Journal of
Antimicrobial
Chemotherapy

A behavioural approach to specifying interventions: what insights can be gained for the reporting and implementation of interventions to reduce antibiotic use in hospitals?

Eilidh M. Duncan [ID] [1]*, Esmita Charani [ID] [2], Janet E. Clarkson[3], Jill J. Francis[4], Katie Gillies[1], Jeremy M. Grimshaw[5], Winfried V. Kern[6], Fabiana Lorencatto[7], Charis A. Marwick[8], Jo McEwen[9], Ralph Möhler[10], Andrew M. Morris[11], Craig R. Ramsay[1], Susan Rogers Van Katwyk[12], Magdalena Rzewuska[1], Brita Skodvin[13], Ingrid Smith[14], Kathryn N. Suh[15] and Peter G. Davey[8]†

[1]Health Services Research Unit, University of Aberdeen, Aberdeen, Scotland, UK; [2]NIHR Health Protection Research Unit in Healthcare Associated Infections and Antimicrobial Resistance, Faculty of Medicine, Imperial College London, London, UK; [3]Schools of Dentistry, University of Dundee, Dundee, UK & University of Manchester, Manchester, UK, NHS Education for Scotland, Scotland; [4]School of Health Sciences, City University of London, London, UK; [5]Clinical Epidemiology Program, Ottawa Hospital Research Institute, Ottawa, Ontario, Canada and Department of Medicine, University of Ottawa, Ottawa, Ontario, Canada; [6]University of Freiburg Medical Center and Faculty of Medicine, Department of Medicine II/Infectious Diseases, Freiburg im Breisgau, Germany; [7]Centre for Behaviour Change, University College London, London, UK; [8]Division of Population Health and Genomics, School of Medicine, University of Dundee, Scotland, UK; [9]Ninewells Hospital, Dundee, UK; [10]Department of Health Services Research and Nursing Science, School of Public Health, Bielefeld University, Bielefeld, Germany; [11]Sinai Health System, University Health Network and University of Toronto, Toronto, Canada; [12]School of Epidemiology and Public Health, University of Ottawa, Ottawa, Ontario, Canada; [13]Norwegian Advisory Unit for Antibiotic Use in Hospitals, Haukeland University Hospital, Bergen, Norway; [14]Department of Essential Medicines and Health Products, World Health Organization, Geneva, Switzerland; [15]Department of Medicine, University of Ottawa and the Ottawa Hospital Research Institute, Ottawa, Ontario, Canada

*Corresponding author. E-mail: e.duncan@abdn.ac.uk
†Authors between the first author and the last author are listed in alphabetical order by surname.

Background: Reducing unnecessary antibiotic exposure is a key strategy in reducing the development and selection of antibiotic-resistant bacteria. Hospital antimicrobial stewardship (AMS) interventions are inherently complex, often requiring multiple healthcare professionals to change multiple behaviours at multiple timepoints along the care pathway. Inaction can arise when roles and responsibilities are unclear. A behavioural perspective can offer insights to maximize the chances of successful implementation.

Objectives: To apply a behavioural framework [the Target Action Context Timing Actors (TACTA) framework] to existing evidence about hospital AMS interventions to specify which key behavioural aspects of interventions are detailed.

Methods: Randomized controlled trials (RCTs) and interrupted time series (ITS) studies with a focus on reducing unnecessary exposure to antibiotics were identified from the most recent Cochrane review of interventions to improve hospital AMS. The TACTA framework was applied to published intervention reports to assess the extent to which key details were reported about what behaviour should be performed, who is responsible for doing it and *when*, *where*, *how often* and *with whom* it should be performed.

Results: The included studies (*n* = 45; 31 RCTs and 14 ITS studies with 49 outcome measures) reported *what* should be done, *where* and *to whom*. However, key details were missing about *who* should act (45%) and *when* (22%). Specification of *who* should act was missing in 79% of 15 interventions to reduce duration of treatment in continuing-care wards.

Conclusions: The lack of precise specification within AMS interventions limits the generalizability and reproducibility of evidence, hampering efforts to implement AMS interventions in practice.

Introduction

Reducing unnecessary exposure to antibiotics in hospitals is a key strategy in reducing the development, selection and spread of antibiotic-resistant bacteria.[1]

Many hospitals around the world have implemented antimicrobial stewardship (AMS) programmes involving a multidisciplinary AMS team and a systematic approach for actions to improve responsible/appropriate antibiotic use.[2] Establishing which interventions are most effective in reducing antibiotic exposure is an important first step towards improving antibiotic prescribing. However, identifying AMS interventions that have been successful in one setting is not enough to ensure effective AMS interventions will be effectively implemented more widely in hospitals.

The Cochrane review of interventions to improve antibiotic prescribing to hospital inpatients provides clear evidence that AMS interventions can increase compliance with antibiotic policy.[3] There were 221 included studies in the review, with the majority focusing on choice, route or dose of antibiotic medicines. There was high-certainty evidence from randomized controlled trials (RCTs) that AMS interventions can reduce the total duration of antibiotic treatment and evidence from interrupted time series (ITS) studies provided additional evidence that the results of AMS interventions are reproducible in routine practice.[3] The aim of this review is to use a behavioural perspective to examine the AMS interventions in these RCTs and ITS studies from the Cochrane review and to make recommendations about the application of behaviour-change principles to the design and reporting of future interventions.

Hospital AMS interventions are inherently complex, often requiring multiple healthcare professionals to change multiple behaviours at multiple timepoints along the care pathway. Inaction can arise when roles and responsibilities are unclear. Effective AMS interventions are more likely to be interpretable, reproducible and implemented if it is clearly specified *what* behaviour(s) should be performed, *who* is responsible for doing it and *when, where, how often* and *with whom* it should be performed.[4,5] Specifying behaviour in this way is known as the TACTA framework: Target (patient group, e.g. elective surgery patients), Action (start or stop antibiotics), Context (specific hospital ward, e.g. surgical ward), Timing (when to start or stop, e.g. 24 h after surgery) and Actors (healthcare professionals responsible for the action, e.g. the surgeon who performed the operation).[6] Poor specification of behaviour creates difficulties for research (hampering interpretation of results, replication of interventions and studies, and evidence synthesis) and practice (impeding replication, scaling up and implementation of effective AMS interventions into clinical settings). Applying TACTA to ensure precise specification of problems and recommendations makes implementation more feasible; it provides greater clarity about what is required and greater certainty about whether it has been accomplished.[6,7]

Our aim in this study was to apply this framework that guides specification of behaviours to evidence from the Cochrane review about interventions focused on reducing unnecessary exposure to antibiotics[3] in order to determine the extent to which stewardship interventions are currently specified in key behavioural elements and thereby explore what insights can be gleaned for efforts to implement AMS interventions in hospitals.

Methods

Study selection

For this review, we included relevant studies from the 196 RCTs and ITS studies included in the Cochrane review of interventions to improve antibiotic prescribing to hospital inpatients.[3] Detailed methods of the Cochrane review are reported elsewhere[3] and Figure 1 provides a diagram of study flow for this review. Studies were included if the prescribing outcome was coded by the original Cochrane review team as a decision to start or stop antibiotics, with the intervention target to reduce exposure. We excluded studies if the target was to increase antibiotic exposure as focusing on reducing unnecessary exposure to antibiotics in hospitals is a key strategy in reducing the development and selection of antibiotic-resistant bacteria.

Data extraction

Two authors (E.M.D. and P.G.D.) reviewed the full text of each included study. We separated the studies into those based in ICUs versus continuing-care wards because ICUs have higher staffing levels with daily rounds by senior medical staff.[8] In contrast, prescribing decisions in continuing-care wards are more likely to be made by doctors-in-training and there is increasing evidence about the complex social and professional dynamics underlying their prescribing decisions.[9–11] In the Cochrane review, 51% of interventions were coded as designed and delivered by a multidisciplinary Antimicrobial Management Team of physicians working with pharmacists and/or nurses.[3] Details of the AMS interventions were extracted verbatim from the original studies. Effective Practice and Organisation of Care (EPOC)
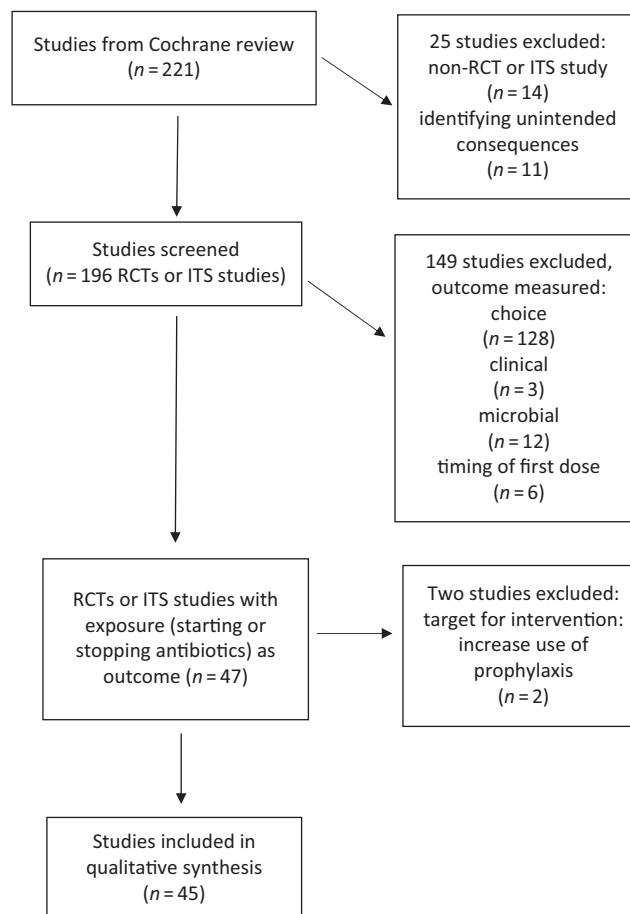

Figure 1. Study flow diagram.

intervention categories were included based on the original Cochrane review coding.[3]

Behavioural specification

The TACTA framework[6] was used to specify verbatim descriptions of the interventions in terms of Target (patient group), Action (start or stop antibiotics), Context (specific hospital ward), Timing (when to start or stop) and Actors (healthcare professionals responsible for the action). Two authors (E.M.D. and P.G.D.) independently coded interventions and then compared coding. Two additional authors (J.J.F. and F.L.) reviewed the final coding. Differences in coding of each element were resolved by discussion.

Results

Details of included studies

The 45 included studies were 31 RCTs and 14 ITS studies and reported on 49 outcomes of AMS interventions (4 studies reported 2 outcomes for their interventions[12–15]). Details of individual studies are given in Tables S1 to S4 (available as Supplementary data at *JAC* Online): country; number of hospitals; context; target patients; intervention; action; timing; actors; and outcome. The most represented country setting was the USA (12 studies), followed by Switzerland (10 studies). Most studies were conducted in a single country setting, but one was carried out across five countries.[16] The maximum number of hospitals within a single study was 41.[17] There were 15 interventions to reduce the number of patients who started antibiotics (Table S1), 4 to reduce duration of antibiotic prophylaxis (Table S2) and 30 to reduce duration of antibiotic treatment; 16 in ICUs (Table S3) and 14 in continuing-care wards (Table S4). Four RCTs[12–15] measured the effect of an intervention both on reducing the number of patients who started antibiotics and on the duration of treatment in patients who started antibiotics.

Five of the EPOC intervention categories[18] are reflected in the included studies: (i) educational outreach through review and recommendation for change; (ii) audit and feedback about compliance with policies; (iii) dissemination of educational materials; (iv) reminders; and (v) structural interventions. In addition, one study included a restrictive intervention.[19]

Defining clinical behaviours with TACTA

The application of the TACTA framework to coding AMS interventions is demonstrated for two studies[20,21] in Table 1 as examples. Both studies were intended to reduce the duration of antibiotic prophylaxis for adults undergoing elective surgery. However, there were important differences with respect to actions, timing and actors (Table 1). Both studies included AMS interventions with explicit assignment of responsibility for stopping antibiotics to the surgeon (actor). However, in one of these studies[20] the action was supported by introducing a default order for prophylactic antibiotics to stop after 24 h and by making pharmacists responsible for review of patients to ensure that antibiotics had been stopped. Both studies used an ITS design and the results show different effects of the AMS interventions over time (Figure 2). Both studies improved performance, but did not reach the target of 95% reliability in the first 6 months after the AMS interventions started. However, in one of the studies[20] changes were made to the intervention over time; the Surgical Infection Prevention Team noted remaining room for improvement and went to the Pharmacy and Therapeutics

Table 1. Examples of TACTA specification of behaviour for two studies of interventions intended to reduce duration of antibiotic prophylaxis after surgery

TACTA domain	Dull *et al.*[20] (2008)	Sun *et al.*[21] (2011)
Target	adults undergoing elective surgery: coronary artery bypass graft (CABG); other cardiac surgery; hip arthroplasty; knee arthroplasty; colorectal surgery; hysterectomy; and vascular surgery	adults undergoing elective surgery: CABG
Action	stop antibiotics	stop antibiotics
Context	surgical wards in two hospitals in the USA	cardiac surgery ward in one hospital in Taiwan
Timing	24 h after surgery (48 h after cardiac surgery)	24 h after surgery
Actors	surgeon who performed the operation and pharmacists	cardiac surgeon

Committee to request that it approve an automatic stop on prophylactic antibiotics after 24 h (48 h for cardiothoracic procedures). Following this approval, pharmacists automatically stopped administration of prophylactic antibiotics ordered for more than 24 or 48 h and this was associated with sustained improvement to 95% reliability.[20] In contrast, there was no change in the intervention in the other study and the process was still only 60%–70% reliable at 10–12 months post-intervention (Figure 2).[21]

When the TACTA framework was applied to all studies we found that the action, context and target patients were always specified, but specification of timing and actors was more variable (Table 2).

Actions

Action was specified across all studies included in this review and three actions were apparent: (i) starting antibiotics; (ii) stopping prophylactic antibiotics; and (iii) stopping therapeutic antibiotics.

Starting antibiotics

Fifteen studies evaluated interventions relating to starting, or not starting, antibiotics (Table 2; further details in Table S1). In 12 of these, the AMS intervention was a reminder linked to a laboratory test result: procalcitonin in 9 studies,[12–15,22–26] rapid microbiology diagnostic test for viruses or atypical bacteria in 2 studies[27,28] and IL-8 in 1 study.[16] In three studies, the AMS intervention was the introduction of a guideline about management of bronchiolitis,[17,29,30] with audit and feedback in two of these studies.[29,30]

Stopping prophylactic antibiotics

There were four ITS studies of AMS interventions to reduce duration of prophylactic antibiotics in adult surgical patients (Table 2;
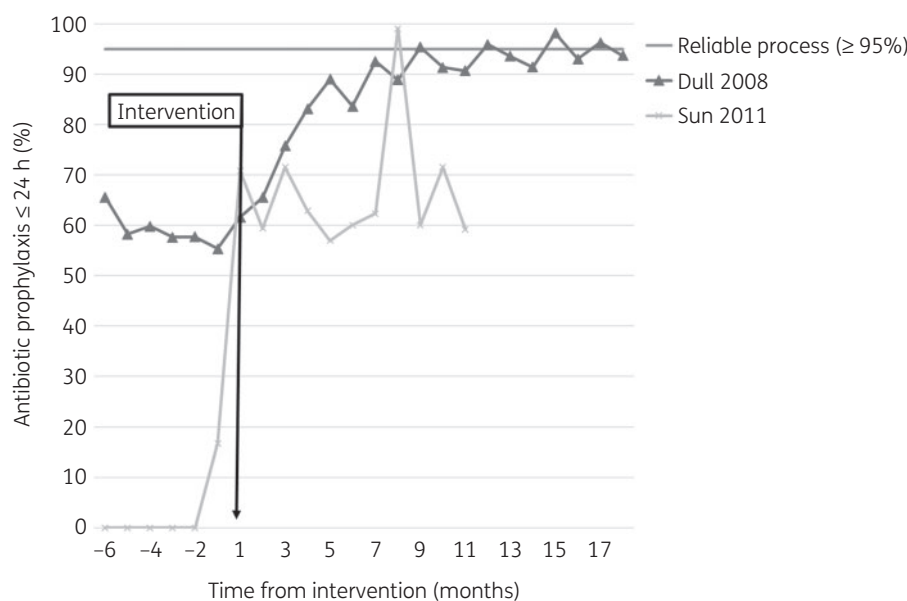
Figure 2. Intervention effect over time for two studies that aimed to increase the percentage of patients who received surgical antibiotic prophylaxis for ≤24 h. Drawn from data reported by Dull et al.[20] (2008) and Sun et al.[21] (2011).

Table 2. Number of studies that specified target, action, context, timing and actors

Action	Context	Studies (design)	Target patients	Timing	Actors
Starting antibiotics	emergency department	9 (6 RCT[12,13,22,25,26,28,] 3 ITS[17,29,30])	8 community-acquired LRTI, 1 fever	9 on admission	3 resident, supervised, 3 treating physician, 3 not clear
	ward	6 (6 RCT[14–16,23,24,27])	3 community-acquired LRTI, 1 acute exacerbation of asthma, 1 community-acquired fever in neonates, 1 post-cardiac surgery	5 on admission, 1 after surgery	5 treating physician, 1 physician in charge
Stopping prophylactic antibiotics	operating theatre	2 (2 ITS[31,32])	2 elective surgery	2 at start of operation	2 not clear
	surgical ward	2 (2 ITS[20,21])	2 elective surgery	2 at 24 h post-operative	1 pharmacist and surgeon, 1 surgeon
Stopping therapeutic antibiotics	ICU	16 (14 RCT[19,33–45,] 2 ITS[46,47])	8 sepsis, 5 hospital-acquired LRTI, 3 all on antibiotics	9 multiple (e.g. daily) reviews, 2 single review (e.g. at 48–72 h), 5 not clear	6 treating physician, 2 physician in charge, 1 one of four ICU consultants, 1 AMT member, 6 not clear
	ward	14 (9 RCT[12–15,49,51,55–57,] 5 ITS[48,50,52–54])	6 all on antibiotics, 5 community-acquired LRTI, 1 positive blood cultures, 1 acute pancreatitis, 1 acute exacerbations of pulmonary fibrosis	3 multiple (e.g. daily) reviews, 5 single review (e.g. at 48–72 h), 6 not clear	3 treating physician, 11 not clear

LRTI, lower respiratory tract infection; AMT, Antimicrobial Management Team.
Note that the total number of studies is 49 because 4 RCTs[12–15] measured the effect of an intervention on two actions (starting and stopping antibiotic treatment) with different outcome measures for each action.

further details in Table S2). The interventions were audit and feedback in three studies[20,21,31] and a new guideline in one.[32]

Stopping therapeutic antibiotics

There were 16 studies of AMS interventions to reduce duration of antibiotic treatment in ICUs (Table 2; details in Table S3), introduction of procalcitonin testing in 11 studies,[33–43] review of prescribed antibiotics by members of the AMS team in 4 studies[19,44–46] and introduction of a new guideline in one study.[47] There were 14 studies of AMS interventions on duration of antibiotic treatment in inpatient wards (Table 2; details in Table S4), including review and recommendation for change by a member of the AMS team in 5 studies,[48–52] antibiotic guidelines in 2 studies[53,54] and rapid microbiology testing in 1 study.[55] Procalcitonin featured in six studies.[12–15,56,57]

Context

Context was specified across all the studies included in this review and included emergency departments (in 9 studies), operating theatres (in 2 studies), surgical wards (in 2 studies), ICUs (in 16 studies) and wards (in 20 studies).

Target

The target patients for AMS interventions were specified across all the studies and included patients with community-acquired lower respiratory tract infection (in 16 studies), all patients (in 9 studies), patients with sepsis (in 8 studies), patients with hospital-acquired lower respiratory tract infection (in 5 studies), elective surgical patients (in 4 studies), patients with fever (in 1 study), neonatal patients with community-acquired fever (in 1 study), post-cardiac surgical patients (in 1 study), patients with positive blood cultures (in 1 study), patients with acute pancreatitis (in 1 study) and patients with acute exacerbations of pulmonary fibrosis (in 1 study).

Timing

Overall, the timing of when an intervention should occur was specified in 76% of studies. Timing was specified for all interventions that targeted starting antibiotics or stopping prophylactic antibiotics. However, timing of interventions to stop therapeutic antibiotic treatment was specified for only 11 (69%) of 16 studies in ICUs and 7 (50%) of 14 studies in wards (Table 2).

Actors

Overall, the actor of an intervention was specified in 55% of the studies. Actors were specified for 12 (80%) of 15 AMS interventions targeted at starting antibiotics, but only for 2 (50%) of 4 AMS interventions targeted at stopping prophylactic antibiotics. Actors were specified in 10 (63%) of 16 ICU studies and 3 (21%) of 14 ward studies where AMS interventions were to stop antibiotic treatment (Table 2). Three of the interventions targeted at starting antibiotics specified that the actor was a resident who was supervised by a senior physician[12,13,22] and two of the interventions targeted at stopping antibiotics in ICUs specified that the actor was one of four ICU consultants[46] or the member of the Antimicrobial Management Team (AMT) who reviewed the patient.[19] In contrast,

several studies specified actors as either the 'treating physician' or 'physician in charge' (Table 2), terms that do not clarify the role of junior and senior doctors or the clinical speciality.

Summary of results

When the TACTA framework was applied to all studies we found that the action, context and target were always specified. Emergency departments were the context for 60% of interventions targeting patients who start treatment and ICUs were the context for 56% targeting duration of treatment. Procalcitonin was the most common AMS intervention overall. Specification of timing and actors was less reliable, particularly for AMS interventions targeting antibiotic treatment in wards.

Discussion

The key finding in this review is that studies did not consistently report the actor (who is responsible) and timing (when to start/stop antibiotics), whilst target (patient group), action (what should be done) and context (where, e.g. ward or unit) were always specified. Decision-making about antimicrobial use in hospitals is a complex process, which can involve one or more actors and be influenced by cultural factors such as etiquette and hierarchy.[58–61] Few AMS interventions included in this review specified more than one actor and only one specified an actor who was not a doctor,[20] which fails to reflect the multi-professional care-delivery system of antibiotics in hospitals.[9,10,62–65]

Defining clinical behaviours with the TACTA framework

The first step in a behavioural approach to designing (and reporting) interventions is to define the problem in behavioural terms: who needs to do what differently to whom, where and when? The second step is to identify and prioritize a range of potential target behaviours.[4] Poor specification of the target behaviour, as this review has found for AMS interventions, causes problems for both research (creating difficulties for interpreting results, replication of interventions and studies, and evidence synthesis) and practice (impeding replication, scaling up and implementation of effective AMS interventions into clinical settings). Two of the AMS interventions to stop prophylactic antibiotics identified the surgeon as an actor for their intervention and made them specifically responsible for the action[20,21] (Table 1). Both interventions improved performance, but did not reach the target of 95% reliability within 6 months. In one study the AMS intervention was revised, which was associated with sustained improvement to 95% reliability[20] (Figure 2). Iterative review should be the rule rather than the exception in behaviour-change interventions, with revision of the intervention if it is not achieving its goal or if it has unanticipated, unpleasant consequences.[66–68] However, the study by Dull *et al.*[20] was the only example, among 45 included studies, of review and revision of an intervention through identification of additional actors.

In comparison with stopping therapeutic antibiotics, changing behaviour to stop prophylactic antibiotics may be more straightforward for two reasons. First, there is compelling evidence that stopping prophylactic antibiotics after 24 h does not increase risk of surgical site infection and that continuing antibiotics for >24 h is

likely to increase risk of *Clostridioides difficile* infection,[69] which can be used to influence prescribers' motivation through beliefs about consequences. Second, the patients are undergoing elective surgery, which facilitates the opportunity to clearly identify both the target and the actors for the intervention.

All of the included studies described the physical context for the intervention as either ICUs or continuing-care wards (Table 1). In ICUs, daily rounds by senior doctors are the norm[8] and most AMS programmes already include review by infection specialists.[2,70,71] In contrast, in continuing-care wards, regular review of patients is often done by doctors-in-training, supported by less frequent ward rounds by senior doctors.[9–11,61] A realist review of evidence from 131 studies found that doctors-in-training operate within challenging contexts (hierarchical relationships, powerful prescribing norms, unclear roles and responsibilities) where they prioritize particular responses due to fear of criticism and fear of individual responsibility for patients deteriorating.[11] The authors conclude that these complex dynamics explain how and why doctors-in-training follow senior clinicians' prescribing habits, take into account advice from other health professionals, ask questions or challenge decisions.[11] Furthermore, two recent qualitative studies found that the social context in which doctors-in-training work can be very different in medical and surgical wards.[58,61] There is already evidence about differences in professional identity and culture between medicine and surgery, but these studies demonstrate the need for a thorough understanding of specialty-specific norms surrounding antimicrobial prescribing.[72]

Only three of our included studies explicitly identified doctors-in-training as actors and described their supervision by senior colleagues.[12,13,22] All three of these studies were from emergency departments. In contrast, of the five studies of AMS interventions to stop antibiotics in continuing-care wards through review by a member of the AMS team, only two identified an actor for the recommendation and both of these were ambiguous. Recommendations through 'direct interaction with the prescribing physician'[51] or through communication 'to the clinician caring for the child'[52] could be interpreted as either for the junior doctor who wrote the prescription or reviews the patient regularly, or as the senior doctor who is responsible for the patient. In the remaining three studies, the recommendation was entered into the medical record[48,49] or was communicated 'by telephone, through the electronic medical record or on rounds'[50] so it was not clear who was expected to act on the recommendation.

Hospital AMS interventions focused on reducing exposure to antibiotics

Procalcitonin was the most common intervention focused on exposure overall, accounting for half of the studies targeting patients who start antibiotics on admission to hospital and the duration of therapeutic antibiotics in wards (Table S1), with the majority of studies targeting duration of therapeutic antibiotics in ICUs (Table S3). In 2015, NICE issued guidance on procalcitonin testing for two indications: stopping antibiotic treatment in people with confirmed or highly suspected sepsis in the ICU, or starting and stopping antibiotic treatment in people with suspected bacterial infection presenting to the emergency department.[70] The guidance was based on evidence from a systematic review of 18 studies, which

included 12 RCTs from our review.[12,13,15,25,26,33,34,36–38,43,57] NICE did not recommend adoption of procalcitonin because the control arm in these RCTs did not reflect current standard clinical practice in the UK. We believe that the same concerns apply to five studies from our review that were not included in the NICE guidance.[14,22–24,56]

In 2015, a survey about AMS in 421 hospitals from Asia, Africa, Europe, North America, Oceania and South America reported that testing for procalcitonin or other inflammatory markers was used to influence decisions about starting or stopping antibiotics in only 36% of hospitals.[2] In contrast, the majority of these hospitals used the other AMS interventions from our review: dissemination of guidelines (94%), review and recommendation for change in antibiotic therapy through telephone consultation (89%) or ward rounds (81%), audit (80%) and review of patients with bacteraemia (73%).

There are strengths and limitations to this review to consider. It is a review of studies included within an existing review rather than a systematic review of primary studies. This means that there may have been recently published AMS intervention studies that were not included in the Cochrane review and it is possible that recently conducted studies of AMS interventions have been reported more precisely in published reports. A strength of this review is in the application of an existing behavioural framework, TACTA, which has an established track record of application to reports of interventions[6] and a grounding in behavioural theory.[73] Other frameworks exist to encourage thorough descriptions of interventions and aid replication of studies, such as the TIDieR checklist.[74] However, the TIDieR checklist is focused on reporting of the details of intervention elements within a study rather than clearly specifying the behaviours that need to change as a result of the intervention. A behavioural approach using TACTA can add to reporting guidelines like TIDieR by increasing clarity and helping to operationalize the intervention elements themselves.[75]

Conclusions

The evidence that we have reviewed shows that actors and timing are poorly defined in AMS interventions to reduce unnecessary antibiotic prescribing in hospitals. This lack of specification is likely to hamper efforts to replicate successful interventions, synthesize evidence and implement successful interventions into practice. This lack of specification is particularly true for review of antibiotic treatment in continuing-care wards, where changing professional behaviour to influence antibiotic use is likely to be particularly challenging. There is a growing number of examples of theory-driven, systematic approaches to intervention design.[76,77] However, there is still a need to improve definition of problems in behavioural terms and improve understanding of current behaviour in context in order to maximize learning through evidence synthesis and detailed intervention reporting.[77] Studies reporting AMS interventions to reduce unnecessary antibiotic prescribing in hospitals should consider applying a behavioural framework to ensure that the evidence they provide can be used to help to build a picture of what works and that the *what, who, when, where, how often* and *with whom* of effective interventions can be operationalized into practice.

Funding

Transparency declarations

None to declare.

Supplementary data

Tables S1 to S4 are available as Supplementary data at *JAC* Online

References

1 Rice LB. The Maxwell Finland Lecture: For the duration—rational antibiotic administration in an era of antimicrobial resistance and *Clostridium difficile*. *Clin Infect Dis* 2008; **46**: 491–6.

2 Howard P, Pulcini C, Levy Hara G *et al*. An international cross-sectional survey of antimicrobial stewardship programmes in hospitals. *J Antimicrob Chemother* 2015; **70**: 1245–55.

3 Davey P, Marwick CA, Scott CL *et al*. Interventions to improve antibiotic prescribing practices for hospital inpatients. *Cochrane Database Syst Rev* 2017; issue 2: CD003543.

4 Michie S, Atkins L, West R. *The Behaviour Change Wheel: A Guide to Designing Interventions*. Silverback Publishing, 2014.

5 Atkins L, Francis J, Islam R *et al*. A guide to using the Theoretical Domains Framework of behaviour change to investigate implementation problems. *Implement Sci* 2017; **12**: 77.

6 Francis J, Presseau J. Healthcare practitioner behaviour. In: C Llewellyn, S Ayers, C McManus, eds. *Cambridge Handbook of Psychology, Health and Medicine*. Cambridge University Press, 2019; 325–8.

7 Michie S, Johnston M. Changing clinical behaviour by making guidelines specific. *BMJ* 2004; **328**: 343–5.

8 Marshall JC, Bosco L, Adhikari NK *et al*. What is an intensive care unit? A report of the task force of the World Federation of Societies of Intensive and Critical Care Medicine. *J Crit Care* 2017; **37**: 270–6.

9 Broom A, Broom J, Kirby E. Cultures of resistance? A Bourdieusian analysis of doctors' antibiotic prescribing. *Soc Sci Med* 2014; **110**: 81–8.

10 Lewis PJ, Tully MP. Uncomfortable prescribing decisions in hospitals: the impact of teamwork. *J R Soc Med* 2009; **102**: 481–8.

11 Papoutsi C, Mattick K, Pearson M *et al*. Social and professional influences on antimicrobial prescribing for doctors-in-training: a realist review. *J Antimicrob Chemother* 2017; **72**: 2418–30.

12 Christ-Crain M, Jaccard-Stolz D, Bingisser R *et al*. Effect of procalcitonin-guided treatment on antibiotic use and outcome in lower respiratory tract infections: cluster-randomised, single-blinded intervention trial. *Lancet* 2004; **363**: 600–7.

13 Christ-Crain M, Stolz D, Bingisser R *et al*. Procalcitonin guidance of antibiotic therapy in community-acquired pneumonia: a randomized trial. *Am J Respir Crit Care Med* 2006; **174**: 84–93.

14 Ding J, Chen Z, Feng K. Procalcitonin-guided antibiotic use in acute exacerbations of idiopathic pulmonary fibrosis. *Int J Med Sci* 2013; **10**: 903–7.

15 Esposito S, Tagliabue C, Picciolli I *et al*. Procalcitonin measurements for guiding antibiotic treatment in pediatric pneumonia. *Respir Med* 2011; **105**: 1939–45.

16 Franz AR, Bauer K, Schalk A *et al*. Measurement of interleukin 8 in combination with C-reactive protein reduced unnecessary antibiotic therapy in newborn infants: a multicenter, randomized, controlled trial. *Pediatrics* 2004; **114**: 1–8.

17 Parikh K, Hall M, Teach SJ. Bronchiolitis management before and after the AAP guidelines. *Pediatrics* 2014; **133**: e1–7.

18 Cochrane Effective Practice and Organisation of Care (EPOC) Group. *What Study Designs Should be Included in an EPOC Review and What Should They be Called?* 2016. https://epoc.cochrane.org/sites/epoc.cochrane.org/files/public/uploads/Resources-for-authors2017/what_study_designs_should_be_included_in_an_epoc_review.pdf.

19 Singh N, Rogers P, Atwood CW *et al*. Short-course empiric antibiotic therapy for patients with pulmonary infiltrates in the intensive care unit. A proposed solution for indiscriminate antibiotic prescription. *Am J Respir Crit Care Med* 2000; **162**: 505–11.

20 Dull D, Baird SK, Dulac J *et al*. Improving prophylactic perioperative antibiotic utilization in a hospital system. *J Healthc Qual* 2008; **30**: 48–56.

21 Sun TB, Chao SF, Chang BS *et al*. Quality improvements of antimicrobial prophylaxis in coronary artery bypass grafting. *J Surg Res* 2011; **167**: 329–35.

22 Lacroix L, Manzano S, Vandertuin L *et al*. Impact of the lab-score on antibiotic prescription rate in children with fever without source: a randomized controlled trial. *PLoS One* 2014; **9**: e115061.

23 Long W, Li LJ, Huang GZ *et al*. Procalcitonin guidance for reduction of antibiotic use in patients hospitalized with severe acute exacerbations of asthma: a randomized controlled study with 12-month follow-up. *Crit Care* 2014; **18**: 471.

24 Maravic-Stojkovic V, Lausevic-Vuk L, Jovic M *et al*. Procalcitonin-based therapeutic strategy to reduce antibiotic use in patients after cardiac surgery: a randomized controlled trial. *Srp Arh Celok Lek* 2011; **139**: 736–42.

25 Schuetz P, Christ-Crain M, Thomann R *et al*. Effect of procalcitonin-based guidelines vs standard guidelines on antibiotic use in lower respiratory tract infections: the ProHOSP randomized controlled trial. *JAMA* 2009; **302**: 1059–66.

26 Stolz D, Christ-Crain M, Bingisser R *et al*. Antibiotic treatment of exacerbations of COPD: a randomized, controlled trial comparing procalcitonin-guidance with standard therapy. *Chest* 2007; **131**: 9–19.

27 Oosterheert JJ, Van Loon AM, Schuurman R *et al*. Impact of rapid detection of viral and atypical bacterial pathogens by real-time polymerase chain reaction for patients with lower respiratory tract infection. *Clin Infect Dis* 2005; **41**: 1438–44.

28 Poehling KA, Zhu Y, Tang YW *et al*. Accuracy and impact of a point-of-care rapid influenza test in young children with respiratory illnesses. *Arch Pediatr Adolesc Med* 2006; **160**: 713–8.

29 Akenroye Ayobami T, Baskin Marc N, Samnaliev M *et al*. Impact of a bronchiolitis guideline on ED resource use and cost: a segmented time-series analysis. *Pediatrics* 2014; **133**: e227–34.

30 Mittal V, Darnell C, Walsh B *et al*. Inpatient bronchiolitis guideline implementation and resource utilization. *Pediatrics* 2014; **133**: e730–7.

31 van Kasteren ME, Mannien J, Kullberg BJ *et al*. Quality improvement of surgical prophylaxis in Dutch hospitals: evaluation of a multi-site intervention by time series analysis. *J Antimicrob Chemother* 2005; **56**: 1094–102.

32 Meyer E, Schwab F, Pollitt A *et al*. Impact of a change in antibiotic prophylaxis on total antibiotic use in a surgical intensive care unit. *Infection* 2010; **38**: 19–24.

33 Annane D, Maxime V, Faller JP *et al*. Procalcitonin levels to guide antibiotic therapy in adults with non-microbiologically proven apparent severe sepsis: a randomised controlled trial. *BMJ Open* 2013; **3**: e002186.

34 Bouadma L, Luyt CE, Tubach F *et al*. Use of procalcitonin to reduce patients' exposure to antibiotics in intensive care units (PRORATA trial): a multicentre randomised controlled trial. *Lancet* 2010; **375**: 463–74.

35 Hochreiter M, Kohler T, Schweiger AM *et al*. Procalcitonin to guide duration of antibiotic therapy in intensive care patients: a randomized prospective controlled trial. *Crit Care* 2009; **13**: R83.

36 Layios N, Lambermont B, Canivet JL *et al*. Procalcitonin usefulness for the initiation of antibiotic treatment in intensive care unit patients. *Crit Care Med* 2012; **40**: 2304–9.

37 Liu BH, Li HF, Lei Y *et al*. [Clinical significance of dynamic monitoring of procalcitonin in guiding the use of antibiotics in patients with sepsis in ICU]. *Zhonghua Wei Zhong Bing Ji Jiu Yi Xue* 2013; **25**: 690–3.

38 Nobre V, Harbarth S, Graf JD *et al*. Use of procalcitonin to shorten antibiotic treatment duration in septic patients: a randomized trial. *Am J Respir Crit Care Med* 2008; **177**: 498–505.

39 Oliveira CF, Botoni FA, Oliveira CRA *et al*. Procalcitonin versus C-reactive protein for guiding antibiotic therapy in sepsis: a randomized trial. *Crit Care Med* 2013; **41**: 2336–43.

40 Schroeder S, Hochreiter M, Koehler T *et al*. Procalcitonin (PCT)-guided algorithm reduces length of antibiotic treatment in surgical intensive care patients with severe sepsis: results of a prospective randomized study. *Langenbecks Arch Surg* 2009; **394**: 221–6.

41 Shehabi Y, Sterba M, Garrett PM *et al*. Procalcitonin algorithm in critically ill adults with undifferentiated infection or suspected sepsis. A randomized controlled trial. *Am J Respir Crit Care Med* 2014; **190**: 1102–10.

42 Stocker M, Fontana M, el Helou S *et al*. Use of procalcitonin-guided decision-making to shorten antibiotic therapy in suspected neonatal early-onset sepsis: prospective randomized intervention trial. *Neonatology* 2010; **97**: 165–74.

43 Stolz D, Smyrnios N, Eggimann P *et al*. Procalcitonin for reduced antibiotic exposure in ventilator-associated pneumonia: a randomised study. *Eur Respir J* 2009; **34**: 1364–75.

44 Bouza E, Torres MV, Radice C *et al*. Direct E-test (AB Biodisk) of respiratory samples improves antimicrobial use in ventilator-associated pneumonia. *Clin Infect Dis* 2007; **44**: 382–7.

45 Micek ST, Ward S, Fraser VJ *et al*. A randomized controlled trial of an antibiotic discontinuation policy for clinically suspected ventilator-associated pneumonia. *Chest* 2004; **125**: 1791–9.

46 Peto Z, Benko R, Matuz M *et al*. Results of a local antibiotic management program on antibiotic use in a tertiary intensive care unit in Hungary. *Infection* 2008; **36**: 560–4.

47 Meyer E, Buttler J, Schneider C *et al*. Modified guidelines impact on antibiotic use and costs: duration of treatment for pneumonia in a neurosurgical ICU is reduced. *J Antimicrob Chemother* 2007; **59**: 1148–54.

48 Cook PP, Rizzo S, Gooch M *et al*. Sustained reduction in antimicrobial use and decrease in methicillin-resistant *Staphylococcus aureus* and *Clostridium difficile* infections following implementation of an electronic medical record at a tertiary-care teaching hospital. *J Antimicrob Chemother* 2011; **66**: 205–9.

49 Danaher PJ, Milazzo NA, Kerr KJ *et al*. The antibiotic support team – a successful educational approach to antibiotic stewardship. *Mil Med* 2009; **174**: 201–5.

50 Jump R, Olds D, Seifi N *et al*. Effective antimicrobial stewardship in a long-term care facility through an infectious disease consultation service: keeping a LID on antibiotic use. *Infect Control Hosp Epidemiol* 2012; **33**: 1185–92.

51 Lesprit P, Landelle C, Brun-Buisson C. Clinical impact of unsolicited post-prescription antibiotic review in surgical and medical wards: a randomized controlled trial. *Clin Microbiol Infect* 2013; **19**: E91–7.

52 Newland JG, Stach LM, De Lurgio SA *et al*. Impact of a prospective-audit-with-feedback antimicrobial stewardship program at a children's hospital. *J Pediatr Infect Dis Soc* 2012; **1**: 179–86.

53 Chandy SJ, Naik GS, Charles R *et al*. The impact of policy guidelines on hospital antibiotic use over a decade: a segmented time series analysis. *PLoS One* 2014; **9**: e92206.

54 Schwartz DN, Abiad H, DeMarais PL *et al*. An educational intervention to improve antimicrobial use in a hospital-based long-term care facility. *J Am Geriatr Soc* 2007; **55**: 1236–42.

55 Kerremans JJ, Verboom P, Stijnen T *et al*. Rapid identification and antimicrobial susceptibility testing reduce antibiotic use and accelerate pathogen-directed antibiotic use. *J Antimicrob Chemother* 2008; **61**: 428–35.

56 Kristoffersen KB, Sogaard OS, Wejse C *et al*. Antibiotic treatment interruption of suspected lower respiratory tract infections based on a single procalcitonin measurement at hospital admission–a randomized trial. *Clin Microbiol Infect* 2009; **15**: 481–7.

57 Qu R, Ji Y, Ling Y *et al*. Procalcitonin is a good tool to guide duration of antibiotic therapy in patients with severe acute pancreatitis. A randomized prospective single-center controlled trial. *Saudi Med J* 2012; **33**: 382–7.

58 Charani E, Ahmad R, Rawson TM *et al*. The differences in antibiotic decision-making between acute surgical and acute medical teams: an ethnographic study of culture and team dynamics. *Clin Infect Dis* 2019; **69**: 12–20.

59 Charani E, Castro-Sanchez E, Sevdalis N *et al*. Understanding the determinants of antimicrobial prescribing within hospitals: the role of "prescribing etiquette". *Clin Infect Dis* 2013; **57**: 188–96.

60 Charani E, Tarrant C, Moorthy K *et al*. Understanding antibiotic decision making in surgery-a qualitative analysis. *Clin Microbiol Infect* 2017; **23**: 752–60.

61 Mattick K, Kelly N, Rees C. A window into the lives of junior doctors: narrative interviews exploring antimicrobial prescribing experiences. *J Antimicrob Chemother* 2014; **69**: 2274–83.

62 Brink A, Van den Bergh D, Mendelson M *et al*. Passing the baton to pharmacists and nurses: new models of antibiotic stewardship for South Africa? *S Afr Med J* 2016; **106**: 947–8.

63 Charani E, Cooke J, Holmes A. Antibiotic stewardship programmes–what's missing? *J Antimicrob Chemother* 2010; **65**: 2275–7.

64 Edwards R, Drumright LN, Kiernan M *et al*. Covering more territory to fight resistance: considering nurses' role in antimicrobial stewardship. *J Infect Prev* 2011; **12**: 6–10.

65 Hulscher ME, Grol RP, van der Meer JW. Antibiotic prescribing in hospitals: a social and behavioural scientific approach. *Lancet Infect Dis* 2010; **10**: 167–75.

66 Taylor MJ, McNicholas C, Nicolay C *et al*. Systematic review of the application of the plan-do-study-act method to improve quality in healthcare. *BMJ Qual Saf* 2014; **23**: 290–8.

67 Toma M, Davey P, Marwick C *et al*. A framework for ensuring a balanced accounting of the impact of antimicrobial stewardship interventions. *J Antimicrob Chemother* 2017; **72**: 3223–31.

68 Toma M, Dreischulte T, Gray NM *et al*. Balancing measures or a balanced accounting of improvement impact: a qualitative analysis of individual and focus group interviews with improvement experts in Scotland. *BMJ Qual Saf* 2018; **27**: 547–56.

69 Scottish Intercollegiate Guidelines Network (SIGN). *Antibiotic Prophylaxis in Surgery*. Published 2008, updated 2014. http://www.sign.ac.uk/pdf/sign104.pdf.

70 NICE. *Procalcitonin Testing for Diagnosing and Monitoring Sepsis (ADVIA Centaur BRAHMS PCT assay, BRAHMS PCT Sensitive Kryptor assay, Elecsys BRAHMS PCT assay, LIAISON BRAHMS PCT assay and VIDAS BRAHMS PCT assay)*. 2015. https://www.nice.org.uk/guidance/dg18.

71 Pulcini C, Binda F, Lamkang AS *et al*. Developing core elements and checklist items for global hospital antimicrobial stewardship programmes: a consensus approach. *Clin Microbiol Infect* 2019; **25**: 20–5.

72 Szymczak JE. Are surgeons different? The case for bespoke antimicrobial stewardship. *Clin Infect Dis* 2019; **69**: 21–3.

73 Fishbein M. Attitude and the prediction of behavior. In: *Readings in Attitude Theory and Measurement*. Wiley, 1967; 477–92.

74 Hoffmann TC, Glasziou PP, Boutron I *et al*. Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. *BMJ* 2014; **348**: g1687.

75 Presseau J, McCleary N, Lorencatto F *et al*. Action, actor, context, target, time (AACTT): a framework for specifying behaviour. *Implement Sci* 2019; **14**: 102.

76 Brink AJ, Messina AP, Feldman C *et al*. Antimicrobial stewardship across 47 South African hospitals: an implementation study. *Lancet Infect Dis* 2016; **16**: 1017–25.

77 Lorencatto F, Charani E, Sevdalis N *et al*. Driving sustainable change in antimicrobial prescribing practice: how can social and behavioural sciences help? *J Antimicrob Chemother* 2018; **73**: 2613–24.