiogram using EMR data | The use of EMR-linked, condition-and patient-specific electronic antibiogram that displays susceptibility maps for organisms and antibiotics with visual analytics that is updated periodically based on real time EMR data was deemed a useful tool with increasing monthly access by providers. |
| Mohayya, Sana M., et al. | 2021 | Single-center retrospective cohort | United States | Academic medical Hospital | Assessing the impact of an EMR-based automated electronic antibiotic time-out alert in the setting of gram-negative bacteremia. | The implementation of electronic antibiotic time out alert did not result in statistically significant change in outcomes studied, including modification of treatment within 24 hours of final culture results, antibiotic de-escalation time, and duration of broad-spectrum antibiotics of culture data for subjects with gram-negative bacteremia. |

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| Allan, Newman, et al. | 2016 | Single center application | Southwest England | Critical Care Department | Evaluate the effect of using electronic daily prompts through EMR on provider adherence to AMS policy of writing appropriate and valid antibiotic indications and review/stop date. | Introduction and sequential interrogation of EMR-based daily prompts improved compliance with writing proper antibiotic indications and valid stop/review dates for antibiotic therapy. Starting off with poor AMS guideline adherence to required documentation at prescription level, at the third audit round, more than 78% of antibiotic orders had recorded indications, and 84.7% had valid stop/review date at initial prescription. |
| Berrevoets, Marvin AH, et al. | 2017 | Quasi experimental retrospective study with interrupted time series | Netherlands | Acute care hospital setting. | An interventional study evaluated the effect of a computerized trigger tool for identifying patients who are candidates for an intravenous line (IV) to oral antibiotic switch combined with weekly educational sessions to providers on its use | Utilization of the electronic trigger tool based on pre-specified criteria on patients with ongoing IV antibiotics and identified opportunity for oral switch coupled with weekly physician educational sessions significantly reduced the percentage of IV antibiotics used for more than 72 hours by 19% in the intervention group compared to control, and the median duration of IV antibiotics was reduced by 0.8 days. |
| Kim, Moonsuk, et al. | 2016 | Pre and post intervention analysis | Republic of Korea | Acute care hospital setting | Compared the outcome of electronic alerts and automated infectious diseases consultations on in bloodstream infections in terms of appropriateness of antibiotic therapy (effective therapy, optimal therapy, de-escalation therapy, and intravenous to oral switch therapy). | Electronic pop-up alert was designed to appear to providers with identification and antibiotic susceptibility results of blood culture and prompt providers to optionally consult infectious diseases in an automatic process. Since the implementation of this EMR AMS intervention there was observed statistically significant improvement in the proportion of effective, optimal, and de-escalation therapies for patients with blood stream infections compared to the pre-implementation phase. This intervention also facilitated quicker communication through EMR, and these automated consultations had an average reply time of just 6.8 hours. |

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| Pogue, Jason M., et al. | 2014 | Quasi-experimental retrospective cohort study | United States | Acute care hospital setting | Analysed the impact of implementing an automated alerting system through a third party CDSS coupled with rapid response by antimicrobial stewardship pharmacists on the outcomes of patients with gram-negative bactremia mainly time to appropriate therapy, length of stay, and mortality compared with patients with no formalized stewardship intervention prior to the intervention. | Active alerting (automatic paging/emailing) to AMS pharmacists with updates on positive blood culture results and subsequent intervention had led to a decrease in the time to effective antimicrobial therapy in gram negative bacteremia compared to prior intervention implementation. Patients who received care while using the automated alerting system had a reduction of 2.2 days in their stay. For patients who were not on optimal therapy at time of initial culture positivity, the intervention group had significant reduction in infection-related mortality. |
| Wolfe, Jenna R., et al. | 2019 | Pre and post intervention analysis | United States | Acute care hospital setting | Assessed the impact of introducing an automated antibiotic time-out alerts to providers at 72 hours for all patients receiving broad spectrum antibiotics on improving the practice of antibiotic de-escalation. | Automated antibiotic time-out alerts through the EMR increased the de-escalation of broad-spectrum antibiotics significantly more than prior to the alert implementation which eventually reduced the use of broad-spectrum antibiotics and the workload for AMS program personnel. The study showed a 55% de-escalation rate, shorter hospital stays (8.5 vs. 11.5 days), and fewer adverse events associated with antibiotics (11.9% vs. 16.3%) comparing pre and post intervention implementation records. |
| Katzman, Michael, et al. | 2019 | Single center application | United States | Acute care hospital setting | Detailed description of the built of a customized AMS module within the EMR at the institution to facilitate daily work of AMS team members in prospective audit and feedback with display of the program outcomes and overview of the impact of this module on the program workflow. | By customizing the documentation of AMS interventions and tracking through the EMR rather than manually recording, there was significant increase in the total chart reviewed, increase in the total number of reconcilable interventions, and decrease in the rate of reviewing charts that did not end up with an AMS recommendation which increased the team's efficiency. This intervention was reflected on the ability of the program to reduce antibiotic consumption effectively which eventually helped in improving some reported antibiotic susceptibilities over time in that institution, significant improvements were made. AMS recommendations were relayed to the resident physician 58% of the time and to |

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| | | | | | | the attending physician 19% of the time. The de-escalation category increased from 58% to 66%. The total antimicrobial usage dropped by 9.3 DOT/1000 patient days, which resulted in a 21% decrease in antibiotics. The susceptibility of Escherichia coli to antibiotics like ciprofloxacin increased from 72% to 78%, while that of Pseudomonas aeruginosa risen from 78% to 83%. |
| Brotherton, Amy L., et al. | 2020 | Quasi-experimental retrospective cohort study | United States | Acute care hospital setting | Evaluated the process and outcome of an implemented AMS hard-stop alert that would prompt physicians to use an electronic order set with bundled best practices to follow when first accessing a patient chart with a positive blood culture with *Staphylococcus aureus*. | After the application of this intervention, adherence to *Staphylococcus aureus* bacteremia guidelines improved significantly by 27.2% ($P < 0.001$), and readmissions due to complications with this infection was decreased by 9.6% within 90 days compared to pre intervention. There was also a decrease in 30-day mortality, although the overall outcome difference was insignificant ($P = 0.092$). |
| Clifford, Robert J., et al. | 2018 | Software analysis of antibiotic consumption and resistance data (analytical methods) | United States | Acute care hospital setting. (280-hospital network) | Illustrated the build of an independent software that used EMR data for analysing and reporting large volumes of drug consumption and antibiotic resistance data usually considered essential for AMS efforts. | Using the electronic laboratory information system in EMR, this software was able to collate and trend large data on antibiotic consumption and pre-specified susceptibility pattern for Staphylococcus aureus (used as a protype). Use of such technology will have positive impact on monitoring the trends of antimicrobial-pathogen combinations and adherence with clinical guidelines and ultimately enhancing patient outcomes. |

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| Pettit, Natasha N., et al. | 2019 | Quasi-experimental retrospective cohort study | United States | In the 811-bed acute care academic medical Center, | Assessed the impact of implementing an automated AMS CDSS through the EMR for adult patients with yeast growing from blood culture on the adherence with best practices bundle of care in this setting and the time to starting antifungal treatment. | Comparing pre to post EMR AMS CDSS implementation, there was a significant increase in candidemia bundle of care adherence, going from 48% to 83% (P = 0.001). Median time to initiation of antifungal therapy decreased from 4.8 hours vs 3.3 hours, length of stay was 24 to 18 days, and mortality within 30 days improved from 19% to 26%. |
| Forrest, Graeme N., et al. | 2014 | Literature Review | United States | Acute care hospital setting. | A detailed review of the available EMR systems and clinical decision support systems (CDSS) and their role in facilitating the workflow of AMS programs based on clinical practice guidelines as well as barriers to their implementation and suggested methods to overcome these barriers. | The adoption of EMR is essential for effective review of patient data and therefore providing AMS recommendations on the appropriate use of antimicrobials. The use of CDSS and other EMR functionalities facilitates and enhances AMS program application including effective prospective audit and feedback, formulary restriction and preauthorization, incorporation of evidence-based treatment guidelines, and prompts for modification of antimicrobial therapy based on microbiology results. Cost, logistics, and alert fatigue are among the most common barriers to implementing these interventions. Overall, implementing EMR AMS CDSS was shown to reduce antibiotic use in general among other important improvements AMS metrics. |

## DISCUSSION

This scoping review indicates that implementing an antimicrobial stewardship program through electronic medical records has a positive impact on enhancing AMS activities. Out of 20 studies included in the review, five of the studies reported that implementing an EMR-based AMS system including, a restriction system, clinical decision support system, automated physician consultations, real-time antibiotics prescription, and AMS visual data, resulted in improved accuracy of antimicrobial prescriptions[27,30,37, 45, 46].

six studies reported the outcomes of designed interventions, integrating antimicrobial computer applications and computerized antibiotic time-out systems into electronic medical records, leading to improved appropriate antimicrobial usage [47,28,48,49,50,36]. Alert and automated visualization interventions were found to be used across four studies, impacting adherence to antimicrobial stewardship guidelines [51-54]. Three studies have shown that implementing best practices like electronic triggers, treatment guidelines, and de-escalation of broad-spectrum antibiotics had a positive impact on improving antimicrobial stewardship [35,55-56].

A study in Indonesia showed improvement in the accuracy of antimicrobial prescriptions after implementing an EMR-based restriction system[27]. Similarly, in the United States, a study found that incorporating an antimicrobial clinical decision support system or features into electronic medical records could assist healthcare providers in prescribing appropriate antibiotics based on evidence-based best practices [30]. A study conducted in South Korea aimed to promote appropriate antimicrobial drug prescriptions for blood infections and improve antimicrobial stewardship programs. The study found that using electronic signals along with automated physician consultations led to a significant improvement in therapeutic efficacy (from 87.8% to 94.4%), optimization (from 64.4% to 81.4%), and de-escalation (from 10.0% to 18.6%) after the intervention[37]. Similarly, in Australia, Electronic Medical Records (EMR) have played a vital role in developing and succeeding Antimicrobial Stewardship (AMS) programs targeted toward solving local healthcare issues. The use of EMR has allowed AMS teams to quickly identify the antibiotics prescribed to patients in real-time, resulting in a reduction in AMS rounds from 58 to 44 minutes [45]. In addition, a study conducted in the United States revealed that automated AMS visual data in the electronic medical record (EMR) can significantly aid in ensuring appropriate antibiotic usage and assist staff in adjusting or de-escalating antibiotics as required [46].

On the other hand, six studies showed that implementing AMS-based EMRs can successfully promote appropriate antimicrobial usage. In the United States, integrating antimicrobial computer applications into EMRs has been found to reduce antibiotic usage and narrow the spectrum of antibiotic usage [47]. Additionally, AMS features in electronic medical records, such as alerts, restrictions, availability of guidelines, and workflow, have the potential to improve antimicrobial prescribing behavior [28]. A study conducted in Egypt found that incorporating antimicrobial applications into electronic medical records significantly decreased antimicrobial consumption, from 75.1 to 64.65 defined daily doses /100 bed-days, resulting in a cost savings of E£1,237,476. This implementation also reduced the length of ICU stay, with an average difference of 1.63 days and a decrease in the mortality rate from 1.17% to 0.83% [48]. Similarly, in Canada, an antimicrobial stewardship program in electronic medical records can also decrease hospital stays and costs associated with antimicrobial usage [49].

In the United States, a computerized antibiotic time-out system was implemented through an electronic medical record to reduce adverse clinical events caused by the overuse of antibiotics, particularly for gram-negative bacteria. However, the study found no significant difference between the two groups in terms of changes in treatment within the first 24 hours (24% versus 30%, P = 0.33). Moreover, all secondary measures evaluated were statistically insignificant, including changes in treatment regardless of the time point, antibiotic de-escalation time, and duration of broad-spectrum antibiotics. Furthermore, antibiotic time-out reminders did not change antibiotic treatment modification within the first 24 hours of culture data for subjects with gram-negative infection [50]. Another study in the Netherlands found that electronic prompts were effective in reducing the duration of intravenously administered antibiotics by 19% and found that 72% of individuals adhered to the electronic prompts, indicating that education on the use of electronic prompts can be helpful in this regard [36].

On the other side, four studies prove that implementing AMS-based EMR alerts successfully impacted adherence to antimicrobial stewardship guidelines. In the United States, research has shown that periodic alerts of a positive culture of gram-negative bacteria combined with antimicrobial stewardship intervention facilitated appropriate treatment, reduced hospital stays, and decreased mortality rates across three hospitals. Alert prompt

antimicrobial stewardship intervention substantially reduced the median treatment time to 8 hours versus 14 hours (P = 0.014). Additionally, after accounting for confounding factors, the intervention group showed a 27% decrease in the length of hospital stay compared to the nonintervention group (OR 0.73 with 95% CI 0.62-0.86). Furthermore, patients not receiving appropriate antimicrobial treatment after a positive first culture demonstrated 24% decreased odds in the length of hospital stay (OR 0.76 with 95% CI 0.66-0.86) and 76% decrease in infection-associated death (OR 0.24 with 95% CI 0.08-0.76) [51]. On the other hand, in the United States, the study involved the development of a unique real-time analysis form for antimicrobial stewardship programs and a mutually exclusive tracing workflow with the help of pharmacists and physician experts in antimicrobial stewardship programs. The study communicated a significant improvement in the expansion of the antimicrobial stewardship program, with a substantial drop in antimicrobial use, antimicrobial resistance, and infections associated with Clostridioides difficile (observed expected ratio of less than one since 2014 to 0.62 in 2018) [52]. Another study introduced a cost-effective approach in 280 hospitals in the United States for antimicrobial consumption and resistance surveillance. The semiautomated visualization and analysis of trends (SAVANT) alert system was developed through electronic medical information, with Staphylococcus aureus used as a prototype. Inpatient and outpatient prescriptions for eight essential anti-staphylococcal drugs, patterns of anti-staphylococcal drug dispensation, and resistance among 81,840 isolates from over 6.5 million microbiology cultures were also recorded. The study concluded that SAVANT is an economical method for promoting antimicrobial stewardship programs. Most importantly, healthcare institutions can utilize this regardless of microbial identification and antimicrobial sensitivity analysis[53]. A study conducted by Pettit et al. in 2019 discovered that implementing electronic medical record-based automated prompts significantly improved adherence to the bundle of care for candidemia patients. The adherence rate increased from 48% to 83% (P=0.001), and the time to begin antifungal treatment was reduced [54].

Three studies have shown that implementing best practices can lead to improved compliance with antimicrobial stewardship requirements. A study was conducted in the United Kingdom to assess the effectiveness of electronic triggers in improving antimicrobial stewardship. The study focused on documenting the start and end dates of antibiotics administered in the critical care unit. The study was carried out in two stages - before providing education and after implementing electronic triggers. The findings of the study indicated a significant improvement in the documentation of antibiotic start and end dates (P < 0.0001) in three clinical audits. Additionally, the use of electronic medical record-based reminders led to a significant improvement in the prescription and review dates of antimicrobials. The percentage of prescriptions and review dates increased from 57% and 60%, respectively, to 96% for both parameters. The study concluded that daily use of electronic triggers had a positive impact on improving antimicrobial stewardship[35].

Regarding specific applications related to applying best practices in antimicrobial stewardship, a retrospective study was conducted in the United States to evaluate the effectiveness of an automated, electronic medical record-based, real-time antimicrobial stewardship intervention for managing bacteraemia associated with Staphylococcus aureus in hospitalized patients. The intervention prompted physicians to recognize the treatment guidelines for Staphylococcus aureus bacteraemia, leading to a 27.2% improvement in adherence to all components specific to institutional guidelines. Overall, the study found a reduction in cumulative 90-day readmissions and 30-day mortality[55].

Additionally, another study in the United States evaluated the impact of automated alert systems on the de-escalation of broad-spectrum antibiotics and antimicrobial stewardship. The study found a significant improvement in broad-spectrum antibiotic de-escalation at 72 hours, increasing from 35.1% to 55.0%, shorter antibiotic course (6.9 versus 9.0 days; P = 0.002), reduced length of hospital stays (8.5 versus 11.5 days; P = 0.002), and fewer adverse events associated with antibiotics (11.9% versus 16.3%) after intervention[56].

## CONCLUSION

This scoping review features 20 articles from mostly high-income countries. The review finds that almost all of the articles claimed that the use of EMR-based AMS was effective in improving antimicrobial stewardship practices, particularly antimicrobial prescriptions, hence improving patient outcomes and reducing wastage and costs. The findings in this review suggest that the use of EMR-based AMS should be considered for implementation in healthcare facilities particularly hospitals.

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