Technical Note

Implementation of a Mobile Clinical Decision Support Application to Augment Local Antimicrobial Stewardship

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Abstract

Background: Medical applications for mobile devices allow clinicians to leverage microbiological data and standardized guidelines to treat patients with infectious diseases. We report the implementation of a mobile clinical decision support (CDS) application to augment local antimicrobial stewardship. **Methods:** We detail the implementation of our mobile CDS application over 20 months. Application utilization data were collected and evaluated using descriptive statistics to quantify the impact of our implementation. **Results:** Project initiation focused on engaging key stakeholders, developing a business case, and selecting a mobile platform. The preimplementation phase included content development, creation of a pathway for content approval within the hospital committee structure, engaging clinical leaders, and formatting the first version of the guide. Implementation involved a media campaign, staff education, and integration within the electronic medical record and hospital mobile devices. The postimplementation phase required ongoing quality improvement, revision of outdated content, and repeated staff education. The evaluation phase included a guide utilization analysis, reporting to hospital leadership, and sustainability and innovation planning. The mobile application was downloaded 3056 times and accessed 9259 times during the study period. The companion web viewer was accessed 8214 times. **Conclusions:** Successful implementation of a customizable mobile CDS tool enabled our team to expand beyond microbiological data to clinical diagnosis, treatment, and antimicrobial stewardship, broadening our influence on antimicrobial prescribing and incorporating utilization data to inspire new quality and safety initiatives. Further studies are needed to assess the impact on antimicrobial utilization, infection control measures, and patient care outcomes.

Keywords: Antibiogram, antimicrobial stewardship, guideline, mobile application

Introduction

Antimicrobial stewardship programs (ASPs) are composed of a multidisciplinary health-care team that promotes judicious use of antimicrobials across the continuum of care.[1-4] These teams include physicians, pharmacists, epidemiologists, clinical microbiologists, and support staff. Core strategies of an effective ASP include the production of a local antibiogram, development of clinical decision support (CDS) tools, and health-care provider education. Many ASPs develop internal guides to support safe and effective antimicrobial prescribing based on local susceptibility patterns, institution formulary, and evidence-based international guidelines. This report outlines the implementation of a robust mobile CDS application to augment local antimicrobial stewardship.

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Methods

Technical background

The University of Iowa Hospitals and Clinics (UIHC) is the largest teaching hospital in Iowa. It is a 761-bed tertiary care adult and pediatric academic medical center with Level 1 trauma capability, multiple intensive care units (including neonatal) as well as approximately 300 outpatient clinics and care areas. In the fiscal year 2016, the health system employed 1662 resident, fellow, and staff physicians and dentists. In addition, the institution employed 9297 nonphysician staff members

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including pharmacists, nurses, and microbiology and pathology laboratory staff.

In 1996, our institution printed its first antibiogram after approval by the Pharmacy and Therapeutics Committee. This foldable pocket guide included the hospital antibiogram, a formulary antimicrobial list, the estimated cost of common antimicrobials, and an injectable antibiotic dosing guide for patients with renal dysfunction. The guide was updated annually and printed each year for distribution to clinical staff. This form of CDS persisted until our team implemented the hospital's first mobile CDS application on July 1, 2016.

Distribution of an antibiogram is a key function of most clinical microbiology laboratories. Standardized rules for construction of the antibiogram are published in Clinical and Laboratory Standards Institute document M39.[5] The College of American Pathologists (CAP) currently requires that laboratories distribute this data to the medical staff at least yearly, but there is no standard for how this should be done. Combined electronic distribution of the antibiogram and related information from pharmacy, infectious diseases (IDs), and hospital epidemiology presents an informatics challenge where solutions are not well described in the literature.

Antimicrobial stewardship team

The work described herein represents a collaboration between antimicrobial stewardship teams (ASTs) at a large academic medical center and neighboring veterans affairs hospital with the purpose of improving city-wide and regional antimicrobial prescribing. The team consisted of one clinical microbiologist, four ID pharmacists, and two ID physicians. Content was developed by the ASTs, vetted by staff physicians with clinical expertise to ensure practicality and end-user acceptance, and submitted to the Antimicrobial Advisory Subcommittee (AAS) and finally the Pharmacy and Therapeutics Committee.

Table 1: Mobile application platform considerations

Advantages	Disadvantages
Support tools more readily available to a greater audience	Not all clinicians carry devices capable of accessing a mobile guide
Content can be expanded to a greater depth and scope	Only a fraction of users will be early adopters of new technology
Updates are pushed out seamlessly to clinicians in real time	Cost-effectiveness can be a barrier to implementing technology
Ability to measure guide utilization and other metrics	
Allows for continual quality improvement and content expansion	
Mobile application is self-promoting to a certain extent[a]	

[a]Matching modern trends in social behavior with the methods used to provide education and support to clinicians is a powerful social engineering tool to ensure successful implementation

Technology platform

A mobile application platform has several distinct advantages over the traditional method of printed paper CDS tools [Table 1]. Many commercial platforms are available to serve as a mobile clinical application platform. Table 2 summarizes mobile applications with content related to IDs that are designed to be used at the point of care. MicroGuide™ was chosen as the preferred platform for implementation in our health system. MicroGuide™ was codesigned and developed in 2011–2012 by Horizon Strategic Partners (HSP) Limited and University Hospital Southampton in the United Kingdom to allow pharmacists to publish local antimicrobial guidelines to clinical staff. The mobile application is now exclusively owned by HSP Limited. The application has more than 90,000 users worldwide, and HSP has won several awards for its mobile products.

Results

Project timeline

Table 3 and Figure 1 present a timeline and breakdown of key events in each phase of the project. Candidate products [Table 2, last row] were evaluated according to cost, maintenance requirements, distribution methods, and ease of use. MicroGuide™ was selected based on its comparable cost to printing paper antibiograms, ease of editing in a web-based HTML editor, and automatic republishing to Apple, Android, and web-browser platforms. Access to the application through web browser was deemed a critical feature as the use of personal devices in the hospital environment is limited by security, infection control, technical barriers, and individual practitioner preference. Further, a web browser allows remote access for those with home computers who does not own mobile smart devices or choose not to install a mobile app. Postimplementation use of the web viewer has been high, validating the prioritization of this feature.

Preimplementation

The Legal and Health Care Information Systems Departments for UIHC reviewed the disclaimers for use to ensure minimal liability to the institution on dissemination of the electronic CDS tools. Liability arising from public availability of proprietary information, risks of utilizing an offsite application server maintained by the vendor, and risks associated with installation of an outside vendor application on UIHC Voalte™ phones (iPhone-based clinical communication devices used by clinical staff throughout the institution; Voalte™, Inc., Sarasota, FL, USA)[30] were assessed. These risks were deemed minimal and the project was permitted to move forward with our selected vendor.

Once approved, the content from our most recently printed paper CDS was uploaded into MicroGuide™ and published as version 1.0. Content was limited to the hospital antibiogram, formulary antimicrobial list, and renal dosing guides. The first major expansion of the CDS content included body system-based, institution-specific empiric prescribing

Table 2: Mobile Application Overview[a]

Application type	Examples	Pro	Con
General medical reference	Up to date[6] DynaMed[7] ePocrates[8]	Comprehensive, "all-in-one" overview of medicine	Treatment recommendations are very broad No information on local antibiogram
Medical calculators	MedCalc[9] QXCalculate[10]	Available calculator may assist clinical decision making and dose adjustments	No specific treatment information
ID-specific reference	RedBook[11] 5-min ID consult[12]	The focus is on infectious disease management	Treatment recommendations are very broad No information on local antibiogram
Condition specific reference	Candidemia management[13]	Very specialized	Inconvenient to have one application per condition Treatment recommendations are very broad No information on local antibiogram
Pharmacopoeia	LexiComp[14] Micromedex[15]	Covers antimicrobial drug dosing, uses and interactions	Focus is on FDA-approved uses Information is drug-based, not syndrome, or condition-based No information on local antibiogram
Antimicrobial-specific applications	Nelson's Pediatric Antimicrobial Therapy[16] Sanford Guide[17] Johns Hopkins ABX Guide[18]	Focus is on optimal antimicrobial drug choice, use, dosing FDA and non-FDA approved uses Some information on resistance trends	Recommendations are very broad No information on local antibiogram
Institution-based stewardship applications	St-Michael's Antibiogram (TARGeT; Toronto, Canada)[19] RCSI Hospitals Antimicrobial (Ireland)[20] Impact (Hong Kong)[21] Infectious diseases: There's an App for That (Ohio State)[22]	Application tailored to the institution's needs Usually free for the users General and local treatment recommendations Local antibiogram often available	Expensive to develop and maintain locally
Commercial customizable stewardship applications	MicroGuide (Horizon Strategic Partners)[23] Spectrum App (Spectrum)[24] Teqqa (Teqqa)[25] eASYapp (Northern Sydney Local Health District)[26] Dorsata (Dorsata)[27] Antibiograms (Portable Databases)[28] VA Health Antibiogram (limited to United States Veterans Administration)[29]	Application tailored to the institution's needs Usually free for the users Application development and support is provided by the developer General and local treatment recommendations Local antibiogram often available	Can be expensive for the institution Varying degrees of technical expertise necessary, from database maintenance to turnkey text editing Variable platforms for deployment (Apple devices, Android devices, Web) Distribution to devices is not always automatic; potential for retention and use of old information Variable ability to make institutional guides "private"

[a]The examples provided are based on a limited search at the time of this publication. Search terms included antimicrobial stewardship, antimicrobials, infectious diseases from the Apple App Store and Google Play. FDA: Food and Drug Administration

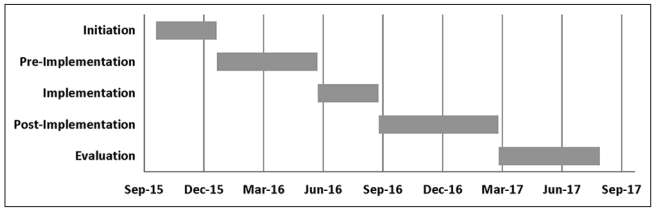

Figure 1: Timeline of key events

guidelines. Guide recommendations were based on published, evidence-based national guidelines and informed by local antibiogram data, hospital formulary, and antimicrobial stewardship considerations to minimize the development of antimicrobial resistance and antibiotic overuse. An example of a new interdisciplinary guide for *Clostridium difficile* diagnosis and treatment is shown in screenshots from an Android device in Figure 2.[31] The guide in Figure 2 utilized ID and pathology subject matter experts (SMEs) to formulate a concise guide to diagnose *C. difficile* infection (CDI) and how to interpret local testing for CDI [Figure 2b]. Pharmacy and ID SMEs added treatment regimens and duration of therapy, with current published references to best practices [Figure 2c].

Table 3: Project phases

Project phase	Key activities
1 – initiation	Engage pharmacy leadership
	Develop a business case
	Select and purchase the platform
	Platform training for AST members
	Select an existing guide template
2 – preimplementation	Discuss key issues with health-system lawyers
	Public antibiogram and clinical guides
	Data safety and legal considerations
	Discuss information technology barriers
	Remote server where guides are stored
	Staff willingness to install the application on personal devices
	Determine guide style and format
	Develop new content and guides
	Identify clinical subject matter experts
	Approve content via committees with expert input
	Upload and publish initial guide
3 – implementation	Test mobile applications and HTML web viewer
	Integrate web viewer into electronic medical record
	Install the application on hospital mobile devices (Voalte™[30])
	Educate staff
	Conduct a local media campaign
4 – postimplementation	Develop and approve new content (ongoing)
	Revise outdated content as applicable
	Publish version updates (ongoing)
	Educate staff (ongoing)
5 – evaluation	Evaluate data and utilization metrics
	Report to hospital leadership
	Plan for sustainability
	Educate new staff and trainees annually
	Plan for future innovation

AST: Antimicrobial Stewardship Team

Once developed by the core AST, the first draft of the guide was then sent to content experts in that area for review, edits, and endorsement. For example, medical leaders in pulmonary medicine were consulted to review guides for pneumonia. The second draft was then presented to the AAS. The AAS subsequently provides recommendations to the Pharmacy and Therapeutics Committee regarding all requests directly pertaining to IDs and anti-infective therapy. Each empiric prescribing guide was put through this preparation and review process before implementation into the electronic CDS guide. The MicroGuide™ software facilitates this process through version control: Once a draft is edited and approved, content can be published as often as needed when approved by the committee. Once a new version is finalized and published by our team, the content is pushed directly to all users who downloaded and saved the guide and to the web viewer. Notably, guide content is downloaded to mobile devices and can be accessed without internet access. When new versions are published, the user is automatically prompted to access the updated content. Version 1.0 was thus the product of the preimplementation process and the first available content in MicroGuide™.

Implementation

The mobile application and web viewer were tested thoroughly before go live with clinical staff. The UIHC uses the Epic™ suite of software applications (Epic™ Systems, Inc., Madison, WI, USA). A link to the web viewer was embedded throughout the electronic medical record to improve visibility and access to clinicians at the point of care. Specifically, the link was included in the clinical resource list on the Epic™ dashboard for clinicians, in the order entry screen for all formulary antimicrobials, in the hospital formulary database, and on the hospital's web-based file collaboration service with other clinical practice references. An example of the embedded link within the order entry screen for vancomycin can be seen in Figure 3. Simultaneously, the mobile application was loaded onto hospital-provided Voalte™ mobile devices for clinical use. The electronic CDS application was downloaded by the hospital's information technology group onto each device for direct availability to clinicians.

A multifaceted media campaign and education strategy was implemented in July 2016 to coincide with the arrival and training of new staff. A screen saver for all hospital computers and televisions highlighted MicroGuide™ as the institution's new clinical mobile software application. Support from clinical leadership, a sample of content within the guide, and instructions for how to download the guide were contained in the screen saver. In addition, a flyer with the same content was distributed by the Chief Quality Officer during training of new staff. Business cards with highlights of content and instructions for downloading were created and distributed to clinicians in both hospital and community settings. Education was provided directly to key user groups through the Department of Internal Medicine's Grand Rounds.

The first antibiogram published in the electronic guide was a replication of the printed version. Subsequently, this implementation expanded with the addition of pediatric and cystic fibrosis-specific antibiograms. The ability to edit more complicated documents collaboratively, to release incremental updates to new material, and to make corrections more than the once per year specified by CAP facilitated the largest change in the antibiogram's 20-year history and allowed UIHC to meet the Infectious Diseases Society of America's recommendation to publish stratified rather than hospital-wide data.[3] In addition, the lack of incremental costs associated with printing (both for cost of materials and for practical drawbacks such as increased thickness of printed pocket guide) enables the team to update the information in the guide more frequently. The structure of our electronic guide was customized to meet the needs of our institution and deviates from other institutions' guides across the world using the same

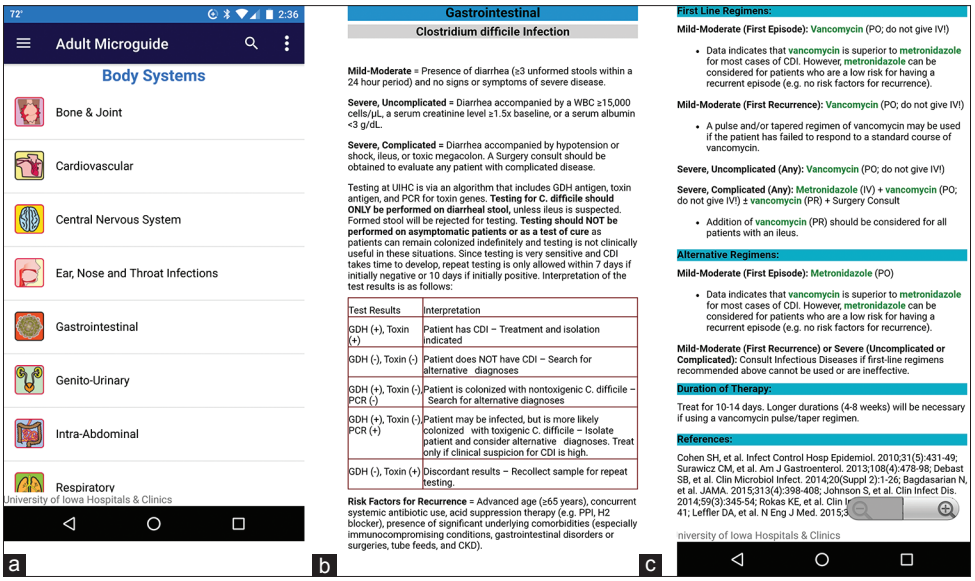

Figure 2: Example of a body system-based guideline for the diagnosis and treatment of *Clostridium difficile* disease. (a) Body systems under which individual guides are filed. (b) Clinical and laboratory diagnostic guide to *Clostridium difficile* infection. (c) treatment parameters and evidence base for the *C. difficile* guideline

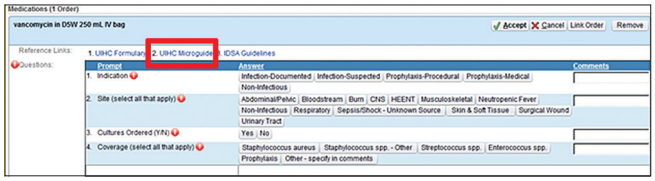

Figure 3: Electronic clinical decision support link embedded within the electronic medical record (link #2, boxed)

platform. Empiric prescribing guides in our application include general diagnostic and microbiology information, first-line treatment regimens, alternative regimens for patients with beta-lactam antibiotic allergies, duration of therapy guidance, and references. Content expansion beyond empiric prescribing guides included surgical prophylaxis tables, epidemiology of current enteric and respiratory pathogens in our health system, and infection prevention resources such as precautions, sharps injury, and work restrictions.

Postimplementation

After the initial implementation phase, the ASP core team continued to develop and update new content for approval and inclusion into the guide. Ongoing efforts are needed to maintain the antibiogram (at least yearly) and maintain pharmacy, clinical practice, and epidemiology standards. Major staff education efforts recur each July as new staff are trained in our health system.

Several features of the MicroGuide™ software facilitate postimplementation quality assurance. First, old versions are timestamped and archived, allowing future users to access old data (e.g., the antibiogram) without relying on a specific user to maintain an archive. Second, access to the application is controlled by a designated top-level administrator who may delegate editing, publishing, and administrator-level permissions to other users. Separate guides on other topics, related or not to ID, may also be purchased and delegated. For instance, our institution is currently developing an anticoagulation guide on the same platform. The benefits of accessing local guidelines or procedures at the point of care in a convenient, modern format extend far beyond IDs.

Data and utilization metrics

The following data represent guide utilization between June 1, 2016, and July 31, 2017. The mobile application was downloaded 3056 times over 14 months. Figure 4 graphically represents application downloads by month. The mobile application guide was accessed 9259 times and the web viewer 8214 times. Figure 5 shows that the monthly number of times the CDS guide was accessed by both mobile application and web viewer. The most commonly accessed individual guides by either mobile application or web viewer are highlighted by rank order in Table 4. User demographics data are available for each individual who downloaded the application based on mandatory self-reporting. The primary practice area for users who downloaded the application is 83% hospital, 16% primary care, and 1% "health board"/other. The breakdown of user profession is 66% medicine, 18% pharmacy, 6% other, 5% nursing, and 5% physician associates or equivalent. In medicine, practice-level selections included student 27%, intern 17%, resident 12%, attending physician 33%, and management 11%. Data were made available by the application design mentor on request from our AST.

Discussion

This report outlines the implementation of a digital CDS application to augment local antimicrobial stewardship in our institution and community. One distinct advantage of a digital CDS tool over historical methods is access to

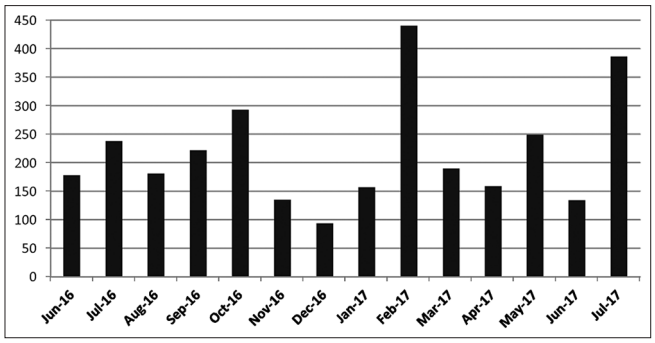

Figure 4: Application downloads by month. Guides downloaded between June 1, 2016, and July 31, 2017

Table 4: Most commonly accessed guides

Rank	Guide name	Accessed
1	Community-acquired pneumonia	3725
2	Antibiogram – Gram-negatives	3216
3	Antibiogram – Gram-positives	2931
4	Antimicrobial dosing in renal insufficiency	2918
5	Spontaneous bacterial peritonitis	2576
6	Uncomplicated cystitis	2139
7	Pyelonephritis/bacteremic UTIs	1941
9	Complicated cystitis	1596
10	Cellulitis without abscess (nonpurulent)	1263
11	Aspiration pneumonia	969
12	Intraoperative antibiotic guide	840
13	Osteomyelitis	590
14	Cellulitis with abscess (purulent)	540
15	Diverticulitis	475

Guides accessed by clinicians through mobile application or web viewer between June 1, 2016, and July 31, 2017. UTIs: Urinary tract infections

utilization data. These data are valuable to assess the success of implementation and to inform ongoing quality improvement initiatives. A data-informed antimicrobial stewardship program can identify new opportunities for education and support by targeting niche areas and specific disease states based on institution-specific guide utilization. Implementation of the mobile CDS tool and companion web viewer in our institution provided antimicrobial support to a large proportion of our target audience. Application download data from June 2016 to July 2017 indicate that 3,056 clinicians and trainees downloaded the guide. In addition, other clinicians in our region have downloaded and used the application, effectively broadening our influence on antimicrobial prescribing to the local community. Top guides within our application have been accessed hundreds to thousands of times providing data and opportunities that were not possible with paper guides.

Use of computerized decision support systems by an ASP is recommended by antimicrobial stewardship experts and international guidelines.[3] The mobile CDS tools presented here represent a novel form of computerized decision support. Several studies found an association between computerized decision support systems and improved antibiotic dosing, more appropriate antibiotic selection, fewer prescribing

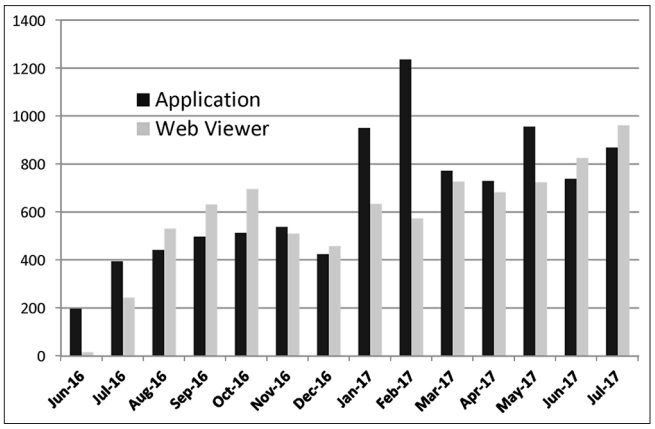

Figure 5: Clinical decision support guide access by month. Guides accessed by clinicians through mobile application and web viewer between June 1, 2016, and July 31, 2017

errors, reduced antibiotic resistance, adverse events, use of broad-spectrum antibiotics, length of stay, antibiotic costs, and mortality.[32-38] The preliminary results for provider utilization at our institution are encouraging. Long-term impacts on antimicrobial prescribing and patient outcomes will need to be assessed in future studies. For example, our guides favor nonquinolone antibiotics in the treatment of many uncomplicated infections.[39] Assessing the impact on quinolone prescribing and *Clostridium difficile* infection rates will be critical to further quantify the impact of these CDS tools. Overall, further studies are needed to assess the impact of our mobile CDS application on antimicrobial utilization, infection control measures, and patient care outcomes.

Despite successful implementation, our team faces new challenges. Continual quality improvement in terms of application content, esthetics, and functionality is critical in today's rapidly evolving medical community. Future success and sustainability may hinge on quantifying the impact on antimicrobial prescribing trends in our institution and community. Finally, smaller hospitals and critical access sites in our area that lack resources to support a diverse team of ID clinicians and microbiologists may benefit from access to this CDS tool. Increasing antimicrobial resistance is a community dilemma, and stewardship strategies that promote collaborative community-based solutions are paramount to future success.

Conclusions

Mobile applications are a powerful tool for providing education and support to frontline clinicians. Through thoughtful design and implementation of a mobile CDS, our AST is better able to provide cutting-edge clinical recommendations directly to the fingertips of prescribers in our institution. Successful implementation allowed us to broaden the scope of what was initially an antibiogram-focused delivery platform to standardized guidelines for diagnosis and treatment of infections and delivery of infection control and epidemiological information. This broadens our CDS application's influence on antimicrobial prescribing. Moreover, the availability of utilization data

allows us to better target efforts to improve our application. Further studies are needed to assess the impact on antimicrobial utilization, infection control measures, and patient care outcomes.

Acknowledgment

Successful implementation of this new clinical decision support tool required tremendous collaboration and support from many different teams in our institution. The authors would like to thank the many clinicians at the University of Iowa Hospitals and Clinics for contributing to the development and implementation of these guidelines. We also thank the design mentor, Eamus Halpin, from Horizon Strategic Partners for customizing the application to meet the unique needs of our institution and providing utilization data vital to ongoing quality and process improvement efforts.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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