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Time for precision: Rethinking antimicrobial use to combat AMR globally

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Perspective

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Abstract

The rise of antimicrobial resistance (AMR), driven by relentless microbial evolution, threatens the foundations of global healthcare. Rather than following the so far undeliverable promise of evermore broad-spectrum antibiotics, infectious disease treatment can follow the example of oncology, which has, over a short period, augmented a platform of commodity anti-cancer agents with precision medicines and diagnostics to combat cancer evolution on a personalised basis. It is this shift that has allowed a significant extension in survival and has created entirely new subsectors of biotech. Sophisticated thinking and concerted action have also made changes to clinical practice and pathways. Applying these principles, precision antimicrobials, guided by rapid diagnostics and used alongside commodity products, offer a way to target resistant infections more effectively. Moreover, thinking about medicines that target multi-drug resistant infections as precision agents for rare occurrences opens up precedented reimbursement frameworks that could break the economic logjam that has smothered the sector for a generation. This is not the science of the future. The foundations of precision antimicrobial approaches are already emerging, with an ecosystem of initiatives to wrap around and support their development. Among these, Pathways to Antimicrobial Clinical Efficacy, a global AMR R&D platform that funds and offers wrap-around support for the development of new diagnostics and therapeutics, provides crucial infrastructure for emerging pipelines. Precision approaches have the potential to save lives that could otherwise be lost to resistant infections, while preserving the effectiveness of existing antimicrobials for future generations. Change is starting but cannot be left in the 'too difficult' tray. Microbial evolution and our own actions guarantee that we will need to adopt a new approach in our antimicrobial battle, and our lessons from the COVID-19 pandemic are that we need to act in advance, not in crisis.

Impact statement

Antimicrobial resistance (AMR) is undermining the medicines that keep people safe, from routine surgeries to life-saving treatments. Traditional approaches, broad-spectrum antibiotics used without precise guidance, are increasingly failing and driving resistance. Our article highlights precision antimicrobials as a solution. These therapies use detailed information about pathogens and patients to target infections more effectively, reduce side effects and slow the rise of resistant microbes. By combining rapid diagnostics and advanced drug modalities this approach mirrors the precision medicine revolution in cancer care, offering a smarter, sustainable way to tackle infections. The benefits are global: better patient outcomes in hospitals, more effective use of antibiotics in communities and feasible solutions even in resource-limited settings. Overcoming AMR is not simply a matter of discovering new drugs – it requires a systemic shift. Precision strategies, supported by diagnostics and nurtured through global collaborations, are essential to transform antimicrobial use, combat resistance and safeguard effective treatments for future generations.

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Introduction: The AMR crisis demands new thinking

Antimicrobial resistance (AMR) has emerged as one of the global health challenges of our time, yet our therapeutic approach has changed little over the past century. In most clinical settings, the default remains empiric therapy with broad-spectrum antibiotics – a blunt instrument used out of necessity rather than precision. While this strategy does deliver clinical benefit, its continued widespread practice is unsustainable. In many scenarios, treatment fails or results in collateral harm to individuals, either by disrupting the microbiome or through drug-associated toxicity. At a system level, the practice drives resistance and steadily narrows treatment options over time.

The overuse and misuse of antimicrobials, whether in hospitals, communities, conflict zones, as well as in animal health and agriculture, continue to fuel this escalating evolution of resistant pathogens. While clinical management of infections has seen advances such as antimicrobial stewardship, broader change has been slow and deaths due to AMR continue to rise (GBD 2021 Antimicrobial Resistance Collaborators, 2024). Concurrently, the global pipeline for new

antimicrobials and diagnostics remains insufficient (World Health Organisation, 2025a, 2025b), hindered by scientific, regulatory and economic challenges (Årdal et al., 2020; Datta, 2021; Theuretzbacher et al., 2023). Efforts to develop ever broader or more potent antibiotics have failed to yield durable solutions, repeating a century-old playbook that no longer works. By contrast, other therapeutic fields facing similar challenges – the need to address drug resistance and evolutionary adaptation – most notably oncology, have embraced precision medicine. In oncology, the integration of novel therapeutic modalities, combination strategies and adaptive approaches is being used to manage resistance, guided by molecular diagnostics and supported by innovative reimbursement models (DasGupta et al., 2022).

Antimicrobial therapeutics must now make a similar leap. It is time to move beyond current practice and towards a smarter, more sophisticated pharmacopoeia: one that integrates precision diagnostics, targeted therapies and data-driven stewardship across all healthcare systems and settings. Drawing inspiration from the orphan drug paradigm, advances in enabling sciences and recent progress in value-based pricing for antimicrobials, we can reimagine how antimicrobial R&D is incentivised and deployed. This article argues that adopting the precision medicine framework for infectious diseases is not just an aspiration but urgently needed – one that could redefine how the world combats AMR and restore momentum to a field at risk of scientific, economic and clinical stagnation.

What are precision antimicrobials?

Precision antimicrobials represent a shift towards smarter, more informed infectious disease treatment, moving beyond empiric, one-size-fits-all approaches without abandoning the essential role of broad-spectrum antibiotics. Precision antimicrobials are the right drugs against the right pathogens to the right patients at the right time and dose, guided by detailed pathogen and host information. Therapy is targeted not only to the pathogen and its resistance profile but also to patient-specific factors such as immune status, host genetics, comorbidities and overall clinical risk. This stratification optimises efficacy while minimising collateral harm and toxicity. They address discrete gaps in our arsenal that are formed by microbial evolution, which we are accelerating. They augment existing antimicrobial platforms and provide high-value, high-impact rescue treatments for those who will die tomorrow of infections they could survive today.

A shift towards a precision paradigm will enhance clinical outcomes by making broad-spectrum use more intentional and informed – employing them only where necessary, such as to treat severe and rapidly progressing or polymicrobial infections where rapid diagnostics are unavailable. Crucially, broad-spectrum antimicrobials will be complemented with a new generation of narrow-spectrum, high-value, pathogen-specific precision agents enabled by diagnostics (Altarac, 2021). These targeted drugs are designed to act specifically against the causative pathogen, minimise off-target effects and slow the acceleration of resistance that accompanies suboptimal or excessive antibiotic use. Advances in therapeutic drug monitoring and adaptive dosing will also allow clinical care teams to maintain effective drug concentrations while avoiding toxicity, further improving outcomes and supporting antimicrobial stewardship (Bulman et al., 2022). By emphasising specificity and clinical value rather than volume-based commoditisation, precision antimicrobials can also be reimbursed based on lifesaving, low-use value, drawing on models successfully developed for rare and orphan drugs (Huang et al., 2022; U.S. Food and Drug Administration, 2024).

There are clear parallels with precision oncology. Just as cancer treatment increasingly relies on molecular profiling, targeted chemotherapeutics and companion diagnostics to anticipate and overcome tumour evolution and resistance, precision antimicrobials leverage molecular and phenotypic diagnostics to guide therapy against evolving pathogens. In both fields, the combination of diagnostic insight, patient stratification and targeted therapy represents a move from 'one-size-fits-all' approaches to adaptive, individualised interventions that improve outcomes and extend therapeutic longevity. They are not simply narrower or more potent drugs; they constitute a systems-level reimagining of infectious disease management. By integrating advanced diagnostics, novel therapeutics and innovative reimbursement strategies, this approach can improve clinical outcomes for individuals and drive sustainability at a system level, slowing antimicrobial resistance and preserving treatment options for the future.

Why now? – Enablers of the precision paradigm shift

The urgency of rethinking antimicrobial therapy is underscored by microbial evolution: since the last new antibiotic class was discovered, microbes have undergone more than a million generations, continually refining resistance mechanisms (Zaman et al., 2017). Data with AI/ML analytics allow us to map and predict these evolutionary trajectories, anticipate resistance emergence and even guide the design of next-generation molecules (Charlebois, 2023; Howard et al., 2025). Integrated surveillance, resistance pathway modelling and predictive analytics provide actionable insights at both patient and population levels. Ultimately innovators will be enabled to develop and target discrete, precision interventions where they will be needed.

Advances in diagnostic technologies promise to translate insights into the pathophysiology of infectious disease to effect clinical decision-making. The application of breakthroughs in next-generation sequencing, clustered regularly interspaced short palindromic repeats (CRISPR)-based assays and isothermal amplification technologies such as loop-mediated isothermal amplification (LAMP) has the potential to dramatically improve the speed, sensitivity and specificity of pathogen detection and antibiotic sensitivity testing (Kaprou et al., 2021; Huang et al., 2023). Lessons from the COVID-19 pandemic demonstrate that lab-free, rapid testing in both clinical and lay environments is achievable, providing timely guidance to optimise therapy. Falling costs and decentralisation will also enable rapid, point-of-care deployment in resource-limited settings.

Emerging therapeutic modalities also promise to be a timely and critical enabler for the precision antimicrobial paradigm. Over the last decade and across therapy areas, drug modalities have diversified significantly, moving beyond traditional small molecules and conventional biologics to encompass a new era of specialised targeted therapies. These include next-generation antibodies (such as antibody-drug conjugates or bispecific antibodies), nanomedicines (e.g. nucleic acid drugs), targeted protein degraders (e.g. PROTACs) and bioengineered biologics (e.g. phage) (Fuente-Nunez et al., 2018; Altamirano and Barr, 2019; Eladl, 2025). There is also ongoing innovation in small molecule drug discovery in part driven by AI and computational methods. In therapy areas outside of infectious diseases, next-generation drug modalities are transforming our ability to tackle previously intractable targets with specificity and

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precision. This expansion of therapeutic approaches is beginning to take hold in antimicrobial R&D, where early-stage pipelines now feature engineered phages, antibody-based and host-directed therapies (HDTs; World Health Organisation, 2025a). These approaches are designed to deliver targeted activity and reduce collateral effects, including the selection pressure that drives resistance. This convergence of therapeutic innovation with predictive analytics and rapid diagnostics is necessary and timely; the continuing evolution of microbial resistance is no longer met with empiric, blunt solutions, but can instead be addressed with intelligent, targeted and precision interventions that improve individual outcomes and preserve treatment options at a global scale.

Policy, stewardship and reimbursement frameworks are evolving to support this paradigm. There is growing advocacy for policy that encourages precision-informed therapy through mandating diagnostic-guided, selective treatment rather than simple restriction of use (Darzi et al., 2024; Review on Antimicrobial Resistance, 2016). Concurrently, programmes for value-based and rare/orphan drug-style reimbursement in other disease areas (Huang et al., 2022; U.S. Food and Drug Administration, 2024), and the UK value-based pricing model for antibiotics (National Institute for Health and Care Excellence, 2025), demonstrate that low-use, high-value antimicrobials can be sustainably supported, encouraging continued investment and adoption. Together, these policy and financial levers provide the commercial model and pull-incentives necessary to fund and translate scientific and technological advances into real-world impact, improving patient outcomes and slowing the global rise of AMR.

Examples of emerging precision antimicrobial approaches

Encouraging examples of precision strategies are emerging that illustrate how precision thinking could reshape infection management.

There are real-world examples of diagnostic-led stewardship, both in high-income countries and low- and middle-income countries (LMICs). Rapid pathogen identification, as exemplified by the adoption of rapid diagnostic tests for malaria, has enabled more targeted prescribing, reduced unnecessary treatment exposure, and improved patient outcomes. In LMIC settings, decentralised molecular platforms and networked data systems are becoming a possibility, demonstrating precision stewardship is feasible even where laboratory infrastructure is limited (The Digital Diagnostics for Africa Network, 2022). Precision principles are also being applied to the use of agents with broad-spectrum activity. Shionogi's development of Cefiderocol, a siderophore cephalosporin active against all major carbapenem resistance mechanisms, demonstrated how incorporating diagnostic tests into clinical trials can guide patient selection and optimise efficacy data (Echols et al., 2019). It is also of note that Shionogi have launched an *in vitro* diagnostic in their domestic market to support the appropriate clinical use of Cefiderocol, further reinforcing the move towards precision use (Shionogi, 2024). This model of diagnostic-enabled development and deployment could and should inform future antibiotic development and use.

Examples of next-generation therapeutic approaches reaching clinical phase testing include bacteriophage (phage) and antibody-coupled therapies. Phages offer highly targeted, pathogen-specific activity and can be personalised to the infecting strains, reducing collateral damage to the microbiome and limiting resistance selection. Recent compassionate-use and clinical studies have demonstrated tangible success, particularly in chronic and drug-resistant infections, which has renewed global interest in this century-old approach (Hatfull et al., 2022). Antibody-based therapies also apply precision principles by targeting defined bacterial antigens or virulence factors. For example the monoclonal antibody CMTX-101 has received FDA fast-track designation as an adjunct to antibiotics against *Pseudomonas aeruginosa* infections in high-risk populations with Cystic Fibrosis (Cystic Fibrosis Foundation, 2024). HDTs also provide a different but complementary precision strategy – modulating the immune response or host pathways rather than directly targeting pathogens. In conditions such as sepsis and tuberculosis, HDTs aim to restore immune balance, enhance pathogen clearance, and reduce tissue damage. Recent studies in TB, for example, have explored the use of repurposed drugs and immunomodulators to shorten treatment duration and improve outcomes in drug-resistant disease. Looking ahead, stratifying patients according to immune or inflammatory biomarkers offers a route to personalise HDT use; matching therapeutic interventions to individual host responses for maximal benefit and minimal harm (Kaufmann et al., 2017).

These advances represent the green shoots of progress in translating precision principles into clinical reality. They deserve both scientific and policy support. The global collaborative Pathways to Antimicrobial Clinical Efficacy (PACE; Figure 1) is now helping to accelerate this transition by identifying unmet needs, funding innovative diagnostics and therapeutics, and providing vital wrap-around R&D support. These developments demonstrate that precision in antimicrobials is taking shape.

Barriers and challenges to implementation

Despite encouraging scientific and policy momentum, significant barriers remain to embedding precision antimicrobial approaches into clinical practice at scale. Beyond the voices of the cynics, the real challenges span scientific, regulatory, economic and behavioural domains and must be tackled collaboratively if the promise of precision antimicrobials is to translate into real-world benefit.

A key obstacle lies in clinical adoption and practice change. For decades, empiric prescribing of broad-spectrum antibiotics has been the default, shaped by time pressure, diagnostic uncertainty and established habits. Many prescribers remain hesitant to rely on new diagnostics, whether due to concerns about reliability, turnaround time or a lack of familiarity with integrating results into clinical decision-making (Burrowes et al., 2021). Precision antimicrobial strategies will only succeed if designed around the realities of clinical workflows, not in isolation from them. Overcoming this natural inertia requires confidence-building through education, the co-creation of tools, clear guidance and the demonstration of both clinical and economic value in routine care are critical to encouraging uptake.

Scientific and clinical challenges also constrain progress. Developing and manufacturing novel therapeutic modalities presents complex chemistry, manufacturing and control issues with unprecedented regulatory routes and high cost of goods that limit adoption (Gutierrez et al., 2020). Encouragingly, advances in synthetic-biology and manufacturing, such as modular, automated and cell-free systems, are beginning to reduce production costs, create previously unmakeable constructs and improve accessibility, creating the prospect that such therapies may eventually be available even in resource-limited settings (Ranbhor, 2025).

Traditional trial paradigms, built for broad-spectrum drugs, are poorly suited to precision antimicrobials. As with precision oncology,

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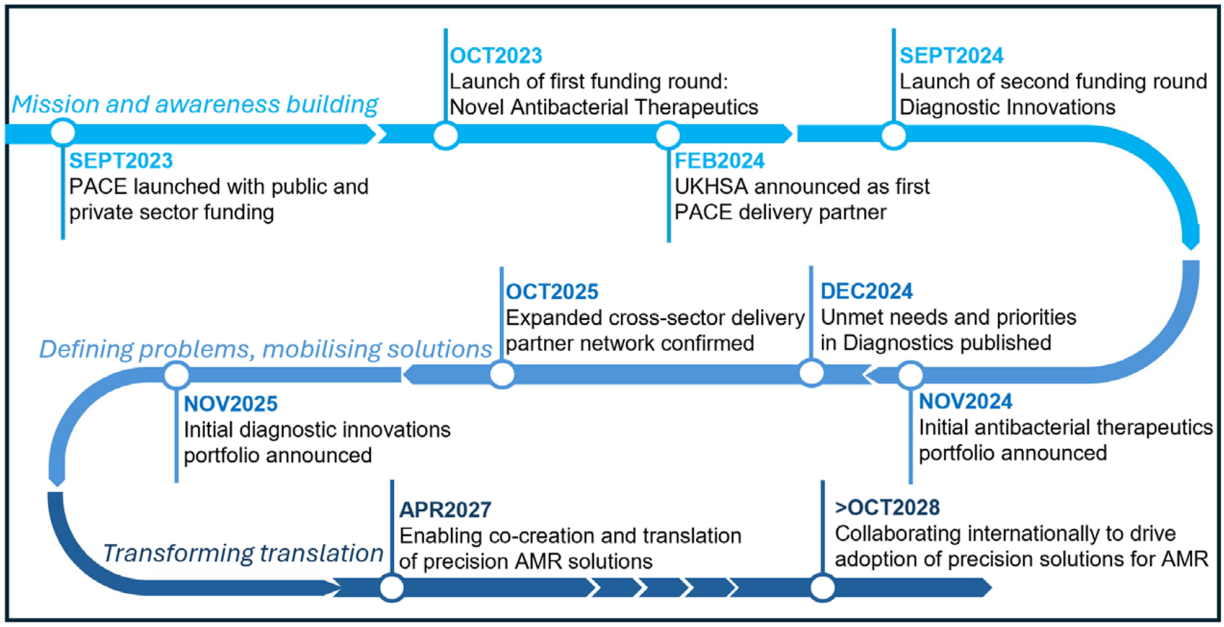


Figure 1. Pathways to Antimicrobial Clinical Efficacy (PACE) – a pathway into precision innovation in AMR. Timeline of PACE progress, from mission launch and awareness building, through defining problems and mobilising solutions, to co-creation of precision-driven approaches for AMR. More information: https://www.pace-amr.org.uk.

trials for narrow-spectrum or pathogen-specific agents face difficulties in patient recruitment, variable pathogen prevalence and the need for adaptive or platform designs capable of accommodating emerging data. The standard regulatory frameworks are also misaligned. Innovative trial design and regulatory reform will be essential to foster the emergent innovation in the field (Alm and Lahiri, 2020; Altarac, 2021; Duan et al., 2024). Likewise, conventional volume-based pricing and reimbursement models discourage the development of narrow, high-value agents that must be used sparingly to preserve efficacy (Årdal et al., 2020). Incentive structures that reward precision patient outcomes and healthcare value rather than sales volume will be essential for sustainable implementation.

Precision medicine thinking and commercial models can be adapted from the rare and orphan disease field, where tailored evidence requirements, market exclusivity and innovative reimbursement schemes have enabled progress despite small patient populations (Huang et al., 2022). Multidrug resistance can be seen as a 'rare' treatment, allowing these models to be applied by recognising its high value rather than market size, and could unlock the commercial logjam that has smothered antimicrobial R&D for a generation. Accelerated approval pathways, adaptive licensing and value-based pricing models already piloted in other therapeutic areas also provide a template for rewarding innovation while ensuring equitable access. Ultimately, overcoming these barriers requires more than scientific and technical solutions; it demands that we choose to make a shift in mindset and language, from a paradigm of high-volume commodities and empiricism to one of precision, value and stewardship. Only through co-ordinated effort between researchers, people affected by AMR, their clinical care teams, regulators and payers can precision antimicrobials fulfil their potential to transform infectious disease care globally, as has been done for cancer.

Conclusions and future perspectives

Precision antimicrobials are not optional; they are an essential component of the antimicrobial toolbox required to drive best-practice treatment and stewardship outcomes. The accelerating threat of AMR demands that we move beyond empiricism and recognise new antimicrobials as precision tools rather than blunt commodities. Without this shift, our ability to keep pace with microbial evolution will remain fundamentally constrained. The future of infection management lies, as it does in today's oncology pathways, in the progressive shift towards diagnostic-guided precision therapeutics, alongside the continued use of broad-spectrum agents where clinically indicated.

To realise this vision, several sets of innovation are required. First, diagnostic and therapeutic development should proceed in tandem, ensuring that new drugs are designed and deployed with appropriate diagnostics from the outset. Second, clinical trial design must evolve – embracing adaptive, pathogen-focused and data-enriched approaches that generate robust evidence for narrow or targeted interventions. Third, the regulatory and reimbursement environment must reward precision rather than volume, drawing from the proven frameworks of rare and orphan drug innovation to value lifesaving, low-use medicines appropriately. Finally clinical pathways must be redrawn and retaught to gradually embed the principles of precision antimicrobials within a system still reliant on broad-spectrum, empiric treatment models.

This transformation cannot be left to chance but must be purposefully supported and driven. Changing the model changes the economics as well as the clinical practice: just as small biotech companies became the vanguard of orphan drug development, so too could they lead the precision antimicrobial revolution if today's oncology model is applied. Globally co-ordinated public-private investment and balanced push-pull mechanisms are needed to nurture innovation and equitable access and must be developed while being mindful of the transformational shift that is required. Multistakeholder initiatives such as PACE exemplify how such collaboration can catalyse progress. The task ahead is clear: to move from rhetoric to reality, ensuring that precision in antimicrobials becomes not an aspiration, but the standard for global infection care.

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