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REVIEW

Can We Lower the Burden of Antimicrobial Resistance (AMR) in Heavily Immunocompromised Patients? A Narrative Review and Call to Action

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ABSTRACT

Effective antibiotics are a cornerstone of treatment for heavily immunocompromised patients such as those undergoing cancer treatment or transplantation procedures, as these patients are at particularly high risk of adverse outcomes from infections. However, rising antimicrobial resistance (AMR) threatens to undermine our ability to deliver modern treatments, and without action, recent advances in clinical care may be undone. In this narrative review, we examine the broad burdens of AMR for patients and healthcare systems, including excess mortality, underlying disease outcomes, economic costs and the damage to patients' quality of life. Despite the profound impact on individual wellbeing, the patient voice and patient-reported experience measures are largely absent from current research. To protect the everyday benefits of antibiotics, it is vital to educate all those involved in patient care on how we can combat AMR, including appropriate testing, use of

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effective antibiotics and infection control procedures. Moreover, given the high investment in novel anticancer treatments, good antimicrobial stewardship has the potential to deliver overall cost savings to healthcare systems while ensuring that patients can safely access and benefit from these therapies.

PLAIN LANGUAGE SUMMARY

Antibiotics are essential for people with serious health conditions like cancer or those who have received an organ transplant. These patients have weakened immune systems and are more likely to develop infections; however, antimicrobial resistance (AMR), where bacteria no longer respond to antibiotics, is making these infections harder to treat. This review looked at the impact of AMR in heavily immunocompromised patients. It found that resistant infections are common and can cause delays to cancer treatment, longer hospital stays and a higher risk of death. These infections can also reduce quality of life and increase healthcare costs. The review found that current efforts to manage AMR are inconsistent. There is a need for faster diagnostic testing, better education for healthcare providers and patients, and more consistent use of infection control and antibiotic stewardship programmes. These steps could help optimise the treatment of resistant bacteria and improve outcomes. As treatments like chemotherapy and organ transplantation are very costly, preventing infections and early mortality through better AMR management could also help reduce overall healthcare spending. The review highlights the importance of improving awareness, strengthening hospital systems and investing in new antibiotics so that patients continue to benefit from modern medical treatments.

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Key Summary Points

Heavily immunocompromised patients, such as those with solid cancers, haematological malignancies and solid-organ transplant recipients, face a heightened risk from antimicrobial resistance (AMR), which significantly complicates treatment, delays recovery and increases the likelihood of adverse outcomes.

The direct and indirect economic burdens of AMR in these populations add substantial strain to healthcare systems already managing the high costs of underlying disease treatment.

There are critical gaps in research and interventions, including inconsistent stewardship approaches, limited use of rapid diagnostics and a lack of targeted prophylaxis strategies, which contribute to suboptimal patient care and missed opportunities for earlier and more effective intervention.

Tackling these challenges requires better recognition of the burdens faced by patients who suffer lasting impacts from AMR infections, as well as enhanced antimicrobial stewardship and education for healthcare providers and patients to optimise care and combat AMR effectively. Moreover, stronger investment is essential to revitalise the antibiotic development pipeline, which remains fragile as a result of limited commercial viability, thereby supporting earlier access to appropriate treatment and improving outcomes for vulnerable patient groups.

INTRODUCTION

Antimicrobial resistance (AMR) is a growing threat to global health security. In 2021, AMR was associated with 4.7 million deaths, with 1.1 million deaths directly attributable to bacterial resistant infections [1]—six bacterial pathogens were responsible for more than 80% of these deaths: *Staphylococcus aureus*, *Acinetobacter baumannii*, *Escherichia coli*, *Klebsiella pneumoniae*, *Streptococcus pneumoniae* and *Pseudomonas aeruginosa* [1]. By 2050, deaths associated with AMR could reach 8.2 million per year [1], with an associated loss of up to 3.8% of global gross domestic product—equivalent to 6.1 trillion USD per year [2].

Bacteria are constantly evolving to counteract available antibiotics, including hydrolysis, genetic mutation of binding sites and preventing accumulation of antibiotics within the cell [3]. Despite the growing threat of AMR, the development pipeline for new antibiotics to overcome resistance remains challenging; of the 32 traditional antibiotics currently under development against the World Health Organization (WHO) bacterial priority pathogens, only two meet all four WHO innovation criteria [4, 5].

Patients with cancer and transplant recipients are at particular risk from bacterial infections because of their immunocompromised status, frequent hospitalisations, need to undergo invasive procedures, prior use of broad-spectrum antibiotics and the necessity for prophylactic antibiotics [6–8]. Compared with the general US population, patients with cancer are nearly three times more likely to die from infection [9], and in a UK survey of 100 oncologists, almost half (46.0%) were concerned chemotherapy may soon become unviable as a result of the rise of AMR [10]. In the case of solid-organ transplant (SOT), the challenge of managing AMR infections can act as a relative contraindication in certain patients, depending on their other comorbidities, because of the high burden of infectious complications [7, 11].

The aim of this narrative review is to explore recent publications about the burdens faced by heavily immunocompromised patients and healthcare systems from bacterial AMR, particularly underexplored issues around treatment delays and patient experience, and issue a call to action for us as an infectious disease community to do more to recognise and improve outcomes from infectious complications.

METHODS

We conducted a keyword search using PubMed for publications from a 5-year period (November 2018–2023) reporting burdens from AMR bacterial infections, including mortality, underlying disease outcome (e.g. treatment delays) and patient quality of life, from English language publications from Europe and North America. The regional focus was chosen to improve consistency in testing and reporting methodologies in identified publications. Our search focused on bacterial infections (excluding fungi and viral infections) to manage the scale of our review; moreover, the unique challenges in treating fungal infections due the similarities between eukaryotic and fungal cells were beyond our scope [12]. Search terms and selection criteria are available in the Supplementary Material.

Ethical Approval

This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors. No new data were generated.

RESULTS

Results of the search (Fig. 1) were considered at a virtual steering committee meeting. Additional publications that were considered relevant were included on the basis of the experience of the authors. Most studies identified in the literature reported retrospective cohort data ($n=113$), with the next most common being prospective cohorts ($n=35$). Given the potential for reporting bias in observational studies, the findings reported herein should be interpreted in this context. Moreover, the patterns of AMR detected also depend on the local epidemiology as well as the extent and methods of testing employed.

Epidemiology of AMR and Its Mortality

The frequency of AMR in cancer and transplant patients with bacterial infections is approximately 10–30% globally [13–21]; this rate is

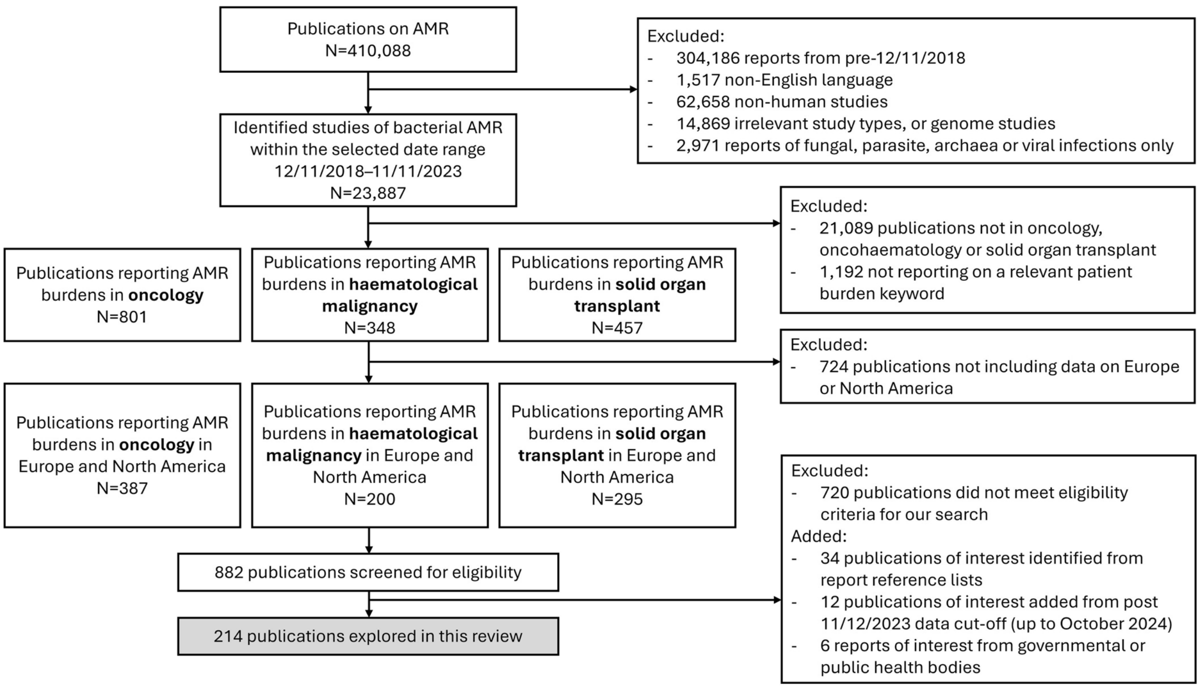

Fig. 1 Literature identification: flow chart of results identified and screened. *AMR* antimicrobial resistance

consistent with previous estimates for these immunocompromised populations, who have frequent contact with the healthcare system [8, 22–29]. The reported frequency of AMR varies widely by disease and geography, with resistance patterns closely correlated with prior type and duration of antibiotic prophylaxis [22, 30–33]. Of particular concern, some centres have reported zero susceptibility to common β-lactams and fluoroquinolones used as prophylaxis, highlighting the increasing threat of AMR for these patient populations [34, 35].

Concerningly, most of the studies identified reported multidrug resistance—a subset of AMR where bacteria are resistant to at least one agent in three or more antibiotic classes—with detected frequencies ranging from less than 1% to as high as 73.8% of bacterial samples tested (Table 1) [13–21, 31, 34–143]. Of note, while not explicitly explored as part of our search, resistant bacterial infection can often co-occur with invasive fungal infection, which can complicate management and worsen outcomes [33, 77, 144, 145].

The impact of AMR on mortality was similarly varied by population and disease type, with 30-day mortality ranging from 3.0% to 64.6% [13, 15, 17, 30, 31, 34–38, 41, 42, 45–50, 53, 55, 57, 60, 63, 64, 68, 69, 81, 84, 90, 93, 94, 97, 98, 102, 104, 107, 109, 111, 121, 126–129, 136, 145–154] and from 8.7% to 75.0% for timepoints beyond 1 year [13, 43, 48, 49, 102, 105, 126, 127, 147, 150, 153, 154]. Differences in AMR frequency and associated mortality across populations may reflect variations in underlying disease types, treatment intensity, patient comorbidities and the ability to tolerate or access specific antimicrobial regimens [44, 84, 105, 155–157].

Inappropriate empiric antibiotic therapy (IEAT)—antibiotic treatment that is ineffective against the infecting pathogen—is a key factor contributing to AMR-associated mortality and is one of the few modifiable risk factors [18, 20, 25, 30, 60, 63, 84, 89, 114, 148, 158]. Reported rates of IEAT at 16.8–68.6% highlight the growing threat of AMR in immunocompromised patients [18–20, 30, 40, 52, 60, 62, 84, 86, 89, 90, 99, 114,

Table 1 Summary of findings for each disease area explored

	Solid cancer	Haematological malignancy	Solid-organ transplant
Frequency of AMR	0.6–71.7% [44, 101]	1.7–52.3% [16, 126]	0–73.8% [93, 132]
30-day mortality	29.5–43.0% [36, 64]	6.1–50.0% [45, 128]	3.9–50% [104, 151]
Comments	Highest frequency of AMR reported in CCA (71.7%) [101] Lowest in pre-surgery patients with gynaecological cancer (0.6%) [44]	Highest frequency of AMR reported in paediatric HSCT recipients (52.3%) [126] However, paediatric patients had the lowest overall mortality rate (0–8.7%) [75, 126]	Highest frequency of AMR reported in intestinal and liver transplant recipients Multidrug-resistant cultures were reported in 3.4–14.0% [39, 70] of donors Mortality with AMR was generally lowest for kidney transplant recipients (8.6–22.0% [80, 154]); whereas mortality was typically highest in liver transplant recipients [104], especially those who developed CRE infection [27, 136]

AMR antimicrobial resistance, *CCA* cholangiocarcinoma, *CRE* carbapenem-resistant Enterobacteriaceae, *HSCT* haematopoietic stem cell transplant

124, 133, 134, 148, 159]. In line with this finding, consistently poor outcomes were reported with carbapenem-resistant bacteria, likely due to the limited management options available for these pathogens [17, 18, 32, 35, 36, 43, 47–49, 53, 69, 81, 85, 91, 97, 98, 105, 110, 124, 145, 150, 152, 153, 160, 161].

Solid Tumours

The prevalence of AMR in patients with solid cancers was lowest for pre-surgery patients with gynaecological cancer: 0.6% had methicillin-resistant *S. aureus* (MRSA) [44]. The highest frequency of infections due to resistant bacterial pathogens in studies of solid tumours was reported in cholangiocarcinoma (CCA). One study found that 71.7% of patients undergoing resection of extrahepatic CCA had resistant bacterial infections, accounting for 84.5% of all microbiologic growth from common hepatic duct samples [101]. Two other studies of CCA reported postoperative AMR frequencies of 31.2% and 32.0% [107, 111], while AMR infections were identified in 29.2% of bile samples from patients with ductal adenocarcinoma after pancreatoduodenectomy [105]. The frequency of AMR, particularly in Gram-negative bacteria (GNB), is on the rise [134]. Despite this, there is a lack of involvement of infectious disease specialists—a Spanish study of pneumonia in patients with cancer reported that only 26.0% of cases were evaluated by an infectious disease specialist [155].

Infection remains a leading cause of death for patients with solid tumours [8], with worse overall survival reported for AMR versus no AMR. Notably, for patients with solid tumours this mortality deficit was present for both patients with active infection [101, 105] as well as those colonised with AMR bacteria, possibly as a result of their risk of developing a later infection with the same resistant pathogen [84, 94, 107, 111]. Median overall survival in AMR-colonised patients was just 6.0–17.0 months compared with 23.9–50.0 months for non-colonised patients with cancer [84, 94, 111]. Mortality estimates for patients with AMR vary widely. A 90-day mortality rate of 8.3% was observed in those with perioperative biliary cultures positive for multidrug-resistant organisms, compared with 0% in those with negative cultures, following surgery for perihilar CCA [107]. In another study, patients colonised with AMR who underwent surgical resection for CCA had a mortality rate of 55.6% compared with 17.4% in those without AMR. Of those with AMR, 30.0% of deaths were attributed to infection-related causes—an equal proportion to those attributed to cancer-related causes [111].

It has previously been suggested that the contribution of infections to cancer deaths may be underreported on death certificates [8], and this may be due to the difficulty in determining the cause of death in patients who have several comorbidities. Although patients' performance status and disease severity are key predictors of mortality [84, 155], a Spanish study highlighted that only 41.0% of patients with cancer who died within 30 days of pneumonia diagnosis at their centre were terminally ill [155]. Moreover, infection is a common reason for patients with cancer to be admitted to hospital, highlighting the key role of infections in the trajectory of negative outcomes [156, 157].

Importantly, the impact of AMR extends beyond infection-related mortality—two studies reported up to 30.0% of patients with infections experienced delays or non-compliance with adjuvant chemo-, radio- or immunotherapy [44, 105], and nosocomial infection was associated with greater tumour volume in a single study of brain cancer [162]; however, there are insufficient data to confirm the ultimate impact of treatment delays due to infections on long-term disease control and cancer survivorship.

Haematological Malignancies

Studies of haematological malignancies reported AMR positivity in 1.7–52.3% of cases, often in the context of bloodstream infections (BSIs) [13, 15, 16, 18, 19, 31, 35, 37, 38, 41, 43, 45, 46, 50, 52, 55, 58, 60, 63, 73, 74, 79, 87–92, 95, 97, 98, 103, 112, 114, 119, 120, 122, 125, 128, 130, 138–140, 163, 164]. Resistant infections were most commonly reported in southern/eastern Europe (Czechia, Greece, Italy, Poland and Spain): 7.5–52.3% [16, 31, 35, 50, 52, 55, 60, 63, 75, 77, 88–90, 92, 95, 97, 98, 103, 112, 114, 120, 125, 126, 128, 130, 138] compared with 2.9–19.2% in northwestern Europe (Germany, Finland, France and the UK) [41, 46, 74, 87, 91, 119, 139].

Expectedly, survival is very poor in these patients, with a 30-day mortality of 6.1–50.0%, rising to as high as 74.0% at 1 year [13, 15, 30, 31, 35, 46, 60, 63, 90, 98, 128, 129, 142, 152], and AMR bacteria are associated with higher rates of septic shock and infection-related mortality than in non-AMR BSIs [98]. Those patients who develop AMR BSIs, particularly from GNB, were shown to have a 2–5-fold elevated risk of death versus patients with non-AMR BSIs [13, 31, 43, 77, 89]. Alarmingly, the rates of AMR-GNB reported in onco-haematological BSIs appear to be rising with time [15, 60, 90].

As might be expected, mortality rates were more favourable for AMR infection in paediatric cancer cases, ranging between 0 and 8.7%, with complications often occurring within the context of graft-versus-host disease (GvHD) [50, 55, 126, 160]. While infections and infection-related mortality in haematological malignancy are commonly associated with GvHD [35, 37, 50, 55, 58, 92, 126, 160], especially in patients with high antibiotic exposure [92, 165], whether AMR directly influences the incidence of GvHD is unclear [13, 38, 92, 122]; however, at least in paediatric patients, it has been suggested that different types of antibiotic prophylaxis may exacerbate or be protective against GvHD, with gentamicin contributing to decreased rates of acute GvHD, while ciprofloxacin and colistin may increase GvHD risk after allogeneic HSCT [92, 165]. Whether AMR is correlated or causative in this context is unclear; however, the presence of AMR nonetheless complicates infection management.

Patients with haematological malignancies also suffer high rates of catheter/port removal for infection source control, which has been reported to occur prior to the completion of chemotherapy in up to 31.0% of cases [75], leading to treatment non-compliance and hampering control of underlying disease [97]. While there may be a relationship between complete remission and favourable infection resolution [98, 166], there are insufficient data available to confirm this.

SOT Recipients

The frequency of AMR was highly variable in SOT recipients. AMR was reported post transplantation at rates up to 73.8% [21, 34, 49, 56, 61, 62, 66, 71, 72, 76, 82, 86, 93, 96, 104, 110, 117, 118, 121, 124, 136, 137], with similar occurrence across liver (9.3–60.0%) [17, 47, 48, 54, 57, 65, 68, 85, 102, 106], kidney (6.2–63.0%) [59, 69, 80, 108, 115, 127, 131] and lung transplantation (0–60.7%) [14, 51, 109, 132, 135]; 30-day mortality for transplant recipients ranged from 4.0% to 50.0% [34, 68, 93, 104, 109, 121, 146, 148, 151], rising to 13.0–64.0% up to and beyond 1 year, with the highest mortality rates in those developing carbapenem-resistant Enterobacterales (CRE) infection [17, 48, 49, 66, 102, 147, 150, 153].

While most studies reported statistically worse mortality with AMR bacteria [47–49, 54, 57, 85, 102, 109, 110, 146, 147, 151, 153, 154, 160], others reported no difference [65, 66, 80, 93, 96, 104, 121], perhaps owing to improvements in modern screening practices, although the worst outcomes typically presented in those with multidrug-resistant infection [66, 80, 104]. Two meta-analyses using available data have reported a greater than twofold risk of death within 1 year for SOT recipients with AMR colonisation versus non-colonised patients [153], increasing to fourfold for SOT recipients with infections caused by carbapenem-resistant GNB [160].

In line with previous reports [27, 167], liver transplant was consistently associated with high mortality from AMR (13.0–58.0%) [17, 47, 48, 54, 57, 65, 68, 85, 102, 146, 168], while mortality in kidney recipients was generally more moderate (8.6–22.0%) [69, 80, 154]. Reported raw mortality in lung transplant was also high (16.0–50.0%), although this was often complicated by the presence of other comorbidities such as cystic fibrosis [109, 147, 151].

The development of infectious complications was also more often associated with delayed or loss of graft function [110, 115, 131, 137, 154, 169, 170], with rates up to 35.0% for infections involving extended-spectrum β-lactamase-producing (ESBL) GNB [154] or CRE [110], although this did not appear to be the case for AMR colonisation only [59, 100, 153].

An important source of infection in SOT is the donor organ. AMR cultures were reported in 3.4–14.0% of donors [39, 53, 70, 100, 136], and this can lead to donor-derived infection (DDI) with the same pathogen in recipients [27, 53, 100, 109, 136], although it has been suggested that, at least for the liver, transplantation from a live donor may reduce the risk of CRE transmission [110].

While appropriate screening appears to have had a positive impact on transmission rates [39, 53], lack of knowledge of the donor's microbiological status increases the risk of infection [70] and the presence of resistant pathogens in donors can go undetected as a result of them being asymptomatic carriers [169].

There is a need to optimise protocols in order to maximise the number of organs available [136]; however, clinicians are understandably cautious about the risks of DDI, and colonisation with AMR-GNB leads to lower organ utilisation [70]. While AMR colonisation does not necessarily lead to graft loss or mortality [100], the use of such organs remains controversial [70].

DISCUSSION

Consequences for Patients

The wide variability in reported AMR rates across studies reflects differences in patient populations, study designs, and local epidemiology and microbiological practices, which limits the comparability of findings and underscores the need for more consistent, standardised approaches to testing and reporting. As noted in a recent review, the limited data on optimal use and interpretation of diagnostic tools in SOT recipients further constrains the ability to assess clinical associations in this population [28].

Notably, several case reports highlighted the significant burdens arising from AMR for heavily immunocompromised patients, including social isolation, invasive surgical revisions and, in extreme cases, amputation, which all degrade a patient's long-term quality of life [166, 171, 172]. Despite the large body of evidence reporting on the clinical outcomes of AMR in oncology and transplant, we found no controlled studies exploring patient-reported experience measures, and a lack of data on real-world outcomes of antibiotic stewardship programmes. This highlights a significant limitation and the need for future studies to collect and report these data as a priority to understand patients' perspectives in more detail.

Several case studies highlighted the significant impacts of invasive AMR infection management procedures, including surgical revisions [131] or debridement, which can require skin grafting post intervention [166, 171, 172]. Two case reports of patients with leukaemia also highlighted the extreme case of amputation—a significant lasting impact of their infection with AMR *P. aeruginosa*—despite both patients otherwise successfully achieving a complete response for their underlying cancer [172].

Central venous catheter (CVC) infections are also a significant concern in oncology patients, often necessitating catheter removal [75]. This can complicate the administration of treatments like chemotherapy, which may then require peripheral intravenous (IV) access [75, 173]. As peripheral IV administration is associated with risks such as phlebitis and eventual obliteration of peripheral veins, potentially leading to long-term vascular damage, CVC infections can lead to delays or non-compliance with treatment regimens, reducing the quality of care for patients [75].

There is a need for future initiatives to improve communication and health literacy around the risks of AMR to patients; indeed, one study in paediatric kidney transplant recipients highlighted the potential for patient education to help minimise the frequency of infections where patients are required to self-catheterise [59].

Psychological and Social Impacts of AMR

Beyond clinical consequences, AMR can have lasting psychological and social effects, including long periods of isolation, anxiety and disruption to family life. Patients who develop resistant infections are also often admitted to the hospital intensive care unit (ICU), which brings additional burdens such as invasive mechanical ventilation [166, 171, 172, 174–176]. During their recovery, a prolonged period of social isolation is often required to prevent the wider spread of the pathogen as well as protect them from further infection—this places a significant burden on patients who must go through substantial periods of time without contact with relatives and close social connections [166, 172, 177].

Patients may also experience the burden of social isolation outside of the ICU. In a survey of patients with leukaemia, many reported avoiding social contact because of the fear of catching a potentially life-threatening infection, which negatively impacted their quality of life [178]. While this suggests patients are aware of everyday dangers of infection, it is unclear how aware immunocompromised patients are of the specific dangers of AMR, which is especially relevant to them given their frequent hospital contact and antibiotic use.

Clinical Management Practices

Against the background of AMR, many standard prophylactic regimens could be considered inadequate, particularly in oncology [38, 122, 179]. It is important for antibiotic treatment to be tailored to the local epidemiology [24], and in the case of SOT, risk assessment tools such as INCREMENT may also support clinicians in their initial choice of empiric antibiotic therapy [17, 21, 148]. Importantly, even patients scored at low risk of infection may benefit from targeted therapy in areas with high prevalence of certain types of resistance [180], for example, European countries where the frequency of carbapenem resistance is higher than the regional average, such as Greece, Italy, Spain, Poland, Portugal and Turkey [28, 181]. Although CRE carriage is strongly associated with infection risk, its predictive value can be further refined using clinical risk prediction models, such as the CRECOOLT score developed for liver transplant recipients, to better stratify patients and optimise preventive and therapeutic strategies [17].

While the optimal course of management is not necessarily always clear because of a lack of high-quality evidence [24, 182–184], knowledge of the microbiological status of patients and organ donors is consistently linked with favourable outcomes [39, 53, 81, 185]. Despite this, screening and reporting practices are not standardised [27, 28]; however, the emergence of rapid diagnostic tests for AMR provides an opportunity to ensure clinicians have access to timely microbiology results [179, 186, 187]. Not all hospitals have access to 24-h microbiology labs or rapid antimicrobial susceptibility testing, and achieving equity of facilities access will be a key step in improving AMR screening [42].

A key part of maintaining the effectiveness of existing antibiotics is appropriate stewardship, including avoiding their use for probable viral infections to prevent unnecessary contributions to AMR [188]. Prolonged use of antibiotics exacerbates AMR trends [189]. Although controversial in febrile neutropenia [190], short-duration, broad-spectrum antibiotic therapy with prompt de-escalation of duration of therapy has been shown non-inferior to alternative protocols [25, 30, 140]. Such interventions are relatively simple to implement and can reduce the selective pressures that drive and maintain AMR.

Direct and Indirect Costs of AMR

Development of an AMR infection adds significantly to healthcare costs, primarily as a result of extended durations of hospital stay and ICU/ventilator utilisation [22, 160]. The presence of an AMR infection can extend hospital stay by up to 30 days longer versus no AMR [14, 22, 37, 44, 47, 48, 53, 54, 56, 57, 65, 68, 69, 80, 84, 86, 93, 97, 104, 109, 121, 124, 129, 142, 146, 147, 156, 159, 162, 191], increasing the cost of management similar to other infections such as *Clostridioides difficile*, which can add over 50,000 USD to direct healthcare costs [22]. These costs may be even higher for hospital-onset AMR *P. aeruginosa*, up to 208,836 USD [192].

Other contributors to direct costs include the potential for surgical revisions [62, 101, 116, 131, 156, 171] and catheter/central line replacement [42, 60, 90, 98, 99, 149, 171, 193]. Central line-associated bloodstream infection (CLABSI) has been reported to incur direct costs of approximately 8810 EUR [191].

The requirement for targeted antibiotics also adds to the cost of managing resistant infections. The direct cost of targeted empiric therapy against vancomycin-resistant enterococci (VRE) was estimated at 1604–27,000 USD [22, 194], and 8542–31,811 USD for therapy against carbapenem-resistant *P. aeruginosa*, both versus susceptible strains in high-risk oncology and transplant patients in US hospitals [160]. These figures are similar to the 31,338 USD cost per BSI due to MRSA in the general US hospital population [195].

In contrast, the costs of managing an immunocompromised patient's underlying disease can vastly outstrip the costs of infection management. Cancer treatment in the USA can total a cumulative cost of 77,339–225,270 USD per patient over 23 months post diagnosis for colorectal, lung and female breast cancer [196], while costs associated with haematological malignancy range from 458,490 USD to as high as 731,682 USD for chimeric antigen receptor T cell (CAR T) therapy [197], and can reach a total of approximately 1,071,700 USD in the case of allogeneic HSCT [198]. Similar ranges are seen in SOT, with costs ranging from 408,800 USD (pancreas) to 1,664,800 USD (heart) [198].

The wide disparity in costs between infection management versus the price of treatment for underlying diseases means that greater investment in infection control and management with testing and targeted therapies has the potential to deliver cost savings to the healthcare system. Moreover, implementation of appropriate antimicrobial stewardship programmes was shown to deliver overall cost savings of 732 USD per patient in a recent meta-analysis [199]. There is a need for a cost model in immunocompromised patients to comprehensively evaluate the direct impact of appropriate versus inappropriate management of infections.

Indirect costs are less well understood, as there are limited data on the broader impacts AMR infections have on the lives of patients such as their ability to work. In addition, AMR infections can result in treatment delays for the underlying condition, leading to worse outcomes, including higher mortality rates [200]. The World Bank has estimated that in the general population indirect costs could rise in line with the growing presence of AMR, potentially reaching up to 3.8% of global gross domestic product by 2050, equivalent to 6.1 trillion USD, as a result of the indirect loss of economic output [2].

There is also an indirect cost of infections on hospital efficiency due to impacts on logistics. While data on this topic are limited, many clinicians will be acutely aware of how, from their recent personal experience of the COVID pandemic, infection management can impact broader hospital resource efficiency [201, 202].

There is an unmet need for comprehensive cost-effectiveness analyses within the context of vulnerable patient populations who are at high risk of infection-related morbidity and mortality to provide a complete picture for policy makers. Future cost-analyses may consider exploring the far-reaching impacts of AMR infection on the cost-effectiveness of underlying disease management as well as societal participation. This may also support implementation of incentive mechanisms to increase investment in the development of new antibiotic agents [4, 5, 203].

CONCLUSION

AMR is a growing societal problem, placing additional stresses on healthcare resources as well as significant burdens on patients, including treatment delays, invasive management and social isolation, as well as potential long-term reductions in quality of life. In the case of cancer and transplant, the high cost of underlying disease treatment means that effective management of infections has the potential to deliver cost savings for healthcare systems while improving patient outcomes and quality of life.

To address these challenges, there is a need for greater education of clinicians working in and across oncology and transplant, including physicians, nurses and pharmacists, to support the use of appropriate antibiotics tailored to the patient and local microbiology. This includes promoting the use of rapid diagnostic tools to enable timely identification of pathogens and resistance patterns, as well as implementing screening protocols to detect and stratify patients at high risk. Education on the need for effective stewardship programmes is equally important to limit the rise of AMR and maintain the effectiveness of our current antibiotic therapies.

Patients should be assessed and reassessed for AMR pathogens, even if known to the admitting centre, to appropriately fine-tune the type and duration of antibiotic treatment. These patients must also be supported by initiatives to ensure equity of access not just to novel antibiotics but also hospital screening and laboratory facilities. Efforts to improve AMR outcomes must reflect the lived experience and priorities of immunocompromised patients, for whom delays, inadequate treatment options or poor access can have life-altering consequences. Integrating the patient voice into AMR policy, stewardship design and care planning is essential to ensure that solutions are grounded in what matters most to patients, such as timely, effective and accessible treatment. Education is also imperative for patients at high risk of resistant infections to empower them to promptly report symptoms to their healthcare providers and enhance their self-care capabilities. This education should extend to hospital measures to improve infection control and maintain good antimicrobial and testing stewardship.

Finally, there is a pressing need to strengthen the antibiotic development pipeline, which remains fragile and underfunded, posing a risk to future health security and the progress of modern medicine [4, 5]. Appropriate financial incentives should be put in place to ensure the antibiotics of the future are available when needed. Addressing this challenge requires not only innovation and investment in antibiotic research and development but also the implementation of effective stewardship programmes to ensure antibiotics are used appropriately and efficiently. A coordinated approach is essential to protect future health security and preserve the benefits of effective antibiotic treatments for patients with cancer and transplant, who are among the most vulnerable and who depend on these therapies to safely receive life-saving care.

CALL TO ACTION: SAFEGUARDING CANCER AND TRANSPLANT CARE FROM AMR

There is increasing recognition of the need for coordinated strategies to address AMR in cancer and transplant care. Structural factors, such as racism and socioeconomic inequalities, contribute to disparities in AMR infection rates, antimicrobial prescribing patterns and access to preventive interventions, particularly in minority populations [204]. Transportation inequities, limited internet access and restrictions on who can prescribe treatments contribute to disparities in access to essential therapeutics, highlighting the need to remove structural barriers to care for high-risk populations [205]. As a result of this review, Cancer Patients Europe is working on a white paper that will be calling for stronger action to protect vulnerable patients through improved surveillance, better access to treatment and stronger policy commitments (Cancer Patients Europe, written communication, 4 July 2025).

We propose that the following actions should be prioritised (Fig. 2):

- Recognise AMR as a barrier to safe and equitable cancer and transplant care, and incorporate it into national cancer plans, transplant guidelines and critical medicines policies.
- Embed AMR surveillance systems that collect cancer-specific and transplant-specific data, including information on treatment delays, infection outcomes and mortality.
- Boost the development of new antibiotics and establish access mechanisms to ensure that these treatments are available to high-risk patients in all healthcare settings.

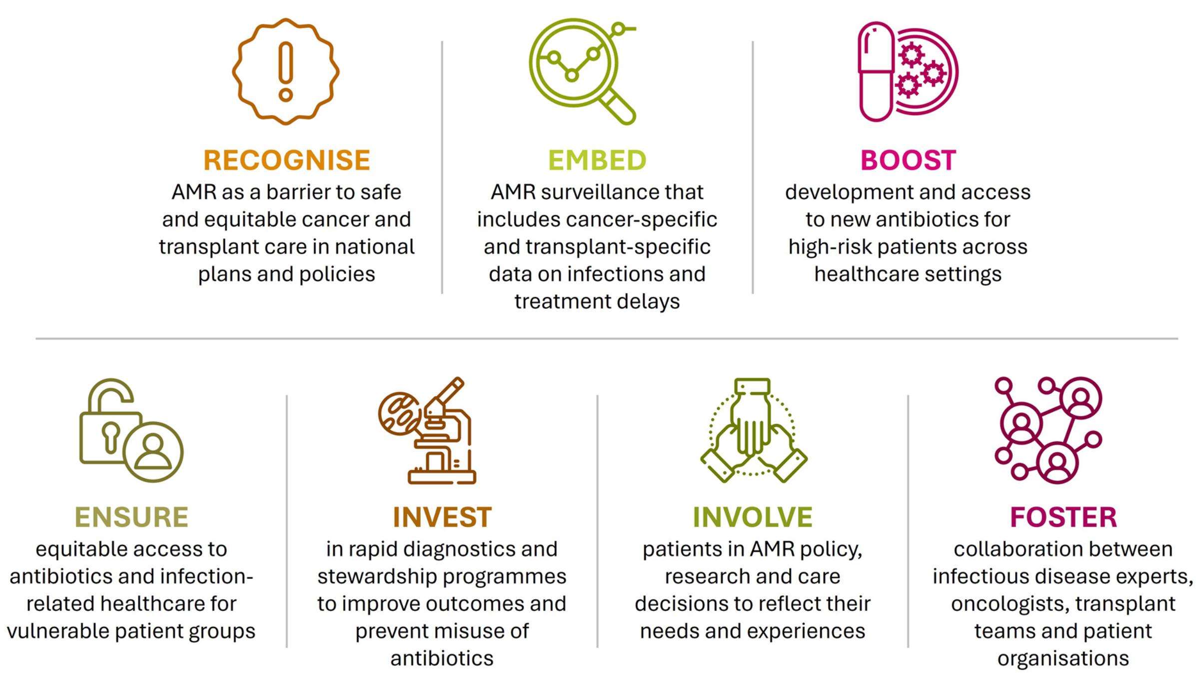

Fig. 2 Priority actions to address AMR in cancer and transplant care. *AMR* antimicrobial resistance

- Ensure equitable access to antibiotics and infection-related healthcare services by implementing targeted access strategies tailored to high-risk patient groups.
- Invest in rapid diagnostic testing and antimicrobial stewardship programmes within oncology and transplant services to improve patient outcomes and reduce unnecessary antibiotic use.
- Involve patients in AMR policymaking, research and healthcare planning to ensure their experiences and needs inform decision-making and care delivery.
- Foster stronger collaborations between infectious disease specialists, oncologists, transplant clinicians and patient organisations to coordinate care pathways and drive sustained action on AMR.

These actions are essential to protect the safety and wellbeing of patients with cancer and transplant and to maintain access to effective, life-saving treatments.

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Declarations

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