Journal of Hospital Infection 100 (2018) 257–264

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevier.com/locate/jhin

Participatory implementation of an antibiotic stewardship programme supported by an innovative surveillance and clinical decision-support system

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ARTICLE INFO

Article history:
Received 23 May 2018
Accepted 24 July 2018
Available online 30 July 2018

Keywords:
Antimicrobial resistance
Antibiotic stewardship programmes
Implementation
Information systems
Clinical decision-support system

SUMMARY

Background: Antibiotic resistance will cause about 10 million deaths per year by 2050. Fighting antimicrobial resistance is a health priority. Interventions aimed to reduce antimicrobial resistance, such as antibiotic stewardship programmes (ASPs), must be implemented. To be effective, those interventions, and the implementation process, should be matched with social–cultural context. The complexity of ASPs can no longer be developed without considering both organizational and information systems.
Aim: To support ASPs through the co-design and implementation, in collaboration with healthcare workers, of a surveillance and clinical decision-support system to monitor antibiotic resistance and improve antibiotic prescription.
Methods: The surveillance and clinical decision-support system was designed and implemented in three Portuguese hospitals, using a participatory approach between researchers and healthcare workers following the Design Science Research Methodology.
Findings: Based on healthcare workers' requirements, we developed HAITooL, a real-time surveillance and clinical decision-support system that integrates visualizations of patient, microbiology, and pharmacy data, facilitating clinical decision. HAITooL monitors antibiotic usage and rates of antibiotic-resistant bacteria, allowing early identification of outbreaks. It is a clinical decision-support tool that integrates evidence-based algorithms to support proper antibiotic prescription. HAITooL was considered valuable to support monitoring of antibiotic resistant infections and an important tool for ASP sustainability.
Conclusion: ASP implementation can be leveraged through a surveillance and clinical decision-support system such as HAITooL that allows antibiotic resistance monitoring and supports antibiotic prescription, once it has been adapted to the context and specific needs of healthcare workers and hospitals.

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https://doi.org/10.1016/j.jhin.2018.07.034
0195-6701/

Introduction

Antibiotic resistance is a major worldwide problem associated with high morbidity, mortality, as well as costs. In Europe 25,000 people per year die with an antibiotic-resistant infection, and it was estimated that by 2050, 10 million people worldwide will die due to antibiotic-resistant infections [1,2]. This scenario led the World Health Organization (WHO) to consider antimicrobial resistance as a global public health priority [3]. Antimicrobial resistance has been associated with inappropriate antibiotic prescribing [4]. The situation of antibiotic misuse and overuse is startling: for instance, it was estimated that 20—50% of antibiotics are improperly prescribed, and antibiotics already account for 30—40% of hospital drug costs [5,6].

Antimicrobial resistance can be prevented by interventions aimed to reduce excessive antibiotic prescribing to hospital inpatients [7]. Antibiotic stewardship programmes (ASPs) are based on seven core elements (leadership commitment; multidisciplinary team; situation assessment; interventions to improve antibiotic use; surveillance; report; and educate) and are designed to optimize antibiotic therapy leading to significant reductions in antibiotic consumption and consequently prevalence of antibiotic resistance bacteria, toxicity, and costs [7—10]. Guidelines for empirical therapy, checklists, dedicated teams, compulsory rules, alerts on incorrect antibiotic use, and antibiotic consumption monitoring, have been described as ASP interventions that had significant benefits in clinical outcomes [10—12].

Surveillance and clinical decision-support systems have the potential to enhance ASP since they increase the information available for healthcare workers, enable a more efficient review of data and facilitate clinical evaluation [13,14]. Moreover, these systems have been described as effective in many ASP interventions: reducing antimicrobial consumption without compromising healthcare quality, optimization of antimicrobial prescription and use, implementing compliance with recommendations, and reducing resistance and costs [7,15—18].

The biggest challenge of a surveillance and clinical decision-support system is to be efficient and effective in hospital settings and to be accepted by healthcare workers as a helpful tool. This requires an appropriate study design and the clear reporting of results with focus on direct patient impact [19]. Furthermore, clinical decision-support systems are usually more effective when: information is generated automatically; are based on a user-friendly system designed with physicians' support; are incorporated into currently operational workflows; data are available in an aggregate form (without requiring access to a separate/new window); and avoid, as much as possible, the need for a broad commitment of hospital information technology departments [13,16,20].

The implementation process of an information system can be challenging since limitations such as the complexity of medical data, security and confidentiality, and a lack of healthcare workers' interest by (an additional, and often not integrated) information systems, are present most of the time [21]. To be effective, the implementation process should be done in close collaboration with healthcare workers and adapted to the social, economic, educational and cultural backgrounds where it will be used [22,23].

In Portugal, ASPs are expected to be implemented in all healthcare institutions; however, data from 2015 revealed that, in spite of 93% of the Portuguese hospitals having implemented an epidemiological surveillance programme for antibiotic-resistant micro-organism monitoring/surveillance, only 40% of those implemented a programme to support antimicrobial prescription [24]. The major limitations for the complete ASP implementation in Portugal are: (i) lack of integrated information; (ii) the excessive price of the available software in the market; (iii) software that is not user-aligned with working processes nor user-friendly; and (iv) the majority do not fulfil healthcare workers' requirements.

The aim of this study was to design and implement, in collaboration with healthcare workers, a real-time surveillance and clinical decision-support system (HAITooL) to support ASP implementation (by monitoring antibiotic resistance and the prescription process), linked with the local ASP strategy, and adapted to the local socio-cultural context.

Methods

Site selection

HAITool was designed and implemented in three different hospitals in order to cover different Portuguese regions, different types of hospital facilities, and different organizational models: (i) an eight-bed polyvalent intensive care unit in Hospital de São Francisco Xavier, Centro Hospitalar de Lisboa Ocidental, a general and tertiary university public hospital, located in Lisbon; (ii) Hospital do Espírito Santo de Évora, a general and tertiary public hospital, located in the south of Portugal, with 331 beds; and (iii) Hospital Distrital da Figueira da Foz, a primary public hospital, located in the central region of Portugal, with 154 beds. To further improve implementation conditions the correspondent hospital boards accepted and signed an implementation agreement.

Study design

This study was intended to be, by itself, an ASP implementation process including the following ASP core elements [10,12]:

- Leadership commitment: written agreements were signed with hospital administration of participating hospitals;
- Multi-disciplinary team: researchers and healthcare workers' teams including physicians, nurses, microbiologists, pharmacists, hospital managers, information service staff, and infection control team;
- Situation assessment: characterization of the healthcare workers' workload on antibiotic prescription practices (see below);
- Interventions to improve antibiotic use: through an information system to antibiotic monitoring and prescription support (see below);
- Educate: distribution of educational posters, flyers, and booklets; presentation of several seminars/meetings.

The study aims were aligned with Portuguese Health Directorate-General recommendations and guidelines for antibiotic resistance prevention and control (based on World Health Organization and European Centre for Disease Prevention and Control guidelines) [25,26].

HAITooL design and implementation process

HAITooL was built using a participatory approach (based on a multi-disciplinary team of researchers and healthcare workers) and the Design Science Research Methodology (DSRM). DSRM connects applied research and professional practice by creating and evaluating information technology artefacts – in this case, an information system to monitor antibiotic resistance and to support antibiotic prescription [27]. DSRM establishes a process with six activities that were thoroughly adapted to this research context [28]. All healthcare workers involved in antibiotic monitoring and prescription processes (infection control team, physicians, pharmacy and microbiology laboratory staff) were enrolled in DSRM activities:

(i) Problem identification: observational time-and-motion studies (healthcare workers were observed during 4 h, in the morning, considered by themselves as the period of day when more work related to antibiotic prescription practices was performed) and meetings were conducted in participating hospitals to characterize and understand healthcare workers' workload involved with antibiotic prescription practices.
(ii) Definition of objectives for a solution: a set of functional objectives was defined to establish an easy and innovative information system that aggregates, in real-time, all antimicrobial resistance-related information, enabling antibiotic-resistant infection control and monitoring – HAITooL.
(iii) Design and development: HAITooL enables management of consumption of antibiotics and monitoring infections caused by antimicrobial-resistant bacteria; it acts as a clinical decision-support system for antimicrobial prescription; and it is aligned with ASP implementation guidelines.
(iv) Demonstration: controlled local events with contextualized implementation (hands-on sessions) of the information system in participating hospitals.
(v) Evaluation: HAITooL design and implementation process, and its effectiveness on ASP implementation, was assessed by Österle's principles and semi-structured interviews, supported by a pre-elaborated questionnaire that included questions on usefulness of HAITooL features [29]. All questions used a five-point Likert-style response scale, from 'not useful' to 'very useful'.
(vi) Communication: of the results to the participating hospitals and to national and international ASP experts.

Results

Antibiotic resistance monitoring and prescription process – bottlenecks and requirements

In order to obtain results based on evidence we characterized and understood healthcare workers' workload on antibiotic prescription practices through meetings and observational time-and-motion studies. Results show that healthcare workers (especially physicians and the infection control team) spend a quarter of their working time (~2 h in our observational studies) interacting with the in-house clinical information systems (e.g. searching for information and inserting data). In addition, several complaints were mentioned: (i) information systems did not fulfil healthcare workers' needs; (ii) hospital data were distributed in a variety of databases, were not easily accessible, and in some cases did not interconnect; (iii) no alerts existed when results from microbiology were available, (iv) local epidemiological data (antibiotic susceptibility patterns and antibiotic resistant infection rates) were not easily accessible.

To answer to these needs, healthcare workers requested a single information system that supports ASP tasks by facilitating antibiotic resistance surveillance (for infection control team) and promotes a more effective antibiotic prescription (for physicians). Thus, it was concluded that HAITooL should: (i) provide access to real-time information (for instance, provide access to weekly/monthly updated epidemiological local data on antibiotic susceptibility); (ii) provide easy access to microbiology laboratory results, updated data on antibiotic consumption, and antibiotic resistance rates (to follow trends and detect outbreaks); (iii) enable an integrated view of all relevant patient-related events over time (including prescribed antibiotics, microbiology results, and vital signs); (iv) promote antibiotic prescription based on guidelines; (v) portray antibiotic-related alerts (e.g. exceeded standard antibiotic duration, multidrug-resistant bacteria, drug–bug mismatches); and (vi) facilitate communication between healthcare workers.

Data sources and data warehouse

In order to solve the problem of multiple sources of hospital/patient data, a web-based information system was developed to support an SQL Server that extracts and aggregates patient data (e.g. vital signs, length of stay, surgeries), results from microbiology laboratory, and data from pharmacy (antibiotic consumption). Data are periodically (e.g. every 5 min) extracted, using automatic routines programed in Java programming language, from the existing information systems in hospitals by an Extract–Transformation–Load (ETL) module written in Java, and are then processed and aggregated in a single data warehouse (Figure 1A).

Data visualization

Optimization of data visualization was one of the main objectives of HAITooL, in response to the request by healthcare workers of data presentation in an easy and understandable way. To achieve this, the visualization module is based on Qlik Sense program (with some additional extensions such as the timeline structure developed by the research team), that reads the aggregated and processed data and allows visualization through a unique and innovative layout (Figure 1B). Additionally, a 'universal' colour code was applied in most of the features. For instance, for information about antibiotic resistance patterns, antibiotic resistance is coloured in red, green represents antibiotic susceptible, and yellow is used for cases of intermediate susceptibility (Figure 2A).

Surveillance system

As requested by healthcare workers (mainly from the infection control team), HAITooL enables the integration of data related with the surveillance of infections caused by antibiotic-resistant bacteria and of healthcare-associated infections as requested by the Portuguese Ministry of Health.

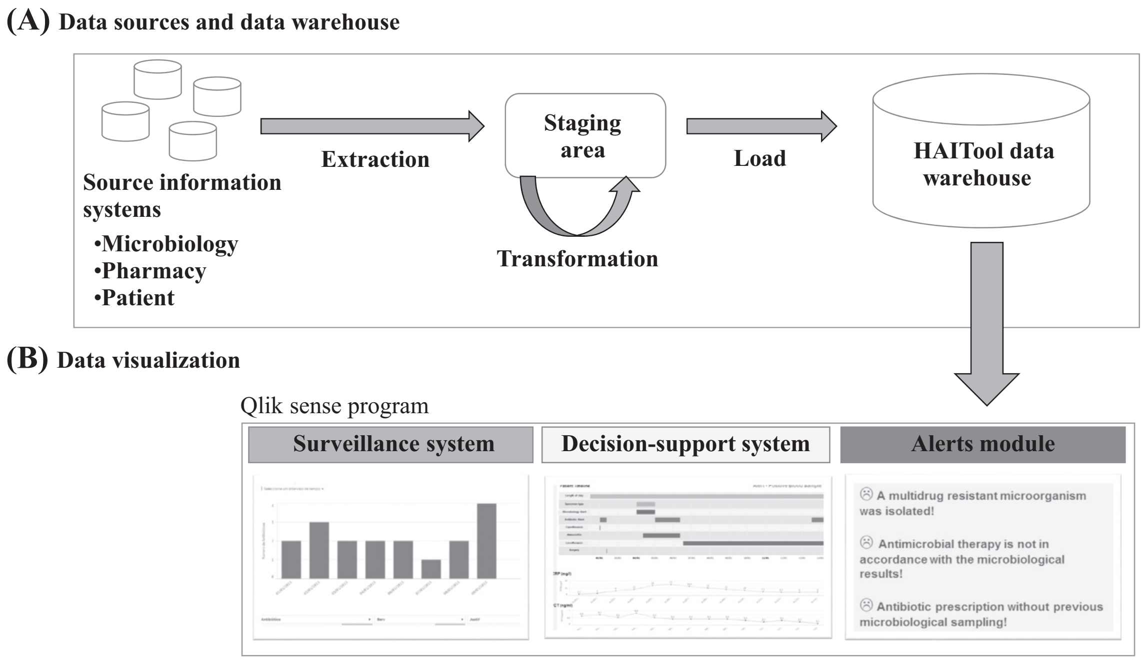

Figure 1. HAITooL information system architecture.

Additionally, some specific data can be aggregated. For instance, it is possible to combine, in the same chart, antibiotic consumption with distribution of antibiotic-resistant bacteria, which enables monitoring and evaluation of the impact of ASP interventions. The surveillance can be done in the whole hospital or in a specific ward since data can be filtered by ward. In the same way, and using available filters, surveillance can be done by specimen type, type of infection, and micro-organism.

Clinical decision-support system for antibiotic prescription

To support physicians on the antibiotic prescription process, HAITooL aggregates, in a single view, all patient-relevant events organized in a temporal way, allowing patient monitoring in real-time: Patient timeline (Figure 2B). This timeline can provide the following types of information: hospital length of stay, vital signs (temperature and blood pressure), biomarkers (C-reactive protein and procalcitonin), specimen types, microbiology laboratory results (bacteria identification and antimicrobial susceptibility pattern), antibiotic consumption, data related to surgery (type of surgery and antimicrobial prophylaxis used), and alerts (see 'Alerts module' below). Data provided in Patient timeline can be adapted according to each hospital department's requirements.

One of the main features of the clinical decision-support system for antibiotic prescription is the possibility of having real-time epidemiological data on antimicrobial susceptibility patterns (Figure 2A). The information can be filtered by patient, ward, micro-organism, and specimen type. This feature is very useful for empirical treatment.

Alert module

HAITooL also includes an alert module that, through a set of programmed algorithms, matches patient and hospital data with guidelines and recommendations from the Portuguese Health Directorate-General. There are alerts for: duration of antimicrobial therapy; surgical antibiotic prophylaxis; prescription of fluoroquinolones and carbapenems (which are overused/overconsumed in Portugal); and multidrug-resistant and epidemiologically important micro-organisms [30].

In addition, the system also emits alerts when: antimicrobial therapy is not in accordance with microbiological results; there is antibiotic prescription without previous microbiological sampling; and when a blood culture becomes positive.

It was suggested that the alert module should not lead to 'alert fatigue'. Based on this request, HAITooL alerts were built to be persuasive instead of restrictive: all HAITooL alerts are 'educative' since none of them releases stop orders.

Demonstration and implementation

HAITooL was implemented in the participant hospitals side by side with healthcare workers and with a special involvement of hospital information system departments that provided support in managing both databases and data links to HAITooL. Interestingly, these workers were often pleased to be involved in such an innovative project. However, the implementation process took more time than expected, mainly because of healthcare workers' busy schedule (healthcare workers were often overloaded with work and HAITooL was not immediately perceived as a helping tool, therefore was not initially prioritized; after the first trials, the attitude changed).

HAITooL evaluation

Semi-structured interviews, supported by a pre-elaborated questionnaire, conducted to evaluate HAITooL design and implementation, revealed that all healthcare workers involved in this study considered HAITooL very useful and time-saving to support prevention and control of antibiotic-resistant

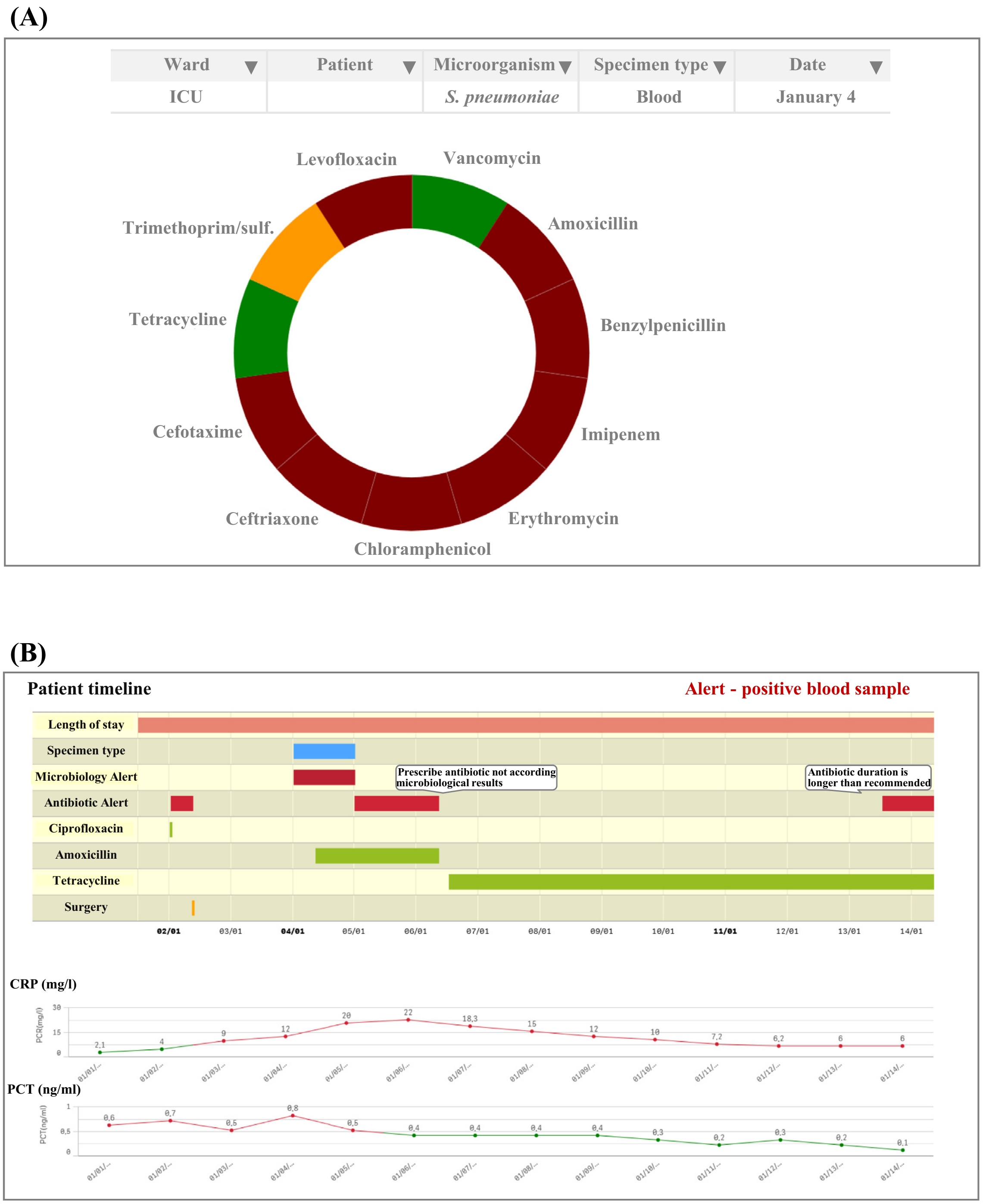

Figure 2. Visualization of HAITooL features. (A) Antimicrobial resistance pattern. (B) Patient timeline. ICU, intensive care unit; CRP, C-reactive protein; PCT, procalcitonin.

infections. The ability to provide real-time epidemiological local data on antibiotic susceptibility was recognized by 75% of the respondent healthcare workers' teams as one of the main features, since it was found to be an important tool in supporting antibiotic prescription and enhanced, in a timely manner, communication between the microbiology laboratory and the other healthcare workers involved in the patient management. The alert module was considered by all respondent healthcare workers as critical to facilitate the decision process. However, the usability (regular usage and impact) of these alerts over time needs further assessment, to properly evaluate the change in prescription and management of antibiotics. The ability to provide an immediate and comprehensive overview of the patient's clinical situation (Patient timeline), the teamwork perspective and multi-disciplinary approach, and the ability to select relevant information by the healthcare worker user, were highlighted as major advantages of the system. Additionally, HAITooL has been used by physicians, at their daily department meetings, to check antibiotic prescription.

The design-oriented information system was evaluated by Österle's principles as described below [29]:

- Abstraction: HAITooL can be used by all (and different types of) healthcare workers, helping them to tackle antibiotic misuse in several scenarios since it is completely adaptable, and data requirements are usually available in any hospital.
- Originality: HAITooL was originally designed by a multi-disciplinary team of researchers and healthcare workers, contributing to an information system that fits healthcare workers' actual needs (e.g. antibiotic prescription support).
- Justification: Antibiotic resistance is a major worldwide cause of death and it is recognized that antibiotic prescription is a complex process [3,4]. HAITooL is a surveillance and clinical decision-support information system to assist antibiotic management and prescription that has been validated by healthcare workers.
- Benefit: HAITooL benefits healthcare professionals and organizations, wider society and public health by facilitating and supporting work in antibiotic management. Proper antibiotic management contributes to reducing antibiotic misuse and antibiotic resistance burden.

Antibiotic stewardship implementation support

Besides enabling surveillance and clinical decision-support on antibiotic prescription, HAITooL was recognized as a new tool for the implementation of interventions to improve antibiotic use (alerts on antibiotic therapy without previous clinical sampling); to facilitate communication of results between microbiology laboratory and physicians; and it can have an educational impact. HAITooL can therefore be considered an important tool on ASP implementation since it supports five of the seven ASP core elements: situation assessment; interventions to improve antibiotics use; surveillance; report; and education.

Discussion

Here, HAITooL is described as a combined surveillance and clinical decision-support system for antibiotic monitoring and prescription support designed and implemented by a participatory approach in order to be properly adapted to the specific needs of healthcare workers and hospitals. As requested, HAITooL integrates patient, microbiology and pharmacy data, using visualization tools that facilitate access to information and improve clinical decision-making (Figures 1 and 2; and Supplementary material).

The potential of information systems for improvement of health systems is considerable, since they generate, analyse and disseminate data enabling timely decision-making [31,32]. Modern public health can no longer exist without information technology approaches, such as integrated clinical decision-support systems that enable faster responses to critical health situations. In fact, several authors have described the use of information systems as fundamental in ASP, to identify bacterial resistance trends, to help empirical antibiotic treatment, to reduce hospital stay, and to reduce antibiotic costs [9,33,34]. However, most of these information systems fail to support antimicrobial prescribing in daily practice, as they are mainly focused on clinical content, rather than on supporting workflow practice [35].

HAITooL is an innovative surveillance and clinical decision-support system since it was designed based on DSRM, a methodology that joins applied research and professional practice to create more effective information technology [27]. In addition, HAITooL is based on evidence and on healthcare workers' real needs, since it was designed and implemented by a participatory approach. A multi-disciplinary team of researchers (from different healthcare areas) and physicians, infection control team, pharmacy, microbiology laboratory and information systems staff was gathered and participated in its conception and deployment since the beginning. Involving healthcare workers allowed HAITooL developers to continuously check the fit between technology and clinical practice [35]. For instance, the healthcare workers suggested specific colours, filter techniques (e.g. per patient or per bacteria) and the ability to visualize aggregated data in a temporal way (Patient timeline). These types of visualization technique had an impact on clinical decision-making by facilitating access to information [36]. On the other hand, it helped physicians and infection control teams to visualize, from the user perspective, what it would be like to work with the system on a daily basis, and to immediately report their needs [35]. The participatory approach also increased the success of the implementation process since it is adapted to organizational, social and cultural context [22,35,37]. However, and despite continuous involvement of healthcare workers, the implementation process took more time than expected due to lack of health informatics support and to some initial skepticism on its advantages. More research is required to better understand implementation processes and impact on ASP over time.

This study's major limitation is that we do not yet have enough data to verify how much HAITooL use can reduce antibiotic consumption and antimicrobial resistance rates. Additionally, and regrettably, economic burden and clinical impacts on patient outcomes, such as appropriateness of antibiotic selection (e.g. reduction of quinolones and cephalosporins prescription) and length of stay, cannot be accurately assessed yet. Data collection on impact on antibiotic resistance, clinical outcomes, and reduction of hospital cost has just started, and a prolonged period of time is needed to enable statistically significant outcomes in such a dynamic and multivariate process. This will be addressed in a forthcoming study. However, one major strength is that HAITooL follows several recommendations and guidelines on antimicrobial use, on information system implementation, and includes several features that a clinical decision-support system should have to increase healthcare workers' compliance [23,35,37–39] (Box 1); therefore, the authors believe that HAITooL will be useful to fight antibiotic resistance.

HAITooL and its implementation research presents a proof of concept on its usefulness to support ASP implementation. For instance, HAITooL enables easy access to microbiology results and to local epidemiological data, by providing integration of real-time microbiology results. This type of feature is a common intervention ASPs since it is effective in increasing the percentage of patients with appropriate empiric therapy and to reduce broad-spectrum antibiotic prescription [18,40].

Box 1
Recommendations on antimicrobial use, on information systems implementation, and on clinical decision-support systems included in HAITooL system.

European guidelines on the prudent use of antimicrobials in human medicine [38]:
- Give information technology support for antimicrobial stewardship activities.
- Enable the monitoring of quality indicators and quantity metrics of antimicrobial use.
- Provide clinical decision-support system to improve antimicrobial prescribing.
- Ensure timely access to clinical microbiology laboratory services.

Interventions to expedite information systems implementation [23]:
- HAITooL creates a fit between technology and work practices.
- HAITooL is always available and reliable.
- HAITooL is user-friendly with regard to ease of use, efficiency in use, and functionality.
- Healthcare workers participated in HAITooL implementation process.
- Implementation process was done by an interdisciplinary team that included developers, members of the information system department, and healthcare workers.
- Healthcare workers' concerns were addressed.

Features of clinical decision-support system that increase healthcare workers' uptake [35,37,39]:
- Integration with clinical practice and as a part of the healthcare workflow.
- HAITooL does not restrict antibiotic use. Instead, it provides recommendations on antibiotic use, promoting action rather than inaction.
- No additional data entry is required.
- The impact of HAITooL use can be easily monitored since rates of antibiotic consumption and resistance can be visualized by ward.
- Was developed by a multidisciplinary team of researchers and healthcare workers.
- Is locally adapted and provides references and easy access to national and local guidelines.
- Is flexible, since it can be adapted to different settings and conditions.
- Integrates both patient and institutional data in real-time.
- Provides easy and effective access to microbiology results.
- Enables access to hospital and unit-specific antimicrobial susceptibly patterns.

In conclusion, HAITooL is a surveillance and clinical decision-support system, developed in partnership with healthcare worker teams, that aims to be an important tool for ASP implementation and sustainability. HAITooL was developed by a multi-disciplinary team including researchers and healthcare workers, promoting the creation of a system better adapted to the context where it is implemented. Both DSRM interactions and the continuous contact with healthcare workers have contributed to add value to the system functionalities, fulfilling their specific requirements. Although it is not possible to confirm yet that HAITooL reduces significantly antimicrobial resistance levels, we are convinced by our field experience that HAITooL is already helping healthcare workers in the management of antibiotic resistance.

Acknowledgements

The authors thank all healthcare workers participating in the HAITooL project and who have contributed to the design and implementation of HAITooL SI, and Qlick and Admin-Saude for the technical support. We also thank P.L. Pinto, M. Gil and M. Mira da Silva for initial support on HAITooL development.

Conflict of interest statement
None declared.

Funding sources
This work was supported by project 'HAITooL – A Toolkit to Prevent, Manage and Control Healthcare-Associated Infections in Portugal' EEA Grants, 000182DT3; and by Fundação para a Ciência e a Tecnologia for funds to GHTM – UID/Multi/04413/2013.

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