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Implementation, adoption and impact of clinical decision support system for antibiotic prescribing in primary care: a systematic review

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Background: Clinical decision support systems (CDSS), computerized tools that assist clinicians in making guideline-based decisions, may support antimicrobial prescribing in primary care.

Methods: Studies on CDSS implementation, use and outcomes in primary care on PubMed/MEDLINE and Embase were included up to June 2025.

Results: Of the 64 full-text articles assessed, 40 were included. Most were multicentric ($n=33$, 82.5%) and conducted in high-income countries ($n=33$, 82.5%), and 19 were randomized controlled trials (47.5%). CDSS mainly targeted respiratory infections ($n=24$, 60%) and were integrated into electronic health records in 24 studies (60%). Implementation strategies were assessed in 19 studies with almost all using a multimodal approach, most commonly involving modification of health record systems ($n=18$, 45%) and audit and feedback ($n=17$, 42.5%). Adoption was highly variable: among the 11 studies reporting use, CDSS were used in more than half of consultations in only five studies. Among the 32 studies assessing clinical outcomes, 17 reported reduced overall antibiotic prescribing. Barriers to CDSS use included perceptions of redundancy, time consumption, language limitations, alert fatigue, technical issues and concerns about negative impacts on patient–doctors trust.

Conclusion: CDSS may improve guideline-concordant antibiotic prescribing in primary care, but wide variability in implementation and real-world adoption limits generalizability and scalability

Introduction

Antimicrobial resistance (AMR) is recognized as one of the top 10 global health threats, with an estimated 38 710 deaths annually, according to the ECDC report.[1] The inappropriate use of antibiotics is a major contributor to this issue, highlighting the need for effective antimicrobial stewardship programmes (ASPs) to optimize antibiotic prescribing and improve patient outcomes.[2] As a result, ASPs have been implemented to optimize antibiotic prescribing and enhance clinical outcomes. Clinical decision support systems (CDSS) are a key strategy within ASPs.

CDSS are computerized tools designed to assist clinicians in making diagnostic and therapeutic decisions,[3,4] ultimately optimizing clinical practice and healthcare quality. These systems provide rapid and easy access to the latest medical knowledge and evidence-based guidelines at the point of care. Studies across various medical disciplines have demonstrated that CDSS improve appropriate care, preventive services, clinical outcomes and healthcare costs.[5] In the field of infectious diseases, CDSS have been increasingly used by expert and non-expert physicians to support infection management and antibiotic prescribing. Their implementation in hospital settings has shown effectiveness in reducing overall antibiotic use,[6] broad-spectrum

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antibiotic consumption[7] and promoting appropriate prescribing. Moreover, CDSS have contributed to fewer adverse events, lower mortality rates[8] and reduced healthcare costs.[9]

However, in Europe, 80%–90% of antibiotic prescriptions occur outside of hospital settings.[10] In England, nearly 25% of antibiotic prescriptions in primary care are considered inappropriate.[11] Despite most antibiotic prescriptions occurring in primary care, evidence regarding the use of CDSS in community settings remains limited.[12] Nevertheless, there are promising indications that CDSS can improve antibiotic prescribing behaviour in primary care settings.[13]

A previous systematic review by Holstiege *et al.*,[13] which included seven studies, demonstrated promising effectiveness of CDSS in improving antibiotic prescribing behaviour in primary care settings. Similarly, another systematic review by Carracedo-Martinez *et al.*[14] reported statistically significant improvements associated with CDSS use, including antibiotic prescribing rates in hospitals, better adherence to antibiotic prescribing guidelines in both primary care and hospital settings and a reduction in inappropriate antibiotic prescriptions in primary care.

Unlike previous reviews that have primarily evaluated the effectiveness of CDSS in improving antibiotic prescribing, this review offers a broader perspective by integrating evidence on clinical outcomes, adoption and implementation factors from quantitative and qualitative studies across diverse CDSS platforms and healthcare settings, including high-income countries (HICs) and low–middle-income countries (LMICs).

Materials and methods

Study selection

CDSS are defined as software tools that use patient-specific information to provide clinicians with tailored assessments or recommendations to support diagnostic or treatment decisions.[13] All studies assessing CDSS implementation strategies and/or their effectiveness in improving antibiotic prescribing practices in primary care were included in this review. Eligible designs included prospective and retrospective original research, such as randomized controlled trials (RCTs) (including cluster-randomized trials), as well as non-randomized studies (case–control, cross-sectional, cohort, before–after and interrupted time series), mixed-methods and qualitative research. Studies were excluded if they focused on CDSS implementation or impact in secondary or tertiary care settings, or if they assessed diagnostic or therapeutic tools (e.g. scores or scales) not integrated into a CDSS.

Population, intervention, comparator, outcomes

Selected studies examined CDSS for guiding diagnosis and/or treatment of infections in primary care and evaluated either implementation strategies or impact on antibiotic prescribing. Eligible study populations included primary care providers, facilities and/or prescribers involved in the use of CDSS as a decision-making tool. The intervention consisted in the implementation of CDSS strategies in primary care settings. Comparators included standard patient care or other antimicrobial stewardship interventions used in primary care. Implementation outcomes included acceptance or usage rates and qualitative feedback. Clinical outcomes encompassed reductions in total or broad-spectrum antibiotic use, greater first-line prescribing, improved patient outcomes and better adherence to clinical guidelines. This study was recorded on the international database of prospectively registered systematic reviews, PROSPERO (registration number: CRD42021274251).

Search strategy

A comprehensive literature search was conducted across the following databases: PubMed/MEDLINE, Embase, Cochrane and Web of Science. The search was guided by a combination of indexed terms (MeSH) and relevant keywords related to antimicrobial agents, common infections, primary care settings, CDSS and electronic health records (EHRs), as well as their synonyms. A detailed search strategy is available in Table S1 (available as Supplementary data at *JAC* Online). Last search was in June 2025.

Data extraction

Two reviewers (CD, EC) independently screened titles/abstracts and full texts for eligibility. Data extraction was performed by one reviewer (RI) and then verified by a second reviewer (NP-S). Key data collected included general study information, setting, characteristics of healthcare professionals and patients, details of the intervention and CDSS platform, system features and specific outcomes.

Risk of bias and quality assessment

The methodological quality of the included studies was assessed using the Integrated Quality Criteria for Systematic Review of Multiple Study Designs (ICROMS) framework according to Zingg *et al.*[15] Risk of bias was independently evaluated by two reviewers, and disagreements were resolved through discussion, with a third reviewer consulted if necessary. All included studies were classified according to their study design and then evaluated if they met the quality mandatory criteria and the minimum score required for each design.

Strategy for data synthesis

Data from primary and secondary outcomes were described using narrative synthesis. Qualitative data were thematically analysed. A detailed summary of each study's data was presented in tables. Quantitative data were expressed as absolute numbers, proportions and medians with interquartile ranges. A meta-analysis was not conducted in this review due to substantial heterogeneity in comparators and outcome measures, even among the RCTs.

Results

Study selection

Full-text eligibility was assessed for 64 studies, of which 40 provided original data and were therefore included in the review (Figure 1). All studies were published between 2000 and 2025, with 35 published after 2010.

Study settings and quality assessment

Out of the 40 selected studies, 19 (47.5%) were RCTs. Other study designs included seven non-controlled before–after (NCBA) (quasi-experimental) studies (17.5%), five qualitative studies (12.5%), four non-controlled interrupted time series (NCITS) (10%), four cohort studies (CSs), and one controlled before–after study (CBA) (Figure 2).

Most studies were multicentric, involving multiple primary care facilities ($n=33$, 82.5%). The most frequently targeted infections by CDSS were respiratory infections, including pharyngitis and sinusitis ($n=24$, 60%), followed by urinary tract infections ($n=6$, 15%) and otitis media ($n=3$, 7.5%). Among the 40 studies, CDSS guided treatment decisions in 24 studies (60%), diagnosis in seven studies (17.5%) and both treatment and diagnosis in nine

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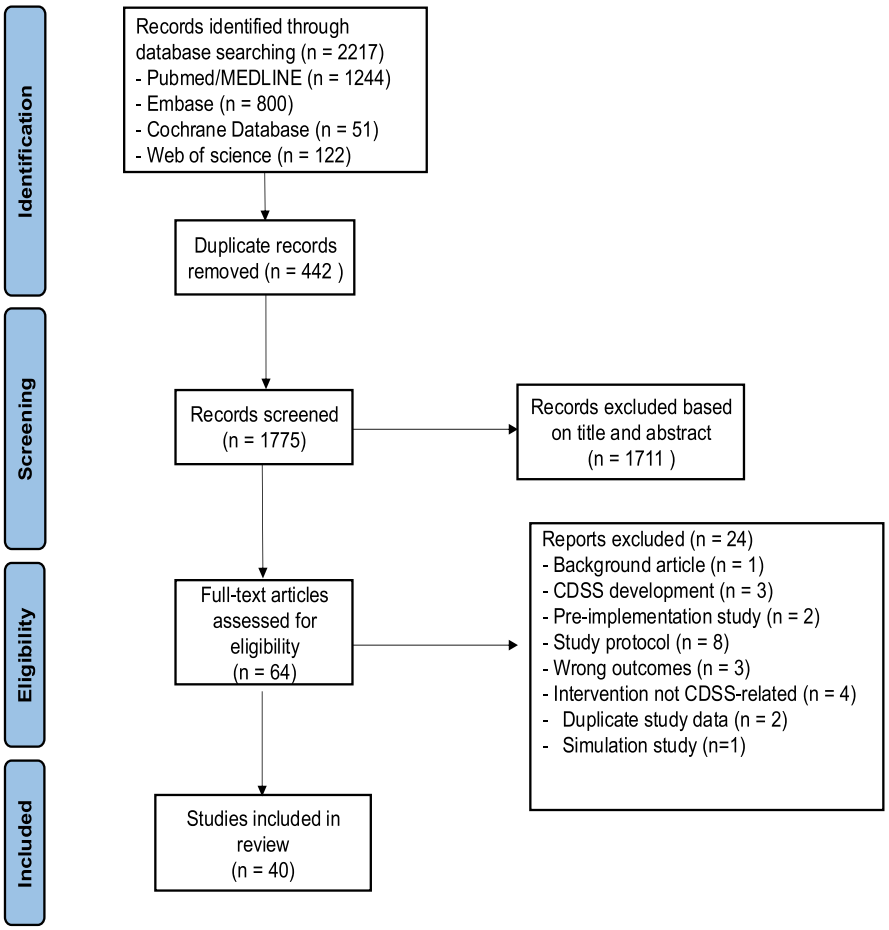


Figure 1. The PRISMA flow diagram of study selection for the systematic review on evaluation of the impact, adoption and implementation of CDSS use in primary care.

studies (22.5%). The majority of the studies ($n=33$, 82%) took place in HICs, distributed as follows: USA ($n=22$), UK ($n=5$), Spain ($n=1$), Australia ($n=1$), Norway ($n=1$) and the Netherlands ($n=1$). The remaining seven studies (17.5%) took place in LMICs (Table 1).

In 24 studies (60%), the CDSS was integrated into EHR, especially in HICs, which streamlined its use during patient visits. Other platforms included web-based tools ($n=3$, 7.5%), mobile or tablet applications ($n=7$, 17.5%) and personal digital assistants ($n=3$, 7.5%).

Primary care providers involved in the studies were mostly general practitioners (GPs) or family medicine physicians ($n=26$, 65%), residents ($n=8$, 20%), nurse practitioners ($n=12$, 30%), physician assistants ($n=10$, 25%) and pharmacists ($n=3$, 7.5%) (Table 1).

Risk of bias was evaluated using ICROMS (Figure 2). All studies met the mandatory criteria and minimum required score, except for one non-controlled before–after study, which failed to meet either.[52] However, 13 of the 18 RCTs (72%) partially met the mandatory criteria, mainly due to inadequate blinding, and one study failed to meet the mandatory criteria despite achieving the minimum required score.[22] A detailed quality assessment using ICROMS can be found in Table S2.

Implementation strategies for CDSS

Of the 40 included studies, 19 (47.5%) assessed CDSS implementation. This included qualitative evaluations of the implementation process ($n=11$) and assessments of CDSS adoption ($n=17$), with nine studies addressing both dimensions. A total of 32 studies (80%) assessed the impact on antibiotic prescribing. Eleven studies (27%) evaluated both the implementation strategy and its impact on antibiotic prescribing, as shown in Table 2.

Various methods were employed to integrate CDSS into primary care settings, such as reminders for clinicians about current treatment guidelines and training on how to effectively use the tool during consultations. Nearly all studies used a multimodal implementation strategy. According to the Expert Recommendations for Implementing Change (ERIC), the strategies included changes to record systems ($n=18$, 45%), audit and feedback ($n=17$, 42.5%), educational meetings ($n=11$,

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	Study design	Mandatory criteria met?	Minimal score met?
Litvin et al, 2013	NCITS		Yes (48)
Daley et al, 2020	NCITS		Yes (42)
Hingorani et al, 2015	NCITS		Yes (28)
Forrest et al, 2013	RCT		Yes (60)
May et al, 2021	NCBA		Yes (32)
Mann et al, 2020	RCT		Yes (52)
McCormick et al, 2020	CS (retrospective)		Yes (34)
Figueiras et al, 2020	RCT		Yes (48)
Mainous et al, 2013	NCBA (quasi experimental)		Yes (51)
Blair et al, 2017	RCT		Yes (31)
Madaras-kelly et al, 2006	CS		Yes (20)
Gulliford et al, 2019	RCT		Yes (43)
Guillford et al, 2014	RCT		Yes (40)
McGinn et al, 2013	RCT		Yes (31)
Linder et al, 2017	RCT		Yes (55)
Meeker et al, 2016	RCT		Yes (61)
Gulliford et al, 2019	RCT		Yes (37)
Linder et al, 2009	RCT		Yes (24)
Gifford et al, 2017	CS (retrospective)		Yes (24)
Samore et al, 2005	RCT		Yes (54)
Fiks et al, 2015	RCT		Yes (26)
Christakis et al, 2001	RCT		Yes (26)
Gonzales et al, 2013	RCT		Yes (39)
Giancola et al, 2020	NCITS		Yes (31)
Keitel et al, 2019	RCT		Yes (42)
Bernasconi et al, 2019	NCBA (quasi experimental)		Yes (28)
Mcdermott et al, 2014	RCT		Yes (28)
Bessat et al, 2019	Qualitative		Yes (36)
Biezen et al, 2021	Qualitative		Yes (38)
Litvin et al, 2012	Qualitative		Yes (47)
Delory et al, 2020	Qualitative		Yes (28)
Rubin et al, 2006	NCBA		Yes (28)
Flottorp et al, 2003	NCBA		Yes (43)
Elligton et al, 2021	Qualitative		Yes (38)
Jeanmougin et al, 2024	RCT		Yes (38)
Schmitz et al, 2021	CBA		Yes (23)
Herter et al, 2022	CS		Yes (55)
Karas et al, 2023	NCBA		No (16)
Hurlimann et al, 2024	NCBA		No (20)
Tan et al, 2024	RCT		Yes (22)

RCT: Randomized controlled trials; NCTIS : Non-controlled interrupted time series ; CBA : Controlled before-after ; NCBA : Non-Controlled before-after ; CS : Cohort study

Green cell : All mandatory criteria are met; Orange cell: only one mandatory criteria not met or partially met; Red cell: more than one mandatory criteria not met or partially met.

Figure 2. Risk of bias assessment for the studies included in the systematic review on the evaluation of CDSS use for antimicrobial stewardship in primary care according to the ICROMS framework.

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Table 1. Characteristics of included studies in the systematic review on evaluation of the impact, adoption and implementation of CDSS in primary care

Study characteristics	Number $n=40$ (%)
Country	
High-income countries	33 (82)
USA	22 (55)
UK	5 (12)
France	2 (5)
Spain	1 (2)
Australia	1 (2)
Norway	1 (2)
The Netherlands	1 (2)
Low–middle-income countries	7 (17)
Tanzania	2 (5)
Nigeria	2 (5)
Burkina Faso	1 (2)
Uganda	1 (2)
Somalia	1 (2)
Settings	
Multicentric	33 (82)
Monocentric	4 (10)
NA	3 (7)
Type of infection	
Respiratory infection (including pharyngitis, sinusitis)	24 (60)
Uncomplicated urinary tract infection	6 (15)
Otitis media	3 (7.5)
Unspecified	8 (20)
CDSS infrastructures	
CDSS integrated in electronic health record	24 (60)
Data mined from electronic medical record	2 (5)
CDSS integrated in existing practice software	1 (2.5)
Web-based tool	3 (7.5)
Personal digital assistance	3 (7.5)
Mobile/tablet-based tool	7 (17.5)
End users of the CDSS	
General practitioners	26 (65)
Physician's assistant	12 (30)
Nurse practitioners	10 (25)
Residents	8 (20)
Paediatricians	3 (7.5)
Pharmacists	3 (7.5)
Unspecified	15 (37.5)

27.5%), use of educational materials ($n=13$, 32.5%), outreach visits ($n=10$, 25%), patients and family's involvement ($n=5$, 12.5%), prompts and reminders ($n=7$, 17.5%) and use of mass media ($n=2$, 5%) (Figure 3).

CDSS adoption by primary healthcare providers

Among the 19 studies that assessed CDSS implementation, 11 (58%) reported quantitative data on tool usage or acceptance, while the remaining studies relied on qualitative feedback from healthcare providers. Usage rates were distributed as follows: five studies (26%) reported usage in more than 50% of visits,[7,28,34,45,46] three studies (16%) reported usage between 20% and 50%[17,26,47] and another three (16%) reported usage below 20%.[20,25,32] Additionally, two studies (10.5%) described low adoption without specifying exact rates,[27,31] while three studies (16%) reported high usage but did not provide numerical data.[24,42,43] (Table 2) Several studies have explored qualitative input from CDSS users. Positive aspects included **awareness of the intervention,**[41] the perception that **prompts were non-intrusive** and that the **patient leaflet was useful for reassurance,**[41] the **provision of feedback reports**[35,43] and the **stimulation of patient–clinician discussions.**[7] Delory *et al*. further reported that **most GPs felt comfortable using the CDSS during consultations**.[45] Conversely, primary care providers highlighted several barriers to CDSS use, such as **perceiving prompts as unnecessary or redundant with existing guidelines,**[20,27,31] finding the tool **time-consuming,**[20,24,31,42] facing **language barriers,**[42] experiencing **alert fatigue**[20] and encountering **technical difficulties.**[42,43] These issues may also **undermine patient–provider trust and communication** during consultations[48] (Table 2).

Clinical outcomes on antibiotic prescribing and guidelines adherence

Out of the 40 studies included, 32 (80%) assessed the impact of CDSS on antibiotic prescribing behaviour and/or adherence to guidelines. Among these 32, 17 studies reported a reduction in overall antibiotic prescribing,[23,26–34,37,39,40,49,50,53,54] three reported a decrease in the use of broad-spectrum antibiotics[7,22,23] and four reported an increase in the use of first-line antibiotics.[16,21,25,52] Litvin *et al*. (2013) showed a decrease in broad-spectrum antibiotic use [estimated 27 months change, −16.30%, (95% CI, −25%, −8%) in adults], while Daley *et al*. showed an increase in first-line antibiotic prescription rate for urinary tract infection (46.3% pre-intervention versus 67.8% post-intervention, $P<0.0001$). Furthermore, May *et al*. have shown a decrease in azithromycin prescription by 12.6% from the pre- and post-intervention (81% versus 69%, $P<0.001$). Additionally, four out of five studies examining guideline adherence showed improved compliance with antibiotic prescribing guidelines.[17,33,35,38] Four studies investigated patient clinical outcomes, showing as successful treatment in CDSS groups,[21,32] no secondary hospitalization or death[36,41] and one indicating a reduction in bacterial complications associated with CDSS use.[31] Giancola *et al*. showed an increase in guideline adherence to the duration of therapy from 29% to 76% ($P<0.01$) (Table 2).

CDSS outcomes: subgroup analysis

CDSS outcome according to adoption rate

Among the eight studies reporting high adoption rates, three evaluated clinical outcomes, of which two reported improvements in antibiotic prescribing and guideline adherence.[28,34] Among the three studies reporting intermediate adoption rates, two demonstrated a positive impact on antibiotic prescribing.[17,26] Of the five studies reporting low adoption rates, four

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Table 2. Evaluation of CDSS impact on antibiotic prescribing, CDSS adoption and implementation strategies evaluation by primary care providers in the systematic review on the evaluation of CDSS use in primary care

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
Litvin *et al.*, USA, demonstration project[7]	2013	Diagnosis and Treatment	ARI	Decrease in broad-spectrum antibiotic use (estimated 27 months change, −16.30%, [95% CI, −24.81%, −7.79%] in adults	ND	ND
Daley *et al.*, USA, interrupted time series[16]	2020	Treatment	UTI	Increase in first-line antibiotic prescription rate for UTI (46.3% pre-intervention versus 67.8% post-intervention, $P<0.0001$)	ND	ND
May *et al.*, USA, quality improvement study[19]	2015	Treatment	Bronchitis, sinusitis	Decrease in azithromycin prescription by 12.6% from the pre- and post-intervention (81.4% versus 68.8%, $P<0.001$)	ND	ND
Mann *et al.*, USA, RCT[20]	2020	Diagnosis	Pharyngitis and respiratory infection	No statistically significant difference for antibiotic prescription ($P=0.781$)	CDSS used in 6.9% of the visits only.	Factors: 'alert fatigue', many alerts are targeting primary care providers through EHR
Mccormick *et al.*, USA, retrospective study[21]	2020	Treatment	UTI	Improved appropriate use of first-line antibiotic and appropriate duration and dose (37% versus 71.6% post-intervention, $P<0.001$)	ND	ND
Figueiras *et al.*, Spain, cluster RCT[22]	2020	Treatment	ARI	Decrease in antibiotic prescription −4.2% (95% CI: −5.3% to −3.2%) after intervention especially for penicillin and overall broad-spectrum antibiotic prescription. −9.0% (95% CI: −14.0% to −4.1%)	ND	ND
Mainous *et al.*, USA, quasi-experimental design[23]	2013	Treatment	ARI	Decline in inappropriate antibiotic use in intervention practices versus control ($P=0.03$) Decline in broad-spectrum antibiotic use ($P<0.0001$)	ND	ND
Blair *et al.*, UK, RCT[24]	2017	Treatment	ARI	Antibiotic prescribing was higher in the children's intervention group (25%) compared to the control group (15.8%, $P=0.018$). Children in the intervention arm were younger (median age 2 versus 3 years, $P=0.03$) and had more severe illness	Widely used but often post-consultation	Physicians reported that it was quick and easy, despite its added 5 min time to consultation
Gulliford *et al.*, UK, cluster RCT[26]	2019	Treatment	ARI	Reduction in antibiotic prescribing rate in adults aged between 15 and 84 years (RR 0.84, 95% CI 0.75–0.95)	Increase in CDSS use from 1% to 28% throughout the study	ND

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Table 2. *Continued*

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
Gulliford *et al.*, UK and Scotland, cluster RCT[27]	2014	Treatment	ARI	There was a 1.85% reduction in consultations resulting in antibiotic prescriptions (95% CI: 0.10%–3.59%, $P=0.038$), and 9.69% fewer prescriptions per 1000 patient-years (95% CI: 0.75%–18.63%, $P=0.034$)	Low use rate	It was not necessary for physicians to access the support tools at every consultation
McGinn *et al.*, USA, RCT[28]	2013	Diagnosis	Pneumonia and streptococcal pharyngitis	Less antibiotic orders in intervention group (age-adjusted relative risk, 0.74; 95% CI, 0.60–0.92)	62.8% having opened the tool and 57.5% of providers accepting the tool	ND
Linder *et al.*, USA, RCT[29]	2017	Treatment	ARI	Inappropriate antibiotic prescribing decreased in control clinics (14.2%–11.8%, −2.4%), but slightly increased for suggested alternatives (7.4%–8.8%, +1.4%). The difference-in-differences was 3.8% (95% CI: −10.3%–17.9%, $P=0.55$), indicating no statistically significant effect	ND	ND
Meeker *et al.*, USA, RCT[30]	2016	Treatment	ARI	Decrease in antibiotic prescription rate from 24.1% to 13.1% at intervention month 18 (absolute difference, −11.0%)	ND	ND
Gulliford *et al.*, UK, RCT[31]	2019	Treatment	ARI	Reduction in antibiotic prescription most in adults aged 15–84 years (adjusted ratio, 0.84; 95% confidence interval, 0.75–0.95). No evidence of an increase in serious bacterial complications (0.92, 0.74–1.13)	Low-rate use	Some GPs' comments: comfortable with ARI management without CDSS use; time-consuming, loss of autonomy. Feel pressure to not prescribe antibiotics
Linder *et al.*, USA, RCT[32]	2009	Diagnosis	ARI	Lower antibiotic prescribing rate for acute bronchitis associated with the ARI Smart Form use (OR, 0.5; 95% CI, 0.3–0.8) and in overall antibiotic use	CDSS was used in only 6% of visits	ND
Samore *et al.*, USA, RCT[34]	2005	Diagnosis and treatment	ARI	Decrease in inappropriate antibiotic prescription from 84.1 to 75.3 per 100 person-years in the CDSS arm, versus 84.3 to 85.2 in community intervention alone, $P=0.03$	Participation to the intervention in 71% of visits	ND
Christakis *et al.*, USA, RCT[36]	2001	Treatment	Otitis media	Reduction of 34% in the proportion of time they prescribed antibiotics for <10 days among intervention providers	ND	ND

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Table 2. *Continued*

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
Gonzales *et al.*, USA, RCT[37]	2013	Treatment	Acute bronchitis	Antibiotic prescriptions decreased at both printed decision support sites (from 80.0% to 68.3%) and computer-assisted sites (from 74.0% to 60.7%) compared to control sites, with statistically significant differences ($P<0.03$)	ND	ND
Keitel *et al.*, Tanzania, RCT[39]	2019	Treatment	ARI	Less antibiotic use for children in the intervention arm 2.3% versus 40.4% in the control arm received antibiotics at D0 [RR, 0.06 (95% CI, 0.04–0.09)]. There were fewer secondary hospitalizations and deaths in the intervention arm: 0.5% (4/865) versus 1.5% (13/854) [RR, 0.30 (95% CI, 0.10–0.93)]	ND	ND
Bernasconi *et al.*, Nigeria, cross-sectional study[40]	2019	Diagnosis	Not specified	Use of clinical decision support (CDS) led to a reduction in antibiotic prescriptions for infants (69.3% versus 77.7%, $P<0.05$) and a significant decrease in inappropriate antibiotic use compared to baseline ($P<0.01$)	ND	ND
Jeanmougin *et al.*, France, RCT[49]	2024	Treatment	Tonsillitis, cystitis	Decrease in the mean volume of systemic antibiotics per GP by 219.2 (SD, 61.4; 95% CI, −339.5 to −98.8; $P<0.001$) defined daily doses in the CDSS-based visit group compared with the control group	ND	ND
Schmitz *et al.*, Nigeria, observational study[50]	2021	Diagnosis	Not specified	Children at ALMANACH facilities had significantly higher caregiver-reported recovery (adjusted OR = 2.63; 95% CI, 1.60–4.32). These facilities also showed higher parenteral (OR = 2.42) and lower oral (OR = 0.40) antimicrobial prescription rates	ND	ND
Herter *et al.*, prospective study[51]	2022	Treatment	UTI	Treatment practices saw a significant increase in successful treatments from 75% to 80% during the pilot ($z=5.47$; $P<0.001$), while control practices showed no change (76% before and during, $P=0.98$). Overall, success rates in treatment practices rose to 83% during the study—significantly higher than the 75% before ($z=4.95$; $P<0.001$)	ND	ND
Hingorani *et al.*, USA, quality improvement process[17]	2015	Diagnosis and treatment	ARI	Improvement in the adherence rate to 90.90% for sinusitis ($P<0.001$), 64.28% for pharyngitis ($P=0.003$), and 96.18% for URI ($P=0.008$)	The CDS tool being used in 39.7% of encounters	ND

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Table 2. *Continued*

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
Forrest *et al.*, USA, RCT[18]	2013	Diagnosis and treatment	Acute otitis media	No change in adherence in the CDS group, significant change in guideline adherence in the feedback group	ND	ND
Gifford *et al.*, USA, retrospective study[33]	2017	Treatment	ARI	There was no change in guideline concordance for azithromycin. However, concordance for fluoroquinolones dropped significantly from 88.6% to 51.3% ($P<0.005$), and for 'all other antibiotics', adjusted odds of concordance decreased notably from 24.4 to 5.5 ($P=0.008$)	ND	ND
Fiks *et al.*, USA, prospective study[35]	2015	Treatment	Otitis media	Increased guideline adherence among CDS users	Clinicians and practices used the CDS system for a mean of 21% (range: 0%–85%) and 17% (0%–51%)	Performance feedback increased CDS use of 9.0 percentage points compared to others ($P=0.001$)
Giancola *et al.*, USA, RCT[38]	2020	Treatment	Uncomplicated cystitis	Increase in guideline adherence to duration of therapy from 29.4% to 76.3%, $P<0.01$	ND	ND
Madaras-kelly *et al.*, USA, cohort study[25]	2006	Treatment	ARI	The PCPs who were contacted by pharmacists were receptive to altering the BSA to first-line antimicrobial therapy, such as amoxicillin or doxycycline	Only 7% of patients agreed to the intervention	ND
Karas *et al.*, USA, quality improvement study[52]	2023	Diagnosis and treatment	UTI	First-line antibiotic use increased, with cephalexin use rising from 27.5% to 74.8%. Use of trimethoprim/sulfamethoxazole dropped from 31.8% to 8.1%, and amoxicillin decreased by 72%	ND	ND
Hurlimann *et al.*, 2024, Somalia, before–after study[53]		Diagnosis	Not specified	After introducing ALMANACH in health facilities, children were nearly four times less likely to receive antibiotics (RR = 0.27). Unnecessary antibiotic treatment for URTIs dropped dramatically by a factor of 30	ND	ND
Tan *et al.*, 2023, Tanzania, RCT[54]		Diagnosis	Not specified	Use of ePOCT + significantly reduced antibiotic prescriptions (23.2% versus 70.1%), with a 46.4% adjusted reduction. Clinical outcomes at day 7 were noninferior to usual care, and there were no differences in secondary safety outcomes, such as death or hospitalizations	ND	ND

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Table 2. *Continued*

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
McDermott *et al.*, UK, RCT[41]	2014	Treatment	ARI	ND	ND	GPs found the prompts usable and grounded in theory. Those in the intervention group reported greater confidence (self-efficacy) in managing RTI patients according to recommended guidelines than those in the control group
Bessat *et al.*, Burkina Faso, qualitative study[42]	2019	Diagnosis and treatment	Not specified	ND	Widely accepted	The intervention led to improvements in patient management and more rational antibiotic use, positive organizational changes, including task shifting and better triage. Limitations included slow device performance, which extended consultation times, and the tool being available in only one language
Biezen *et al.*, Australia, qualitative study[43]	2021	Treatment	Not specified	ND	Acceptable to most GPs	Positive reported points: enthusiastic practice-wide approach, positive practice champions and the passion to reduce inappropriate antibiotic prescribing. limitation: technical issues

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Table 2. *Continued*

Study	Year	Decision support	Infection type	Impact on antibiotic prescribing and/or guidelines adherence	CDSS adoption	Implementation process evaluation
Litvin *et al.*, USA, quality improvement study[44]	2012	Diagnosis and treatment	ARI, pharyngitis	ND	Median use of the CDSS for adult patients was 58.2% and 68.6% for paediatric	Factors promoting CDSS adoption: helped decision-making, stimulates patient discussions, engagement of non-physician staff and an iterative tool development process
Delory *et al.*, France, qualitative study[45]	2020	Treatment	Not specified	ND	96% of responding GPs used the CDSS during consultations. 93% followed the CDSS recommendations	Most GPs were comfortable using the CDSS in front of a patient
Rubin *et al.*, USA, observational study[46]	2006	Diagnosis and treatment	Not specified	ND	Providers logged 14 393 cases using the CDSS, the majority of which ($n=7624$; 53%) were from family practitioners	ND
Flottorp *et al.*, Norway, observational study[47]	2003	Treatment	UTI, pharyngitis	ND	75% agreed to participate, but only 33% met to discuss the guidelines. The CDSS adoption rate was 48%	ND
Elligton *et al.*, Uganda, qualitative study[48]	2021	Diagnosis and treatment	ARI	ND	ND	Health workers showed strong interest in using ALRITE, appreciating its reminders for key medical questions and exams. However, some GPs expressed concern that it could affect patient–provider relationships and trust

AMR, antimicrobial resistance; ARI, acute respiratory infection; ASP, antimicrobial stewardship programmes; EHR, electronic health record; LMICs, low–middle-income countries; ND, not determined; RCT, randomized controlled trial; UTI, urinary tract infection.

showed reductions in antibiotic prescribing despite limited CDSS use,[25,27,31,32] whereas one found no significant effect on prescribing behaviour.[20]

CDSS outcomes according to platform integration (EHR versus non-EHR)

Twenty-four studies evaluated CDSS integrated within EHRs, whereas 16 assessed alternative platforms, including web-based tools, mobile or tablet applications, personal digital assistants or standalone software. Among the 24 studies evaluating EHR-integrated CDSS, 21 assessed clinical outcomes, of which 19 (90.5%) reported positive effects on antibiotic prescribing or guideline adherence. Among studies evaluating non–EHR-based CDSS, 11 assessed clinical outcomes, with 10 (90.9%) reporting positive prescribing outcomes. Overall, both EHR-integrated and non–EHR-based CDSS demonstrated favourable effects on antibiotic prescribing outcomes.

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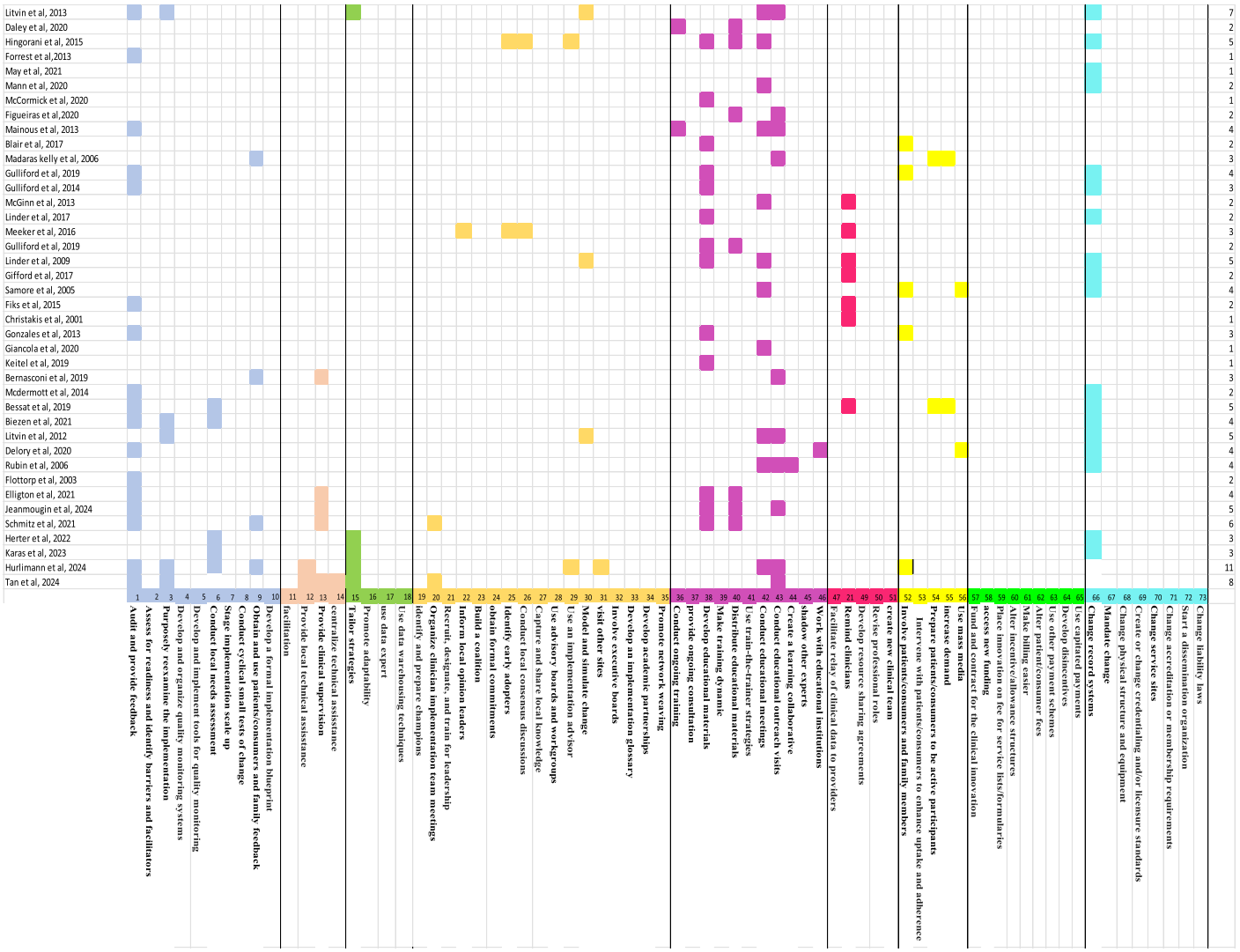


Figure 3. Implementation strategies according to the ERIC for the systematic review on evaluation of CDSS use for antimicrobial stewardship in primary care.

CDSS outcomes according to country income level

Among studies assessing clinical outcomes, positive effects on antibiotic prescribing or guideline adherence were reported in 75% and 71% of studies, respectively. In LMICs, reported benefits included substantial reductions in antibiotic prescribing, improved adherence to clinical algorithms and better patient outcomes. However, qualitative evaluations from LMIC settings more frequently highlighted implementation challenges, including technical difficulties, language barriers and resource constraints. Notably, CDSS implemented in LMIC settings were predominantly non-EHR based ($n=6$).

Discussion

This review provides a broad overview of CDSS use in primary care. It showed significant improvements in antibiotic prescribing practices and adherence to guidelines, even with low to moderate use of the CDSS reported in many studies. The diversity of implementation strategies makes it difficult to determine whether the positive outcomes are due solely to CDSS use or also to other components of the implementation process. As a result, it is difficult to isolate the specific impact of the tool from all the complementary approaches.

Awareness and education prior to implementation

Promoting awareness of the intervention and establishing clear communication before the implementation of CDSS is crucial for fostering its use among GPs. Many studies have shown that educating healthcare providers about the tool and its benefits can lead to higher adoption rates. For example, decision-making prompts were particularly helpful for less experienced clinicians but less relevant for seasoned physicians managing common infections, such as respiratory diseases. For seasoned GPs, intrusive prompts may potentially lead to a lower adoption rate.

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Thus, GPs may prefer optional and not time-consuming prompts. Such features ensure that CDSS remains a supportive tool rather than an additional burden on clinicians' already busy schedules.[41]

Implementation strategies and feedback mechanisms

Effective implementation strategies, such as the use of the Plan-Do-Study-Act (PDSA) cycle, have been shown to significantly increase GP adoption rates of CDSS tools. Hingorani *et al.*[17] demonstrated that integrating the PDSA cycle within a quality improvement process led to improvements in guideline adherence and greater CDSS adoption among healthcare providers. The PDSA approach, which emphasizes iterative changes based on identified problems, helps ensure that the CDSS is continually refined to meet the needs of clinicians and integrate smoothly into their practices. This iterative process is particularly beneficial when CDSS is introduced as part of a residency programme, fostering adoption early in a physician's career and reinforcing best practices in antimicrobial prescribing.[17] Furthermore, feedback reports about guideline adherence can have a significant impact on prescribing practices. Forrest *et al.*[18] and Biezen *et al.*[43] both found that when physicians received feedback on their adherence to clinical guidelines, their prescribing behaviours improved. Similarly, Fiks *et al.*[35] demonstrated a 9.0 percentage point increase in CDSS use when physicians were provided with performance feedback. These findings underscore the importance of feedback mechanisms in driving behavioural change and improving the effectiveness of CDSS in promoting appropriate antibiotic use.[18,35,43]

Barriers to CDSS adoption and use

Despite the advantages of CDSS, several barriers hinder its widespread adoption. One of the most reported challenges is 'alert fatigue', as highlighted in studies by Mann *et al.* Frequent prompts during GP visits can overwhelm clinicians, leading them to ignore or disable the alerts altogether. In addition, some physicians exhibit overconfidence in their clinical judgement, believing that they do not require guideline reminders about antibiotic use. Addressing these concerns requires not only improving the design of CDSS to reduce unnecessary alerts but also fostering a culture of continuous learning and reflection on antibiotic prescribing.[20,26] Another barrier to the successful implementation of CDSS is its integration into clinicians' workflow. Web-based tools, while convenient, have been shown to be used less frequently or postponed until after consultations.[24] In contrast, CDSS integrated into EHR systems tend to be more effective, as it becomes a seamless part of the clinicians' workflow. Of note, Linder *et al.* found that CDSS tools that were not incorporated into the EHR were underutilized, underscoring the importance of integration for maximizing the tool's impact.[32] While EHR-integrated CDSS may enhance adoption through better workflow integration and accessibility, both EHR-based and non–EHR-based tools demonstrated positive clinical outcomes when used, suggesting that successful CDSS impact relies on appropriate implementation strategies and contextual factors rather than the platform alone.

An additional consideration in the use of CDSS is the trust that GPs place in the tool and its purpose. Some GPs expressed concerns about the study's goals, which highlight the importance of building trust between clinicians and the entities implementing CDSS. Clear communication about the purpose of the tool, along with assurances regarding data privacy and the intent behind its use, is essential to alleviate these concerns and encourage more widespread adoption.[43]

CDSS in high-income versus low-income settings

Most of the studies included in this review were conducted in HICs. This raises the question of how applicable these findings are to LMICs, where the challenges related to AMR and healthcare resource limitations are often more pronounced. In HICs, CDSS can capitalize on established healthcare infrastructures, including advanced EHRs, abundant diagnostic tools and a relatively high level of clinician training. These factors make the implementation of CDSS more feasible and potentially more effective. However, in LMICs, they struggle with resource constraints, and the challenge of AMR is particularly urgent where inadequate antimicrobial stewardship practices contribute to the misuse of broad-spectrum antibiotics even for community-acquired infections.[55] In this context, CDSS, even if less sophisticated, could provide evidence-based recommendations in real time, helping clinicians to improve their prescribing practices.[39,40] Bessat *et al.* showed in their study, conducted in primary care facilities in Burkina Faso, that the CDSS tool was very positively perceived by physicians as a very helpful tool for guiding decisions in infants' management, despite a longer time of consultation and some technical and language issues.[42] This highlights the need for providers to have such tools in LMICs, where diagnostic tool shortages appeared to be prevalent.

This review has some limitations. The heterogeneity of CDSS interventions, implementation strategies and outcome measures prevented meta-analysis. Additionally, reporting of implementation determinants and contextual factors was inconsistent, limiting conclusions regarding specific predictors of successful adoption. Despite these limitations, this review provides a more comprehensive understanding of the current evidence available and the factors influencing successful CDSS uptake and impact. Our findings highlight the importance of adoption level, EHR integration, workflow compatibility and organizational support while also emphasizing the need for more standardized reporting and harmonization of study designs and outcome measures in future research to enable stronger comparisons and more robust conclusions.

Conclusion

Existing studies have demonstrated promising clinical outcomes with CDSS, including improved adherence to guidelines and a reduction in overall or specific antibiotic use by primary care providers. However, the heterogeneity of implementation strategies, study contexts and measured outcomes makes it challenging to draw definitive conclusions about their true effect. It is crucial to standardize these strategies to enable a clearer and more consistent evaluation of CDSS in future research.

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Transparency declarations

None to declare.

Author contributions

Racha Ibrahim (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing—original draft), Claire Durand (Conceptualization, Data curation, Formal analysis, Writing—review & editing), Monsey Mcleod (Conceptualization, Writing—review & editing), François-Xavier Lescure (Conceptualization, Writing—review & editing), Esmita Charani (Conceptualization, Methodology, Supervision, Writing—review & editing), Gabriel Birgand (Conceptualization, Supervision, Validation, Writing—review & editing), and Raheelah Ahmad (Conceptualization, Supervision, Writing—review & editing)

Supplementary data

Tables S1 and S2 are available as Supplementary data at *JAC* Online.

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