USING DESIGN SCIENCE RESEARCH METHODOLOGY TO IMPLEMENT A SURVEILLANCE AND DECISION SUPPORT SYSTEM TO MANAGE HEALTHCARE-ASSOCIATED INFECTIONS AND ANTIBIOTIC USE IN HOSPITALS

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Abstract

About thirty seven thousand people die per year in Europe due to infections caused by antibiotic resistant bacteria. Combating antimicrobial resistance is a world top priority so that lives can be saved and associated costs reduced. Indiscriminate antibiotic prescription is an additional and unnecessary selection pressure that accelerates the development of antibiotic resistant bacteria. In this way, initiatives that aim to reduce antimicrobial resistance should take into account antibiotic prescription quality. This paper presents HAITool: a Surveillance and Decision Support System to manage, prevent, and control healthcare-associated infections. The information system was developed using Design Science Research Methodology (DSRM), and is empowered with innovative applications of data visualisation techniques. The information system, designed in close collaboration with healthcare professionals, includes integrated visualisations of patient, microbiology, and pharmacy data, facilitating antibiotic resistant bacteria monitoring, antibiotic prescription support, and clinical decision quality. It also includes an alert component for antibiotic prescriptions, ESKAPE+C and multi-drug resistant microorganism according with norms and guidelines. HAITool has been evaluated, using the Österle principles and interviews with physicians and infection control practitioners, as a very useful Surveillance and Decision Support System.

Keywords: Healthcare-Associated Infections Surveillance System, Clinical Decision Support System, Healthcare-Associated Infections, Antibiotic Resistance, Antibiotic Consumption.

1 INTRODUCTION

As reported by the World Health Organization, Healthcare-associated infections (HAIs) are one of the major worldwide causes of death and disability (Siempos et al. 2007). HAIs lead to 37000 deaths/year (ECDC 2012; ECDC 2013) in Europe and have an important economic impact: 28.4 to 33.8 billion dollars/year in the USA (Scott 2009). Antibiotic resistance increase even more morbidity, mortality and costs associated with HAIs (Neidell et al. 2012).

Antimicrobial resistance occurs when bacteria are incorrectly exposed to antibiotics. Indiscriminate antibiotic prescription leads to an additional and unnecessary selection pressure that sharply accelerates the development of bacteria resistant to commonly used therapeutic agents (Bell et al.

2014). In fact, it is estimated that 20-50% of antibiotics are improperly prescribed (CDC 2014). The problem that we intend to address is the antibiotics misuse.

Antimicrobial resistant HAIs can be reduced by interventions that reduce unnecessary antibiotic prescribing to hospital inpatients (Davey et al. 2013). For instance, computerised surveillance and decision support systems have been proven to be helpful in the prescription errors reduction, medical care improvement and compliance with recommendations (Evans & Pestotnik 1998; Pestotnik 2005).

HAI surveillance has become imperative for quality management, hospital budgeting, public reporting and legal reasons. However, physicians and nurses expect hospital infection control teams to assist them in their daily bedside work and in providing patients with the best possible care, rather than collecting data for epidemiological reporting. This way, systems that are able to either report retrospectively on HAIs according to "classic" HAI surveillance definitions and support clinical ward and bedside work in the form of clinical decision support, overviews of complex matters, alerts, and reminders have an added value (Adlassnig & Berger 2014).

Clinical decision support systems (CDSSs) are playing an increasingly important role in the delivery of healthcare services, providing patient-particular management recommendations through the use of individual patient data coupled with computerized clinical guidance and population statistics. Appropriate antimicrobial therapy for various infections, error avoidance, and the overall quality of care have benefited from CDSSs usage (Blumenthal 2010).

The integration of CDSSs into electronic health record platforms has been shown not only to enrich the quality of clinical care, but also to enhance patient outcomes (Pestotnik & Classen 1996; Evans & Pestotnik 1998; McGregor & Weekes 2006). In particular, highly interactive tools for integrated data visualisation could increase the understanding of a patient's infection status and ultimately enhance decision making for the use of antibiotics (Forsman et al. 2013).

Traditional surveillance systems often fail to capture antimicrobial resistance outbreaks, owing to the fact that they are dependent on delayed data warehouses, usually compiled yearly or a few times per year. On the contrary, other systems like Artemis (Teodoro et al. 2012), do not rely on manual data acquisition. Artemis even has unified semantics across the different data sources, representing concepts using a formal language (RDF/OWL). However, it has not a patient-oriented and integrated visualisation for assisting physicians with the antibiotics prescription, whose misuse or overuse, are primary causes of antibiotic resistances.

Other systems emphasize the information visualisation component as a way to support better decision making for use of antibiotics, stating that further research is needed to effectively embed general alarms (Forsman et al. 2013). We share the importance given to information visualisation and to the inclusion of alarms generated as a consequence of detecting deviations from the antibiotic prescription and antibiotic bacteria resistance norms.

Local microbiology data to improve antibiotic therapy has also been used in past decision support systems like GERB (Rodriguez-Maresca et al. 2014). Through that system physicians had ready access to local resistance maps. However, in addition to support the empiric treatment, the system could assist physicians further, for example in the antibiotic overuse management, by integrating, transforming and presenting information from several other hospital systems (e.g. pharmacy), and not only from the laboratory information system. Some systems explicitly recommend physicians the prescription of particular antibiotics based on pre-defined programmed guidelines (Hum et al. 2014), which is an issue that must be dealt with caution because it could be not appreciated by some physicians.

This paper presents HAITool: a toolkit to manage, prevent, and control HAIs. It is a HAIs surveillance and clinical decision support system expected to give an important contribution in the reduction of antibiotic use (or misuse) and antibiotic resistant HAIs. HAITool was conducted using the Design Science Research Methodology (DSRM) that aims to solve organisational problems by creating and evaluating information technology artefacts (in this case an information system) intended to solve identified organizational problems (Peffers & Tuunanen 2007).

DSRM establishes a process built upon six activities, namely problem identification, objectives definition, design and development, demonstration, evaluation, and communication (Alan et al. 2004). These activities were adapted to the context of this research, as illustrated in Figure 1.

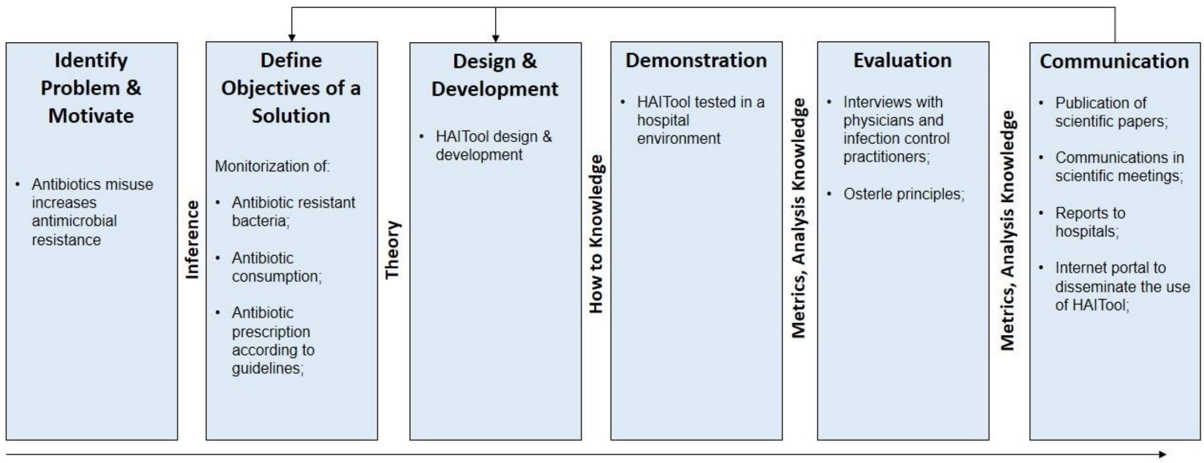

Figure 1. Adapted Design Science Research Methodology process model (Peffers & Tuunanen 2007).

In the next section the research objectives are presented. In section 3 the HAITool design & development are described. In section 4 the demonstration is presented and in section 5 the evaluation is detailed. A conclusion is presented in section 6.

2 OBJECTIVES

The desired objectives of a solution are the following:

- **Monitoring antibiotic consumption -** updated data on antibiotic consumption is relevant for monitoring antimicrobial resistance, once inadequate antibiotic prescriptions are associated with increasing antibiotic resistant bacteria rates.

- **Monitoring antibiotic resistant bacteria -** updated data on antibiotic resistant bacteria rates is important, not only to follow trends, but also to detect outbreaks. In addition, information on antibiotic resistance patterns support the quality of empirical antibiotic prescriptions.

- **Promote antibiotic prescription based on guidelines -** to have an integrated view of patient data, facilitating antibiotic prescriptions. In addition, alerts based on guidelines and on microbiology results are also helpful.

In line with the research objectives, and with the contributions of physicians and infection control practitioners, the HAITool detailed objectives were developed. These objectives help to define our system but they could also be considered in the future by other Surveillance and Decision Support Systems that intend to tackle antibiotic resistance:

- The system should be able to monitor antibiotic consumption.
- The system should be able to monitor antibiotic resistance trends.
- The system should be able to export the presented data into tables for further processing by healthcare professionals.
- The system should portray visually, in a single screen, all the relevant patient-related events over time, including prescribed antibiotics, microbiology results and vital signs.
- The system should portray antibiotic-related alerts (e.g. exceeded antibiotic duration) and bacteria-related alerts (e.g. ESKAPE+C and multi-drug resistant microorganisms) in order to facilitate decision support for physicians and infection control professionals.
- The system should have an alert for drug-bug mismatches. This is relevant for indicating physicians that there is a microbiology result, stating that the infecting bacteria is resistant to the currently prescribed antibiotic.
- The system should include rules deducted from antibiotic prescription and antibiotic bacteria resistance norms and should alert physicians in case of deviations.

- The system should be frequently updated, so that physicians can get an updated picture of their patient's condition.
- The system should be developed by a multidisciplinary team.
- The system should only be accessible within the hospital internal network in order to ensure patient privacy.

3 DESIGN & DEVELOPMENT

Recognising the problem in terms of human lives and resource costs related with antimicrobial resistance and its association with antibiotic consumption, starts the development of HAITool: a Surveillance and Decision Support System to prevent, manage and control healthcare-associated infections.

HAITool has been designed and implemented by a multidisciplinary team that includes physicians, microbiologists, pharmacists, managers, information system researchers and infection control professionals, as well as technological partner (who provided us the web services), all contributing actively to the system's development. Multidisciplinary teams have proved to be successful in the past, regarding antibiotic stewardship initiatives (Struelens 2003; Dik & Hendrix 2015). For project management purposes, we have been using Trello, which is a web-based project management application (http://www.trello.com).

To address its objectives, HAITool rely on patient-related, pharmacy and microbiology data. These data are spread across several hospital information systems. HAITool has periodic routines written in Java, which are responsible for the entire ETL (Extract, Transform and Load) process.

There are routines for extracting data from other systems through web services. The extracted data is verified and transformed, for example, the antibiotics prescription data is checked against prescription norms and guidelines in this phase. The ETL process ends with the load of the validated data into HAITool's database, as illustrated in Figure 2.

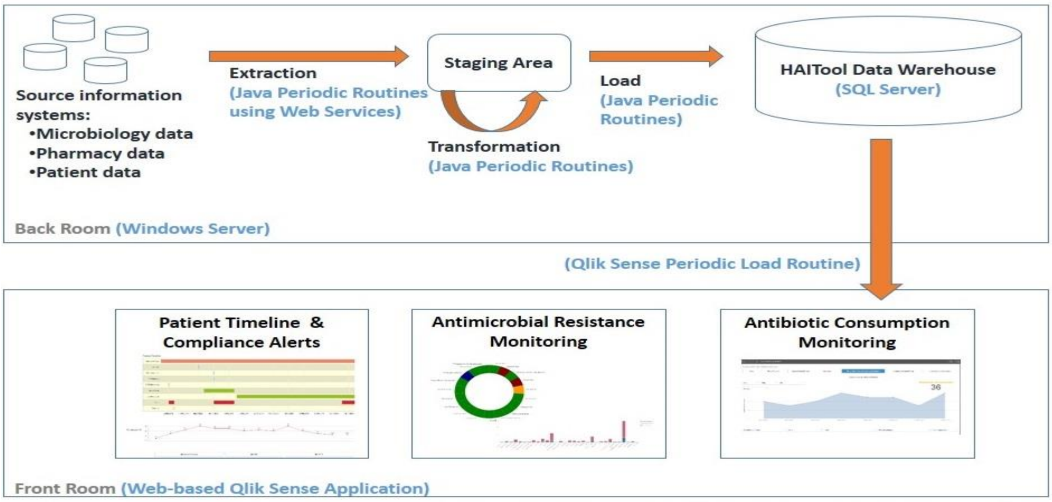

Figure 2. HAITool's architecture

The data visualisation component was implemented using Qlik Sense (with some extensions, e.g. the patient's timeline described further in this paper) and is periodically refreshed through a Qlik Sense routine that reads HAITool's database, resulting into updated patient-related, antimicrobial resistance monitoring, antibiotic consumption visualisations.

Qlik Sense is the newest release from Qlik, which is also the company owning QlikView, that have already been used within several healthcare research contexts (Zeng & Zhang 2013a; Zeng & Zhang 2013b; Burrows 2015).

4 DEMONSTRATION

The first HAITool demonstration took place at a polyvalent ICU (Intensive Care Unit) with 8 beds in a central hospital situated in Lisbon, Portugal.

HAITool was installed in a Windows Server and was connected to the hospital internal network. The system remains in the hospital production environment since January 2016, and it has been tested by healthcare professionals (who can access it through a browser) since then. All the other necessary components were also installed in that server, namely the SQL Server database and Java.

In this hospital, we extracted the data (pharmacy, microbiology, vital signs and other patient-related data) from a local software provider via web services, using Java periodic routines. Other Java periodic routines were used to transform the XML data supplied by those services and load the results into HAITool's database. We had also extracted real past data (since January 2015) in order to make future comparisons and evaluations.

4.1 Monitoring antibiotic resistant bacteria

One of the main features of the solution is the visualisation of antimicrobial resistance patterns through simple and clear graphs (Figure 3). The existence of local antimicrobial resistance patterns is very useful for guiding empirical antimicrobial prescription. The information can be further filtered by microorganism and ward, which facilitates the visualisation. A frequently used code colour was used to indicate the resistance pattern: green, yellow and red colours were used to indicate susceptible, intermediate and resistant microorganism, respectively.

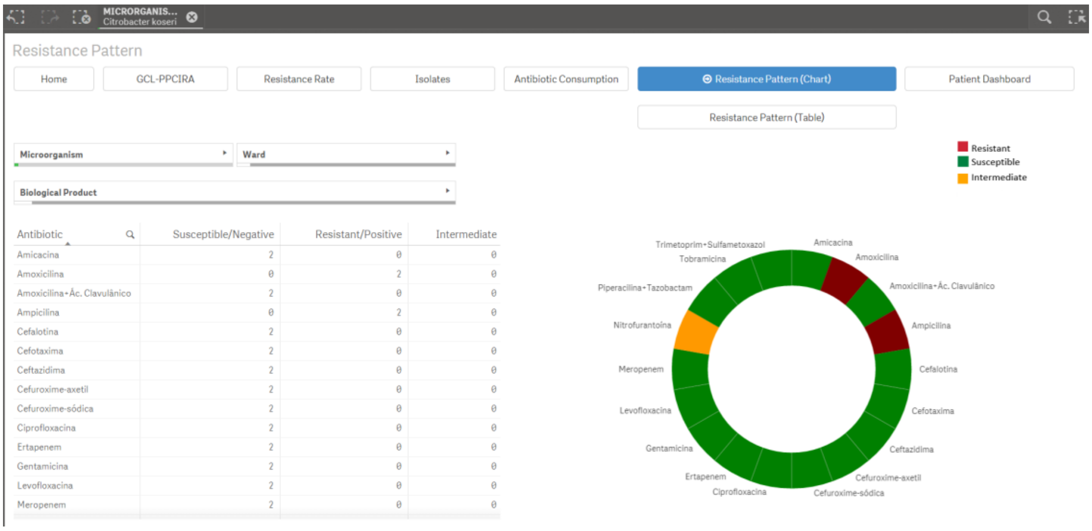

Figure 3. HAITool's microorganism resistant patterns visualisation through a donut chart.

In what concerns microorganism's monitoring, HAITool allows users to understand the distribution of resistant bacteria by ward. It is possible to filter by microorganism and see, for each one, the number of isolates that were found in each ward of the hospital. Information about the antimicrobial susceptibility can also be seen: microorganisms that are resistant to at least one antibiotic are coloured in red, blue represents the number of isolates that were susceptible to all the antibiotics tested, and yellow represents the isolates with intermediate resistance to at least one antibiotic.

4.2 Monitoring antibiotic consumption

Other HAITool's feature is antibiotic consumption which, in this first version of the tool, is measured by the number of antibiotics consumed. As portrayed in Figure 4 it is possible to use filters in order to have a specific data visualisation. This feature, besides allowing monitoring antibiotic consumption, allows the measurement and impact of antibiotic stewardship initiatives.

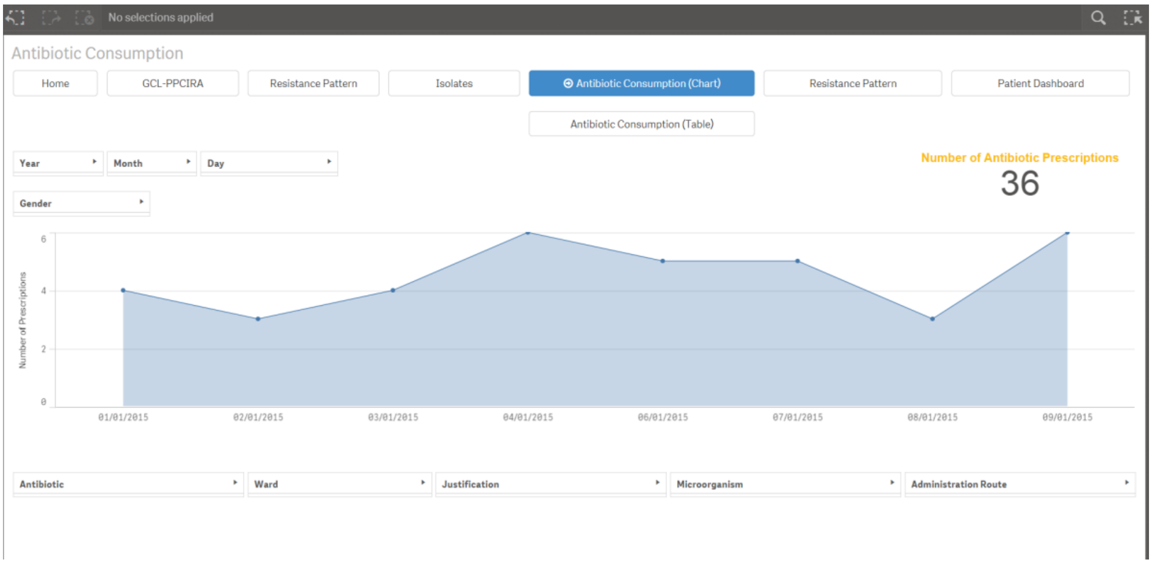

Figure 4. HAITool's antibiotic consumption monitoring.

4.3 Promote antibiotic prescription based on guidelines

Patient's timeline (Figure 5) is an integrated view of relevant patient events, providing information on data such as vital signs (temperature and blood pressure), length of patient stay, microbiology laboratory results, antibiotic consumption and surgery. In addition, bacteria and antibiotic-related alerts are also provided.

If users mouse over an event (row) in the patient's timeline, a text box appears with details related to that event.

This patient's timeline was the result of several interactions with physicians and infection control specialists to facilitate the clinical decision support process, as well as to contribute to the reduction of antibiotics overuse and misuse.

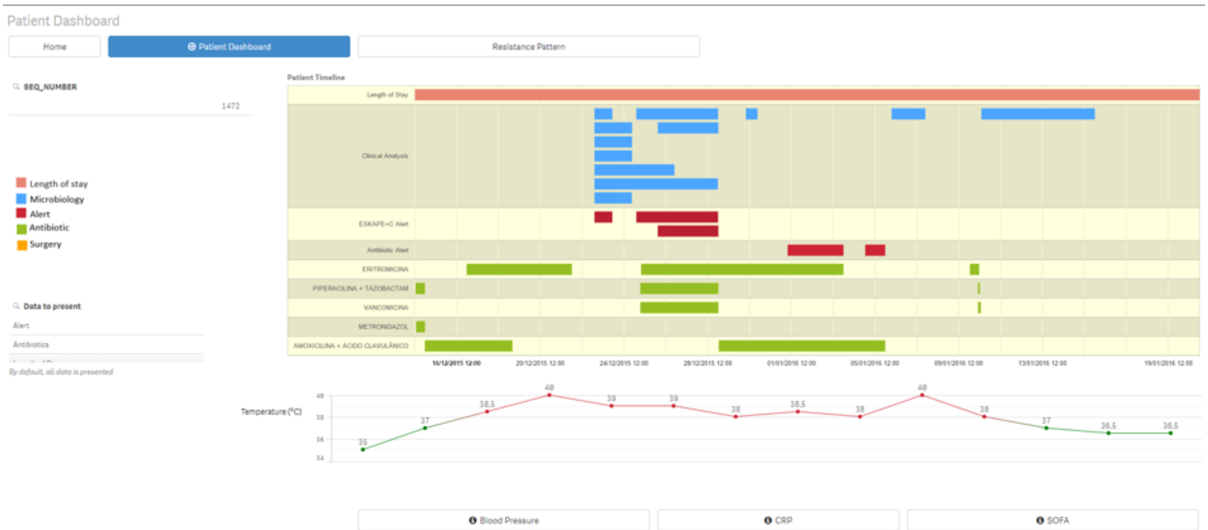

Figure 5. Patient's timeline portraying an integrated view over pharmacy, microbiology, vital signs, antibiotic-related and bacteria-related alerts.

The alerts that appear in the patient-timeline are part of an audit module that deals with antibiotic prescriptions according to norms. Alerts on antibiotic duration and antibiotic prophylaxis in surgery not in conformance with norms (DGS 2013; DGS 2014), antibiotic prescription not in conformance with microbiology results, antibiotic therapy initiated without request of a microbiology test, ESKAPE+C and multi-drug resistant microorganism, appear on patient's timeline and also on the main page of Infection Control Team.

These type of alerts have been described as effective to reduce incidence of catheter related infections, to decrease the length of hospital stay and to reduce workload without scarifying patient safety (Rojo et al. 1999; Sevinç & Prins 1999; Ramirez & Bordon 2001; Mertz & Koller 2009).

5 EVALUATION

In order to evaluate HAITool, we followed a strategy based on interviews with physicians and infection control practitioners (Oates 2005), as well as the Österle principles usage (Österle et al. 2011).

Interviews, used to evaluate the first cycle of DSRM indicated that HAITool was "very useful" on management antimicrobial resistant HAIs by providing antibiotic resistant patterns, antibiotic consumption monitoring, enhancement of communication between the infection control team, microbiology laboratory, physicians and pharmacists, as well as the relevance of alerts on antibiotic prescriptions compliance with norms.

We performed unstructured interviews with physicians, pharmacists, infection control practitioners, and nurses, making a total of 32 healthcare professionals. The interviews were conducted at their workplaces and at the beginning of those interviews the solution main objectives were presented (monitoring antibiotic consumption, monitoring antibiotic resistant bacteria, promote antibiotic prescription based on guidelines), followed by questioning them how HAITool could better contribute for the objectives fulfilment from their point of view. It is important to state that half of these professionals did not participate in the first iteration of the DSRM process. Those interviews triggered some adjustments in the data visualisations, as well as the addition of new alerts to the patient's timeline (Figure 5).

Design-oriented information system research must follow four basic principles: Abstraction, Originality, Justification and Benefit, also known as principles of Österle (Österle et al. 2011). HAITool follows the four Österle principles by:

- **Abstraction:** HAITool is being used by physicians and infection control practitioners to tackle antibiotic misuse at hospitals. Its data requirements are commonly available in any hospital, namely patient, microbiology and pharmacy data, that the system uses to process and create the visualisations. The research objectives and aspects of HAITool's architecture could also be used in future Surveillance and Decision Support Systems.
- **Originality:** HAITool was developed by a multidisciplinary team of researchers in close collaboration (almost daily) with the healthcare professionals of the participant hospitals, contributing to the creation of a system oriented to healthcare professional's real needs. Besides, HAITool is supported by Qlik Sense, which is the newest product provided by Qlik (http://www.qlik.com/). The company is specialized in business intelligence and data visualisation software and, as far as the authors are aware, this is the first research paper that presents an application supported by Qlik Sense in the field of healthcare-associated infection control and antimicrobial resistance. In our opinion, the patient timeline (Figure 5), the information it portrays and the way it is visualized, in a single screen, also contributes to the originality of our proposal.
- **Justification:** According to the World Health Organization, HAIs are a major worldwide cause of death (Siempos et al. 2007). HAITool is an information system to manage, prevent and control HAIs. Its detailed objectives were validated by physicians and infection control practitioners. Furthermore, we believe that a Surveillance and Decision Support System that emphasizes the information visualisation component, increases physicians' understanding of a patient's state of health with less cognitive effort, as state before (Forsman et al. 2013). HAITool also supports antibiotic de-escalation.

- **Benefit:** HAITool benefits healthcare organizations and the society in general by providing an integrated view on patient, microbiology and pharmacy data, facilitating the work of healthcare professionals, namely physicians and infection control practitioners. HAITool contributes to more informed empirical antibiotic prescriptions, once it allows physicians to check antibiotic resistance in their specific wards, making the prescription process more effective (Rodriguez-Maresca et al. 2014). Additionally, by providing an integrated view on patient data, it speeds up the clinical decision process. Infection control practitioners have also the possibility to monitor antibiotic consumption, antibiotic resistance patterns and conformance with infection control guidelines.

6 CONCLUSION

Recognising that prevention and control of antibiotic resistant HAIs is one of the world top priorities at the moment, HAITool design and development is expected to be an important step to achieve that.

The DSRM iterations and the continuous contact with healthcare professionals have contributed for adding value to the system, fulfilling their needs, as well as fulfilling the research objectives of monitoring antibiotic consumption, monitoring bacteria resistances and check the conformance of antibiotic prescriptions with the actual norms.

HAITool's communication was based on the publication of scientific papers, attendance in scientific meetings, reports to hospitals and development of an internet portal (Lapão et al. 2016; Simões et al. 2016).

At this point we have validated HAITool with physicians and infection control practitioners in what concerns the management of healthcare-associated infections. However, we are not yet able to confirm that the use of our system reduces antibiotic misuse and antimicrobial resistance levels.

The next step is to start measuring HAITool's impact in terms of antibiotic consumption, antibiotic prescription compliance with the norms, alerts effectiveness, antibiotic resistance rates and costs. Another major challenge concerns studying the adherence of physicians and infection control practitioners to HAITool usage, which we will be able to analyse because we have activated the system audit logs.

We believe that HAITool achieved the research objectives, according to the current feedback from healthcare professionals, giving them a quick access to patient-centric integrated data visualisations, which supports their daily decisions, including those concerned with antibiotic prescriptions.

Besides its contributions, we recognise that research must proceed in order to embrace issues like using log data to better understand physicians prescribing behaviour.

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