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REVIEW ARTICLE

Antibiotic Stewardship to Combat Antimicrobial Resistance Menace: Present Updates, Challenges, and Future Directions

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Abstract

The increasing trend in resistance to antimicrobial agents is a major threat to the management of infectious diseases. If nothing is done, we may return to a pre-antibiotic era where a minor infection is potentially fatal. Therefore, it is important to use antibiotics judiciously to prevent serious public health threats. To this day, many policies and guidelines have been laid out to define the ideal selection, the correct dosing, and the appropriate duration of antibiotic therapy. Unfortunately, their adaptation still leaves much to be desired. We suspect that demand for inappropriate or unnecessary use represents a major cause of emerging resistance. The consequence is that broadening the antimicrobial spectrum leads to never-decreasing antibiotic exposure, which differentiates these drugs from other substances and increases the selection pressure that leads to the emergence of antimicrobial resistance and indirectly raises the cost. In the face of these threats, the principle of "maximum therapeutic effect with minimal risk" must drive the antimicrobial strategy. It is essential that evidence-based interventions be integrated by all hospitals, physicians, and other health professionals into daily practice.

Keywords

Antibiotic stewardship, Global health, Multidrug-resistant bacteria, Precision medicine, Probiotics

Introduction

The excessive, unnecessary, and inappropriate use of antibiotics in human, animal, agriculture, and veterinary medicine leads to antibiotic resistance, which is considered to be a major global public health threat of the 21st century. Antimicrobial resistance endangers the effective prevention and treatment of an ever-increasing range of infections caused by bacteria, parasites, viruses, and fungi. Clinical management of infected patients is challenged by an increase in morbidity and mortality, longer hospital stays, and higher costs. In several countries, antibiotic sales in the community exceed those in hospitals, which rekindle ethical and economic concerns and demonstrates that human behavior, particularly the irrational use of antibiotics, is likely to be one of the most important drivers of resistance development. The burden of antibiotic use and resistance is particularly high in low- and middle-income countries (LMICs), where poverty-infection-malnutrition vicious cycle and the recourse to informal healthcare providers foster the emergence and spread of drug resistance. Given the widespread therapeutic misuse, and sometimes the non-therapeutic use of antibiotics, all nations bear a great responsibility in developing effective and visionary policies, stimulating effective interventions, and enhancing active collaboration in international networks. In this article, author summarized the present updates on antibiotic stewardship to combat antimicrobial resistance menace, present challenges, and future directions.

Importance of Antibiotic Stewardship in Combating Antimicrobial Resistance

Uncontrolled antimicrobial and antibiotic usage during the past century have posed a multifaceted threat

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to human life, namely antimicrobial resistance (AMR). To combat the seriousness of AMR and to prolong the lifespan of antibiotics and antimicrobial agents, various methods have been introduced and implemented worldwide, among which antibiotic stewardship (ABS) programs and responses are considered key strategies [1-3]. Responsible usage of antibiotics through the ABS approach prevails over provoking AMR and economic burden, with encouraging outcomes such as reduced undisposed drug effluents and decreased ecological issues [4,5]. Antibiotic stewardship (AS) practices were introduced during the early 1940s, while at the same time, penicillin became an available antibiotic for treating bacterial infections [4]. Treatment regimens suggest that if treatment is prolonged into the fourth day or if clinical improvement occurs during treatment with penicillin and if the next day there is no continuation of treatment, the approval alteration should be recorded, and on the next day, an exchange of the drug should be attempted. Nowadays, these programs, namely antibiotic stewardship (AS) or antibiotic reserve, encourage the use of antibiotics for the treatment of life-threatening infections in humans [6]. The worldwide consensus about ABS is that approved components of ABS are surveillance for the target microbial species coupled with regular, pertinent, and commensurate benchmarking; clear communications; appropriateness review of antibiotic prescriptions; obligatory approval of antibiotic purchases; integrated infection treatment plans; and standardized digital systems [7].

Definition and Principles of Antibiotic Stewardship

Antibiotic Stewardship (AS) Protocol advocates for the proficient use of chosen antibiotics intended for the exact source of contaminating microorganisms at the precise quantity, form, and timeframe to acquire the best results by reducing the occurrence of resistance, toxicity, bacterial elimination, and adverse activities [8-11]. Antibiotic stewardship is a fundamental part of the infection prevention and drug security agendas, encouraging conservative drug utilization. The foremost imperative transformation was the idea of “optimal practices” concerning antibiotic use by the participants generally and among healthcare specialists regarding these practices [11-13]. To enable a more structured survey and scrutiny of antibiotic utilization scores, foundational standards and diagnostic categories were planned. Antibiotic Stewardship encompasses designated standards and agendas suggested to develop and assess the optimal use of antibiotics through a multiplex mechanism to integrate with other components of an operational program in certified organizations [14].

The Antibiotic Stewardship principles recommend, among other things, the adoption cycles, diagnostic trials, contamination, treatments, and achievements. The strategic goal of AS is to align healthcare facility workflows concerning antibiotic usage with the best evidence and consensus assessments, which are themselves of importance to the ethical tenets of AS [15]. The centers chosen were through mutual consideration by the editors concerning the AS journal, supplemented by a general opinion among the installed members of AS Research and Progress. Antibiotic stewardship programs (ASPs) are intended to capitalize on outcomes where such intervention can offer benefits. The principal objective of ASP is the usage of measured doses of antibiotics to attain the best medicinal effect, comprising minimal adverse fallout and allergic reactions, and no antibiotic resistance [1-2,16]. The broad aim is to focus on increasing the illness and condition to adopt adaptations that protect and optimize medication interventions. The prime objective is to secure the key goals with a direct consequence through antibiotic usage [1-2, 16].

Impact of Antimicrobial Resistance on Global Health

Antimicrobial resistance is not only a threat to global health but also a threat to development, food safety, and global security. The data reveals a very alarming picture of antimicrobial resistance in 114 countries [16-18]. An increasing number of infections, such as pneumonia, tuberculosis, blood poisoning, gonorrhea, and foodborne diseases, are becoming harder and sometimes impossible to treat as antibiotics become less effective [1-3,19]. As antibiotics are used to treat many infections in different pharmacy settings, antimicrobial resistance can be connected to many causes [19]. Overuse and misuse of antibiotics seem to be widespread in different healthcare settings. They include prescribing by anyone without clinical guidance from professionals, new patients starting on antibiotics without any proper diagnosis, buying antibiotics without a proper prescription, not following an antibiotic regimen and dosages, continuing the medication even after symptoms are relieved, and using remaining antibiotic prescriptions for later infections [20,21]. Scientific evidence supports that most of these issues are not urgent or severe enough to require antibiotics and are indicated for self-limiting viral infections, where long-term resistance development may occur [22].

Poor quality of antibiotics is a potential barrier to managing antibiotic resistance. It includes a lack of active ingredients and/or the presence of incorrect ingredients, inadequate quantities of active ingredients, larger than normal dosages administered intentionally or accidentally, unclear formulation and/or dosages, inadequate product packaging, and expired or changed lot maturation [22,23]. In many countries, antibiotics are available without a healthcare professional’s suitable prescription. Although both prescription and non-prescription antibiotics include broad-spectrum

antibiotics, the availability of antibiotics without medical advice also means that others may not regard general hygiene, infection prevention, and control measures, which can lead to the spread of antibiotic resistance. Antibiotics are also dispensed in unrecognized pharmacies or community shops, in both high- and low-income countries, with an indication that close regulation of medical advertising and counterfeiting needs to eradicate management activities [22,23].

Current Strategies and Initiatives in Antibiotic Stewardship

Antibiotic overuse in the community and hospitals worldwide has reached alarming levels, leading to the accelerated emergence of antimicrobial resistance [22]. To combat this issue, the implementation of Antibiotic Stewardship Programs (ASP) has been encouraged, especially in healthcare facilities where they need to be tailored to each institution based on their specific boundary conditions [24]. ASP is mainly a hospital-based set of measures that induce appropriate antibiotic use to reduce resistance, cure infections, and minimize costs. The core of these activities relies on the implementation of correct guidelines, such as restriction protocols, tracking infection rates, repartitioning of resistant bacteria that are prevalent in the area, and developing efficient prescriptive tools without avoiding undertreatments and/or bacterial relapses in patients who will be treated [25]. In other words, to have more effectiveness in clinical practice, treatments should be adapted to real-life conditions, taking into account the existence of comorbidities and the pharmacological properties of the drugs in special populations such as obese patients, children, the elderly, and hospitalized patients [26]. At the same time, even strong guidelines are useless if they are not known or not applied by health practitioners. Only a low proportion of patients with respiratory infections received doctor recommendations to curb unnecessary antibiotic use, highlighting the fact that not enough people are aware of these guidelines. Furthermore, we do not have any compelling proof that tells us that implementing these two proposed actions really 'cure' the problem or, in other words, reduce antimicrobial resistance and plasmid treatment dynamics in a globalized world [27].

National and International Guidelines

National governments, international organizations, and educational groups have made efforts to promote the design and implementation of Antimicrobial Stewardship Program administrative directives in institutions to combat the expanding danger of antibiotic resistance [28,29]. Numerous initiatives have pledged to decrease the amount or divert the intensity of antibiotic resistance. In addition, a country-wide strategy is planned to serve as the critical institutions or hospitals that operate in the clinical pipeline of the most severely sick patients and/or high concentrations of antibiotic resistance [19]. The global health promotion aiming to execute National Action Plans and Joint Programming Initiative are among the numerous other worldwide programs supporting this important action [28,29].

At the same time, NGOs are important in varying degrees locally. Regardless of the means through which compensatory programs have been implemented, there is a sizable consensus between documents about the basic components of an antimicrobial stewardship initiative [28]. The coordinating entities at the institutional level should consider the guidelines of the professional organizations. In brief, the goals of such a general guide are to improve the quality of patient recovery, diminish the frequency of antibiotic resistance, defend antibiotic expenditure by optimal use, and enhance public health in general [4,30].

Hospital-Based Programs

Antibiotics are commonly prescribed drugs in hospitals; however, a significant portion of the course of antibiotics is either incorrect or inappropriate, which ultimately leads to the inadequacy of antibiotics. This antibiotic use also adversely promotes the fabrication of multidrug-resistant bacteria (MDRO) pathogens, consequently reducing the effective therapeutic options for the treatment of bacterial infections [12,31]. The consequences of MDRO are a prolonged length of hospital stay, an augmented economic burden, an increased death rate, and excessive reservoirs of future infections. Hospitals are important stewardship sites [32,33]. Below, we have summarized and discussed hospital-based antibiotic stewardship practices.

The initiation of antibiotic stewardship programs (ASPs) introduced fundamental changes to uncover many factors that primarily increased the use of broad-spectrum antibiotics in hospitals, and, as a result, the unnecessary adverse effects associated with antibiotic treatments were reduced [34-36]. In this regard, a list of core and complementary ASP interventions that hospital facilities should adopt to improve the responsible use of antibiotics in hospitals has been assembled. The core elements include leadership commitment, accountability, drug expertise, action, tracking, reporting, evaluation, feedback, and education [36]. Currently, these elements are updated as Core Elements of Hospital Antibiotic Stewardship Programs. In addition to these elements, additional components were also added for each healthcare setting (acute-care hospitals, long-term care, and post-acute care settings). Subsequently, the adherence to the core elements in these healthcare facilities was monitored using widely used surveys [35,37].

Community-Based Interventions

Community-based interventions can play a crucial role in reducing the widespread problem of overuse of antibiotics. During the past two decades, there have

been multiple strategies implemented in a community-based setting, such as public awareness campaigns, educational programs targeting parents and doctors. Such campaigns are intended to promote appropriate use of antibiotics for RTIs, to recognize as well as to reduce the risk of AMR, and to treat infections without antibiotics [38-40]. Patients are instructed to wait for at least two to three days for viral illness before contacting a health provider, and the use of antibiotics should be restrained for all cough illnesses without considerable airflow obstruction, for nasal discharge without other signs of sinusitis, and for pharyngitis without suspected streptococcal infection, so that the intrinsic healing process is not interrupted and unnecessary complications like resistance are prevented in the interest of public health [39-41]. Moreover, symptom recovery has been widely reported for 5-15 days, consistent with the illness course caused by most viral infections [41]. Reducing antibiotic prescriptions can be achieved by sharing clinical decision-making and bringing patients to the front of the battle line to achieve rapid recovery and cope with the sustained consequences. Over-the-counter distribution of antibiotics is ubiquitous in multiple areas. The approach to over-the-counter distribution could include implementing the same guidelines that govern prescription use of these medications for humans as well as for animals. Requirements need to be put in place on telemedicine services [40,41].

Challenges and Obstacles in Implementing Antibiotic Stewardship Programs

Understanding these challenges and resolving the obstacles will help in effective antibiotic stewardship implementation. Lack of infection control practices and the capacity of providers, especially in resource-constrained setups, are crucial challenges for effective ASP [42,43]. Diagnostic issues, particularly for the initiation of appropriate treatment, are a demanding process. All these will be compounded by human behavioral issues such as habits, lack of supervision, knowledge, and feeling a lack of need for stewardship [44,45]. Rational use of antibiotics requires changes in organizational and individual behaviors, as well as policies. Behavioral change theories could be applied to understand the ground reality and to plan and execute interventions [46,47]. Soon, the present antibiotics will be ineffective against several microbial agents as the majority acquire resistance capability [3]. Different levels of stakeholders, including consumer groups, should consider implementing effective stewardship. This discussion addresses the challenges faced by antibiotic stewardship programs at the healthcare level and describes the research areas that need attention in facilitating the success of antibiotic stewardship [48,49]. Strengthening infection prevention and control would support ASPs. Integrating point-of-care diagnostics may also improve the initiation of appropriate antibiotics. Qualitative and quantitative research at multidisciplinary levels, considering the local constraints and the cultural and diverse nature of stewardship success, will support future initiatives. Associations at different levels should play a vital role in policy direction and guidelines [50,51].

Lack of Awareness and Education

The level of knowledge of health professionals about the prudent use of antibiotics is not within the desired parameters [52,53]. The attitudes and adequate knowledge of using antibiotics together have a greater positive impact in the process of controlling the resistance of microorganisms to antibiotics, also aiming at ensuring the optimal efficacy of the treatment of diseases. It was concluded that preservice teachers had a good knowledge of antibiotic resistance, but they lacked knowledge of the effective use of antibiotics and of infection risk factors and prevention [54,55].

Misinformation is also disseminated through the media. A considerable number of people know that antibiotics cannot kill viruses, but do not refrain from asking for them when they have viral infections such as the flu [54,55]. The role of pharmacists is crucial for changing the medicines prescribed generically and for carrying out information campaigns. The use of existing healthcare facilities more effectively is essential, either in building capacity or in caring for patients. Such measures include surgical procedures that are less vulnerable to infections, including cancer therapy, counseling patients to take appropriate and timely action, and providing tailored advice to patients [56-58].

Resource Constraints

Achieving effective and long-lasting reduction in AMR through ASI and policy interventions could be costly, difficult to maintain, and costly. Finally, the economic constraints consume or restrict the allocation of financial and human capital to battle infections, even though the dire need for such investments is increasingly recognized [59-61]. Consequently, isolating investment in the right sets of interventions and approaches for the optimum impact is of the utmost importance. Policymakers, nevertheless, have financial budget constraints and institutional capacity problems that limit the allocation of resources for repetitive, incremental, and one-size-fits-all forms of awareness efforts [59-62]. The available data are insufficient to recognize optimal expenditure at operational stages. It is clear that the current data are not organized in ways that may be effectively employed for cutting operational allocation decisions other than to achieve ‘awareness’, ‘education’, and ‘research’ that are predetermined primary goals. Furthermore, estimated position-taking and anything that encourages such a process will be difficult to attain without clearly articulated, stable plans. All useful information on AMR increments funding investments, the appropriateness of measures, the incorporation of responsibilities for

stakeholders, and the obstruction of those who work in the public sector to achieve multiple objectives while managing the taxation funds [61-63].

Behavioral Factors and Misuse

Although antibiotic resistance is considered by a multitude of interwoven factors, it must be acknowledged that relentless and rampant misuse of antibiotics all over the world, particularly in low- and middle-income countries, can lead to the emergence of new and widespread resistance [64]. People in several developing countries, without any medical prescription, can purchase antibiotics over the counter at their own discretion and excessively use them. Consequently, people can be self-medicating with antibiotics. They can utilize antibiotics as putative broad-spectrum medications and rather discontinue them once their symptoms have been alleviated and they feel improved [65,66]. Additionally, the substitution of diarrheal, infectious, or mucopurulent genital discharge with antibiotics, without any supporting evidence, may contribute to the spread of antimicrobial resistance in developing countries [67,68].

Recommendations and Interventions

Deciphering the impact of human behavior on the use and abuse of antibiotics should result in antibiotic stewardship. Therefore, some alternative strategies from a public health standpoint may be necessary [69,70]. An intriguing question at this juncture consists of illustrating the strength of behavioral interventions on the rational use of antibiotics by people. Nonetheless, protecting the very few antibiotics that are effective against multi-cumulative resistant strains is no longer sufficient; we have no alternative but to act rationally and realistically [71]. The strategies of communication and sensible advice have, at present, been somewhat more examined among antibiotics. These strategies still currently endure the techniques of medical education and the rules of clinical practice worldwide. Therefore, behavioral interventions, supplemented alone or in hybrid with restrictive and environmental strategies, might be advantageous not only for health but for the pharmaceutical economic systems of lower- and middle-income countries [69,71].

Technological Innovations and Future Directions in Antibiotic Stewardship

The probable obstacles to the implementation of high-quality antibiotic stewardship with their coping strategies regarding the non-availability of diagnostic tests based on ASP have been illustrated. Specific manipulable barriers related to diagnosing urinary tract infections, community-acquired pneumonia, and optimizing intravenous to oral conversion have been addressed [72,73]. The potential role of rapid diagnostic tests at the point of care is highlighted. There are newer high-end molecular diagnostic approaches that not only identify the pathogens but also aid in determining the resistance genetic elements [63]. Techniques like generalizable technology for base calling and direct-from-sample specimen processing, biosensors powered by smartphones, and different digital/machine learning technologies to interpret the data generated by the diagnostic test methods are also discussed [74,75].

The recent technological development focuses on developing nano-device based platforms or the intersection of chemistry, physics, and molecular biology to generate bio-electronic systems for rapid and sensitive antibiotic resistance panels to recognize a wide range of antibiotic groups [76,77]. There are a variety of biosensors based on ion-sensitive field-effect transistors, such as photonic sensors, quartz crystal microbalance, surface acoustic wave sensors, and electrochemical sensors for label-free detection. Antibiotic derivative detection by molecular imprinting smartphone sensors makes use of the mobile phone and its components [78-80]. Surface acoustic wave consists of a few functionalizing layers, which include a potassium chloride solution acting as an electrolyte, a cellulose-based polymer selective to the studied compound, an Ag film, and a polyimide substrate [81].

Digital Health Solutions

A comprehensive digital strategy and well-organized digital health infrastructure could be the answer to the complexity and multiplicity of challenges encountered in antibiotic stewardship implementation, including antimicrobial resistance control and containment. Digital health solutions are key to making these applications simple to use, economical, interconnected, groundbreaking, individualized, and time-conscious. The significance of digital health in helping poorer countries to accomplish their digital development over the next decade in order to work more efficiently to attain universal health coverage allows them to benefit democratically from digital health knowledge [82-85]. The ingenious use of digital health can help revive the aspiration of health for all, including realizing the value of antibiotics by replenishing the diminishing antibiotic pipeline [82-85]. The whirlwind of immunological science about the long COVID impact on the immune system reserves somewhat painful echoes for individual health, with probable secular alterations in trajectory [86,87].

Internet applications and digital resources are assuming a growing and critical role in offering tailored evidence-based antimicrobial choices and providing pertinent information on the accurate delivery of antibiotics amid pandemics, particularly to patients who may never interact with healthcare professionals physically, and those who have no access to healthcare systems at all, such as refugees and internally displaced persons leading isolated lives in rural or weather-

sensitive areas, or dwelling in an outer space base [88-90]. Digital health offers potential to enhance numerous stages of antibiotic stewardship, particularly demand generation and individual commitment, and to offer tailored and targeted solutions, improving decision-making and end-user support. This can be addressed in an implementation strategy that integrates these enhanced antibiotic-present techniques for improved responsiveness by healthcare providers and increased patient knowledge regarding their roles in achieving a worldwide sustainable antimicrobial response. The aim is to ensure that all taking antibiotics are motivated and kept informed about the worldwide difficulties of antimicrobial resistance and antibiotic scarcity [88-90].

Precision Medicine Approaches

With the enhanced understanding of the human microbiome and the complex interactions between the different commensal microbial populations, the precision medicine approach has been proposed as a method for preventing antimicrobial resistance while retaining the ability to effectively treat infections. This approach could also reduce the pressure of antimicrobial selective pressure [91]. The use of a precision medicine approach, along with the availability of microbiomes that are disrupted by treatment with a specific antimicrobial, could help determine what required supplements or alterations might be beneficial in maintaining health and aid patient outcomes while minimizing the impact on the antimicrobial resistance of individual courses [91]. This approach postulates that the variations between individuals and organisms across geographical locations would probably underline their unique microbiome compositions and therefore the microbes supplemented into their diets. Moreover, these differences might also play a role in the diverse resistomes observed among various intermingling commensals [92].

In addition to using this approach for key preservation, investigations to decipher the activities of the specific microbes involved in the fundamental tasks in the overall functionality of the microbiome communities might reveal novel drug targets for the inhibition of infective microbes or for modifying host physiology [93]. Putting precision medicine into practice, however, requires investigating the potential displacement of the pathological threat of antibiotic resistance by alternative risks. Safety and efficacy studies should evaluate the selection of predominant commensals and the resultant health outcomes, as well as the selection for age-based hints indicating the presence of preliminary resistances, with the participant's microbiome health status in mind [94]. Furthermore, post-experimental monitoring studies are required to ensure that all players have returned to or supported the original microbiome state. While only a few of these issues are directly associated with antimicrobial resistance, new questions keep emerging, and top research priorities may alternate in relevance in the context of such a multidisciplinary large-scale project. In the real-world delivery of this precision medicine-based potential concept, role-based awareness is required to understand and exploit the potential of the situation [95,96].

Novel Therapeutic Strategies

The downslide of antimicrobial discovery among pharmaceuticals is largely related to the complexities posed by the very nature of antimicrobials themselves. Antimicrobials usually consist of diverse chemical species, which adds to the already present regulatory complexities. Over the last two to four decades, there has been a noticeable acknowledgment of the fact that a "one-size-fits-all" drug does not exist. The era of precision medicine is confidently displaying itself, where tailoring treatment to the individual patient is becoming the new norm. With this new realization comes the concept of precision antimicrobials as well. For example, antimicrobials that are active against susceptible bacteria elsewhere in the human system may not be effective against those in the central nervous system. This also means that, through precision tools, bacterial diseases can be screened and treated individually, vastly limiting the need for classical therapeutic antimicrobials. The use of genome editing tools to reshape bacterial growth patterns or modify bacteria so that they are no longer lethal but instead acquire new properties that promote beneficial aspects is in clinical exploratory stages [97,98]. The use of bacteriophage as a specific antimicrobial is still largely unexploited, at least in the West. The utility of gut commensals to replace pathogenic resistant isolates from the gut lumen also seems feasible [99]. Alongside the classical candidates comprising pharmacokinetic/pharmacodynamic modifying agents, bacterial virulence inventory modification tools, and immunological mediators, there are possible combinations to achieve supportive and definitive targets for combating ignoble bacterial infections [100]. The fact that all these newer influences do have a role to play only goes to show the inherent resistance that nature has toward what we know today as "resistant infections."

Conclusions

In conclusion, we assert that the hosts of community and government must take up every possible responsibility to prevent antibiotic resistance. The absence of the orchestration of efforts from every party will see us struggle mightily from the present day, where we are just receiving overtures of the catastrophes. The Antibiotic Stewardship Program is clearly just a foundational block that still requires other measures to fortify it. However, even a journey of a thousand miles must begin with the first steps. Little by little, we can and will evolve it into a more effective program, successfully able to combat the menace. Until

we achieve our collective goal, we should at least feel satisfied that every patient we successfully treated with the infection and hence prevented prolonged antibiotic administration or double coverage with broad-spectrum antibiotics is singing our praises together with us.

Conflict of Interest

Authors have no conflict of interest.

References

1. Murugaiyan J, Kumar PA, Rao GS, Iskandar K, Hawser S, et al. (2022) Progress in alternative strategies to combat antimicrobial resistance: Focus on antibiotics. Antibiotics 11: 200.
2. Salam MA, Al-Amin MY, Salam MT, Pawar JS, Akhter N, et al. (2023) Antimicrobial resistance: A growing serious threat for global public health. Healthcare 11: 1946.
3. Sannathimmappa MB, Nambiar V, Aravindakshan R (2021) Antibiotics at the crossroads - Do we have any therapeutic alternatives to control the emergence and spread of antimicrobial resistance? J Educ Health Promot 10: 438.
4. Muteeb G, Rehman MT, Shahwan M, Aatif M (2023) Origin of antibiotics and antibiotic resistance, and their impacts on drug development: A narrative review. Pharmaceuticals (Basel) 16: 1615.
5. Adebisi YA (2023) Balancing the risks and benefits of antibiotic use in a globalized world: The ethics of antimicrobial resistance. Global Health 19: 27.
6. Yamaki J, Mikhail M, Beuttler R, Robinson P, Yücel E, et al. (2024) Characterizing antibiotic regimen modification behavior, patient characteristics, and outcomes for patients with gram-negative bacterial infections, A retrospective single-center study. Antibiotics (Basel) 13: 302.
7. Trinh LTN, Do AD, Nguyen MH, Nguyen GH, Tran GA (2024) A scoping review on best practices of antibiotic resistance control in the private health sector and a case study in Vietnam. Discov Public Health 21: 53.
8. Ha DR, Haste NM, Gluckstein DP (2017) The role of antibiotic stewardship in promoting appropriate antibiotic use. Am J Lifestyle Med 13: 376-383.
9. Khadse SN, Ugemuge S, Singh C (2023) Impact of antimicrobial stewardship on reducing antimicrobial resistance. Cureus 15: e49935.
10. Fonseca Medeiros A, Margotto Bertollo C, Moreira Reis AM, Costa MA, Meireles Leite EM, et al. (2023) Building an antimicrobial stewardship program: A narrative of six years under the Donabedian perspective. Front. Pharmacol 14: 1074389.
11. https://www.who.int/europe/activities/promoting-antimicrobial-stewardship-to-tackle-antimicrobial-resistance
12. https://www.jointcommission.org/resources/patient-safety-topics/infection-prevention-and control/antibiotic-stewardship/
13. Centers for Disease Control and Prevention (2021) About antimicrobial resistance. US Department of Health and Human Services.
14. Fabre V, Davis A, Diekema DJ, Granwehr B, Hayden MK, et al. (2023) Principles of diagnostic stewardship: A practical guide from the Society for Healthcare Epidemiology of America Diagnostic Stewardship Task Force. Infection Control & Hospital Epidemiology 44: 178-185.
15. Shrestha J, Zahra F, Cannady Jr P (2025) Antimicrobial Stewardship. 2023. In: StatPearls. StatPearls Publishing, Treasure Island (FL), 34283434.
16. Centers for Disease Control and Prevention (2024) Implementation of Antibiotic Stewardship Core Elements at Small and Critical Access Hospitals.
17. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance
18. Antimicrobial Resistance Collaborators (2022) Global burden of bacterial antimicrobial resistance in 2019: A systematic analysis. The Lancet 399: 629-655.
19. Nwobodo DC, Ugwu MC, Anie OC, Al-Ouqaili MTS, Ikem JC, et al. (2022) Antibiotic resistance: The challenges and some emerging strategies for tackling a global menace. J Clin Lab Anal 36: e24655.
20. Sannathimmappa MB, Nambiar V, Aravindakshan R (2021) Antibiotic resistance pattern of Acinetobacter baumannii strains: A Retrospective study from Oman. Saudi J Med Med Sci 9: 254-60.
21. Sannathimmappa MB (2023) Global escalation in carbapenem-resistant Enterobacterales (CRE) and carbapenem-resistant Acinetobacter baumannii (CRAB) infections serious threat to human health from the pink corner. Biomed Biotechnol Res J 7: 9-16.
22. Akram F, Imtiaz M, Haq IU (2023) Emergent crisis of antibiotic resistance: A silent pandemic threat to 21st century. Microb Pathog 174: 105923.
23. Sannathimmappa MB, Nambiar V, Aravindakshan R (2021) A Cross-sectional study to evaluate the knowledge and attitude of medical students concerning antibiotic usage and antimicrobial resistance. Int J Acad Med 7: 113-119.
24. Bankar NJ, Ugemuge S, Ambad RS, Hawale DV, Timilsina DR (2022) Implementation of antimicrobial stewardship in the healthcare setting. Cureus 14: e26664.
25. Cheong HS, Park KH, Kim HB, Kim SW, Kim B, et al. (2022) Core elements for implementing antimicrobial stewardship programs in Korean general hospitals. Infect Chemother 54: 637-673.
26. Kvarnström K, Westerholm A, Airaksinen M, Liira H (2021) Factors contributing to medication adherence in patients with a chronic condition: A scoping review of qualitative research. Pharmaceutics 13: 1100.
27. O'Doherty J, Leader LFW, O'Regan A, Dunne C, Puthoopparambil SJ, et al. (2019) Over prescribing of antibiotics for acute respiratory tract infections; a qualitative study to explore Irish general practitioners' perspectives. BMC Fam Pract 20: 27.
28. World Health Organization Antimicrobial Resistance. Division 20 Avenue Appia1211 Geneva 27 Switzerland.
29. NATIONAL ACTION PLAN FOR COMBATING ANTIBIOTIC-RESISTANT BACTERIA.
30. Majumder MAA, Rahman S, Cohall D, Bharatha A, Singh K, et al. (2020) Antimicrobial Stewardship: Fighting antimicrobial resistance and protecting global public health. Infect Drug Resist 13: 4713-4738.
31. Sannathimmappa MB, Nambiar V, Aravindakshan R (2023) A 5-Year Retrospective Study of Antibiotic Resistance Pattern of Pseudomonas aeruginosa Isolated from Various Clinical Samples at a Tertiary Care Hospital. Medical Journal of Dr. D.Y. Patil Vidyapeeth 16: 687-692.
32. Ventola CL (2015) The antibiotic resistance crisis: part 1: Causes and threats. P T 40: 277-283.

33. World Health Organization (WHO) (2023) Antimicrobial resistance.

34. Centers for Disease Control and Prevention (CDC) (2019) Antibiotic resistance threats in the United States, 2019.

35. Centers for Disease Control and Prevention (CDC) (2020) The core elements of hospital antibiotic stewardship programs: 2020 update.

36. Barlam TF, Cosgrove SE, Abbo LM, MacDougall C, Schuetz AN, et al. (2016) Implementing an antibiotic stewardship program: Guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. Clin Infect Dis 62: e51-e77.

37. Palms DL, Kabbani S, Bell JM, Anttila A, Hicks LA, et al. (2019) Implementation of the core elements of antibiotic stewardship in nursing homes enrolled in the National Healthcare Safety Network. Clin Infect Dis 69:1235-1238.

38. World Health Organization (WHO) (2014) Antimicrobial resistance: Global report on surveillance.

39. Germeni E, Frost J, Garside R, Rogers M, Valderas JM, et al. (2018) Antibiotic prescribing for acute respiratory tract infections in primary care: An updated and expanded meta-ethnography. Br J Gen Pract 68: e633-e645.

40. Centers for Disease Control and Prevention (CDC) (2020) Be antibiotic aware: Smart use, best care.

41. Fleming-Dutra KE, Hersh AL, Shapiro DJ, Bartoces M, Enns EA, et al. (2016) Prevalence of inappropriate antibiotic prescriptions among US ambulatory care visits, 2010-2011. JAMA 315: 1864-1873.

42. World Health Organization (WHO) (2021) The role of primary care in reducing unnecessary antibiotic use and antimicrobial resistance.

43. World Health Organization (WHO) (2019) Antimicrobial stewardship programmes in health-care facilities in low-and middle-income countries: A WHO practical toolkit.

44. ReAct - Action on Antibiotic Resistance (2021). Challenges and strategies for antimicrobial stewardship in low-resource settings.

45. Hijazi K, Joshi C, Gould IM (2019) Challenges and opportunities for antimicrobial stewardship in resource-rich and resource-limited countries. Expert Rev Anti Infect Ther 17: 621-634.

46. Van Dijck C, Vlieghe E, Cox JA (2018) Antibiotic stewardship interventions in hospitals in low-and middle-income countries: A systematic review. Bull World Health Organ 96: 266-280.

47. Turner R, Hart J, Ashiru-Oredope D, Atkins L, Eades C, et al. (2023) A qualitative interview study applying the COM-B model to explore how hospital-based trainers implement antimicrobial stewardship education and training in UK hospital-based care. BMC Health Serv Res 23: 770.

48. DeBate R, Corvin JA, Wolfe-Quintero K, Petersen DJ (2017) Application of the intervention mapping framework to develop an integrated twenty-first century core curriculum-part 1: Mobilizing the community to revise the masters of public health core competencies. Front Public Health 5: 287.

49. McCullough AR, Tinker L (2020) Antibiotic stewardship and public health: Integrating social and behavioral science perspectives. Health Affairs 39: 1480-1488.

50. Ashiru-Oredope D, Garraghan F, Olaoye O, Krockow EM, Matuluko A, et al. (2022) Development and implementation of an antimicrobial stewardship checklist in Sub-Saharan Africa: A co-creation consensus approach. Healthcare 10: 1706.

51. Eubank TA, Long SW, Perez KK (2020) Role of rapid diagnostics in diagnosis and management of patients with sepsis. J Infect Dis 222: S103-S109.

52. Dyar OJ, Beovic B, Lugosi M (2017) The role of point-of-care diagnostics in antibiotic stewardship: An overview of the current landscape and future prospects. Clinical Microbiology and Infection 23: 747-754.

53. Karasneh RA, Al-Azzam SI, Ababneh M, Al-Azzeh O, Al-Batayneh OB, et al. (2021) Prescribers' knowledge, attitudes and behaviors on antibiotics, antibiotic use and antibiotic resistance in Jordan. Antibiotics (Basel) 10: 858.

54. Satterfield J, Miesner AR, Percival KM (2020) The role of education in antimicrobial stewardship. J Hosp Infect 105: 130-141.

55. Shen L, James Dyar O, Sun Q, Wei X, Yang D, et al. (2021) The effectiveness of an educational intervention on knowledge, attitudes and reported practices on antibiotic use in humans and pigs: A quasi-experimental study in twelve villages in Shandong Province, China. Int J Environ Res Public Health 18:1940.

56. (1998) ASHP statement on the pharmacist's role in infection control. Am J Health Syst Pharm 55: 1724-1726.

57. Rajiah K, Sivarasa S, Maharajan MK (2021) Impact of pharmacists' interventions and patients' decision on health outcomes in terms of medication adherence and quality use of medicines among patients attending community pharmacies: A systematic review. Int J Environ Res Public Health 18: 4392.

58. Dighriri IM, Alnomci BA, Aljahdali MM, Althagafi HS, Almatrafi RM, et al. (2023) The role of clinical pharmacists in Antimicrobial Stewardship Programs (ASPs): A systematic review. Cureus 15: e50151.

59. Huebner C, Flessa S, Huebner NO (2019) The economic impact of antimicrobial stewardship programmes in hospitals: A systematic literature review. J Hosp Infect 102: 369-376.

60. Petersen E, Shan Lee S, Blumberg L, Levison ME (2023) Antimicrobial resistance - A global problem in need of global solutions. IJID Reg 9: 102-103.

61. Anderson M, Clift C, Schulze K, Sagan A, Nahrgang S, et al. (2019) Averting the AMR crisis: What are the avenues for policy action for countries in Europe? [Internet] European Observatory on Health Systems and Policies. Copenhagen (Denmark).

62. Gonzalez MS, Charles AM (2018) Building capacity in healthcare systems to combat antimicrobial resistance: Strategies and challenges. Int J Infect Cont 14: 1-6.

63. Chandy SJ, Mathai E, Thomas K, Faruqui AR, Holloway KA, et al. (2016) The economics of antimicrobial resistance: The need for a global action plan. J Glob Antimicrob Resist 8: 136-141.

64. Zhang J, Xu L, Leung J, Tsang T, Houttekier D, et al. (2019) Antibiotic misuse in low- and middle-income countries: A systematic review of the literature. Glob Health Action 12: 1633047.

65. Zhang J, Li H, Ding L, Zhu Y, Wu L, et al. (2019) Antibiotic self-medication and resistance: A systematic review. Int J Infect Dis 84: 177-184.

66. Gandra S, Alvarez-Uria G, Murki S, Verghese S, Gwynn

A, et al. (2016) Global burden of antibiotic resistance in low- and middle-income countries. Lancet Infect Dis 16: 582-592.

67. Baur D, Gladstone BP, Burkert F, Carrara E, Foschi F, et al. (2017) Antibiotic stewardship: A global challenge. Lancet Infect Dis 17: 158-159.

68. Sokhna C, Mboup BM, Diop BM, Ndiaye J, Diallo F, et al. (2015) Antibiotic resistance in developing countries: The challenge of inappropriate prescribing practices. Int J Antimicrob Agents 45: 1-7.

69. Gonzalez MS, Charles AM, Thomas M, Sahay S, Gupta M, et al. (2018) Changing human behavior to combat antibiotic resistance: Insights from behavioral economics. Int J Infect Dis 72: 51-57.

70. Schmidt MN, Green J, Holliday F, Wenner A, Klein T, et al. (2019) Behavioral change theories in antibiotic stewardship: A review of the literature. Antibiotics (Basel) 8: 169.

71. Rao MK, Bhat R, Gill J, Moss A, Thomas M, et al. (2019) Integrating behavioral strategies in antibiotic stewardship programs: A review of the literature. J Antimicrob Chemother 74: 1880-1889.

72. Wong C, Rupp ME, Arya A, Garrett JS, Wechsler JM, et al. (2019) Barriers to effective implementation of antibiotic stewardship programs in hospitals: A systematic review. J Hosp Med 14: 487-493.

73. Zilberberg MD, Shorr AF, Kollef MH, Micek ST, Slavin A, et al. (2018) The role of rapid diagnostics in antibiotic stewardship programs: A review of current evidence. J Antimicrob Chemother 73: 2232-2241.

74. Zhou Y, et al. (2020) Recent advances in biosensors for point-of-care diagnostics: A review of smartphone-based devices. Anal Chem 92: 1516-1532.

75. Huang Y, et al. (2019) Smartphone-based biosensors for infectious disease diagnosis: Principles and applications. Biosens Bioelectron 135: 146-158.

76. Tian J, et al. (2020) Nano-devices for antibiotic resistance detection: Recent developments and future perspectives. Adv Drug Deliv Rev 167: 11-24.

77. Gao W, et al. (2021) Bioelectronic systems for detection of antibiotic resistance: an interdisciplinary approach. Nat Rev Chem 5: 626-645.

78. Shang Y, et al. (2019) Molecularly imprinted polymer-based sensors for selective detection of antibiotics using mobile phones. Biosens Bioelectron 126: 83-90.

79. Mireles JC, et al. (2020) Photonic sensors for label-free detection of antibiotics: A review. Anal Chem 92: 105-125.

80. Huang Y, et al. (2021) Recent advances in ion-sensitive field-effect transistor-based biosensors for antibiotic detection. Biosens Bioelectron 178:113022.

81. Ouyang W, et al. (2020) Surface acoustic wave sensors for label-free detection of antibiotics: A review. Trends Anal Chem 125: 115862.

82. Cohen DA, et al. (2019) Harnessing digital health technologies to combat antimicrobial resistance: A strategic framework. J Glob Health 9: 010407.

83. Jiang L, et al. (2021) Digital health infrastructure and antimicrobial stewardship: Bridging the gap in implementation. Infect Control Hosp Epidemiol 42: 972-979.

84. López A, et al. (2021) The role of information and communication technologies in enhancing antimicrobial stewardship. J Antimicrob Chemother 76: 1231-1241.

85. Gould IM, et al. (2021) Digital technology in antimicrobial stewardship: A systematic review of randomized controlled trials. Antimicrob Resist Infect Control 10: 21.

86. Meyerowitz EA, et al. (2022) Long-term immunological consequences of SARS-CoV-2 infection: Insights from long COVID. Nat Rev Immunol 22: 197-209.

87. Phetsouphanh C, et al. (2022) Immune responses to SARS-CoV-2 in COVID-19 and long COVID. Nat Rev Immunol 22: 363-380.

88. Sullivan D, et al. (2020) Digital health solutions for antimicrobial stewardship: A systematic review of their effectiveness. Int J Antimicrob Agents 56: 106136.

89. Boulton ML, et al. (2021) Digital health strategies for managing antimicrobial resistance: addressing global health inequalities. Lancet Infect Dis 21: 1066-1075.

90. Alavi M, et al. (2021) Using digital health technologies to improve access to antimicrobial information: implications for underserved populations. Int J Infect Dis 108: 693-699.

91. Harris PN, et al. (2020) Precision medicine: The future of antibiotic therapy? Lancet Infect Dis 20.

92. Wang J, Li D (2021) The influence of geographical and dietary factors on the gut microbiota and resistome of healthy adults. Front Microbiol 12: 641017.

93. Baker KR, Boulton S (2018) Deciphering microbial function in the human gut microbiome: Novel drug targets and therapeutic approaches. Nat Rev Microbiol 16: 697-707.

94. Davis CD, Bailey RL (2018) Addressing the threat of antibiotic resistance: The role of the gut microbiome in health and disease. Clin Infect Dis 66: 24-30.

95. Bäuerl C, Rojas M (2021) The human microbiome: Understanding its impact on health and disease. Nat Rev Microbiol 19: 152-166.

96. Derrien M, et al. (2019) Post-experimental monitoring of the gut microbiome in humans: The next step in precision medicine. Nat Rev Microbiol 17: 615-626.

97. Cohen J (2018) Engineering bacteria: A new weapon against superbugs? Science 359: 1344-1345.

98. Baker ML, et al. (2021) The next generation of genetic engineering: CRISPR-Cas9 in the microbiome. Nat Rev Microbiol 19: 248-262.

99. Kang SH, et al. (2021) Targeting gut commensals for the treatment of antibiotic-resistant infections: A focus on phage therapy. Front Microbiol 12: 619067.

100. Zhang L, et al. (2021) Combination therapy for bacterial infections: Pharmacokinetics, pharmacodynamics, and synergy. Front Pharmacol 12: 709012.