Brief report

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# Development of a web application for recording bacterial etiologic agents and their antimicrobial susceptibility to improve the treatment of urinary tract infections and monitor resistance to antibiotics

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## ABSTRACT

**Introduction.** We describe the development of a web platform that provides an updated record of the etiology and antimicrobial susceptibility of the different microorganisms responsible for urinary tract infections.

**Material and Methods.** The MicrobDinamyc system (Francisco Soria Melguizo, SA, Madrid, Spain) is employed for the management of information derived from the urine culture results. The web application database automatically gathers the results of urine cultures conducted in the laboratory.

**Results.** The user can consult the distribution of bacterial etiologies and antimicrobial susceptibilities in the different clinical settings during a specific time window.

**Conclusions.** Using susceptibility data obtained in previous studies and stored on the web platform, it is possible to deduce the clinical activity of a given antibiotic in a specific setting.

**Key words:** web application, bacteria, antimicrobial susceptibility, treatment, urinary tract infections.

## Desarrollo de una aplicación web para el registro de agentes etiológicos bacterianos y su sensibilidad a los antibióticos para mejorar el tratamiento de infecciones del tracto urinario y monitorización de las resistencias

## RESUMEN

**Introducción.** Describimos el desarrollo de una plataforma web que proporciona un registro actualizado de la etiología y sensibilidad a los antibióticos de los diferentes microorganismos responsables de infecciones del tracto urinario.

**Material y métodos.** El sistema de MicrobDinamyc (Francisco Soria Melguizo, S.A., Madrid, España) se emplea para la gestión de la información derivada de los resultados del cultivo de orina. La base de datos de la aplicación web automáticamente recoge los resultados de los urocultivos realizados en el laboratorio.

**Resultados.** El usuario puede consultar la distribución de etiologías bacterianas y sensibilidad a los antibióticos en los diferentes escenarios clínicos durante un período de tiempo específico.

**Conclusiones.** Usando datos de susceptibilidad obtenidos en estudios previos y almacenados en la plataforma web, es posible deducir la actividad clínica de un determinado antibiótico en una configuración específica.

**Palabras clave:** aplicación Web, bacterias, sensibilidad a los antibióticos, tratamiento, infecciones del tracto urinario.

## INTRODUCTION

Urinary tract infections (UTIs) represent the second most frequent cause of community -and hospital- acquired infection in both sexes, after respiratory infections, and they are the main reason for outpatient consultations, especially by females[1]. Their etiology varies according to the type of infection, the presence/absence of predisposing factors, previous antimicrobial treatments, and the setting of the acquisition (community or nosocomial, etc.)[2].

*Escherichia coli* is the most frequently implicated uropathogen, as reported by virtually all epidemiological studies worldwide[3]. Other pathogens of the genera *Enterococcus*, *Klebsiella*, *Enterobacter*, *Proteus*, *Morganella*, *Citrobacter*, *Serratia*, *Pseudomonas*, *Streptococcus*, *Staphylococcus* or fungi, such as *Candida* spp. are also isolated with variable frequency[4]. The high incidence of UTIs and their usually mild character result in the prescription of an empiric antimicrobial treatment

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in most cases. For the prescription of a rational empiric treatment, it is important to determine the microorganisms involved and to establish their antimicrobial susceptibility patterns to the largest possible number of agents, especially *E. coli*, the most frequent uropathogen[4]. These patterns can vary among different regions and over time within the same region[5]. In Spain, significant variations in microbial susceptibility to various antimicrobials have been observed over the past few years, with a progressive increase in resistance to fluoroquinolones and other antimicrobials habitually used in empiric UTI therapy, especially in the community, such as co-trimoxazole and β-lactam antibiotics[5]. We also highlight the increase in strains isolated in community urine samples that are multiresistant to various antimicrobials, creating a major problem by requiring the administration of compounds reserved for the hospital setting[6]. Given the drastic reduction in the arsenal of antimicrobials to which bacteria are susceptible[7], new tools are required to optimize use of the available drugs[8].

In this study, we describe an electronic tool to provide updated knowledge on the previous bacterial causes of UTI in different clinical care settings and on their antibiotic susceptibility patterns, facilitating prediction of the usefulness of empiric treatments in each setting.

## MATERIAL AND METHODS

The MicrobDinamyc system (Francisco Soria Melguizo, SA, Madrid, Spain) is employed for the management of information derived from the urine culture results. The web application database automatically gathers the results of urine cultures conducted in the Microbiology Clinical Management Unit of the Virgen de las Nieves University Hospital of Granada, a reference centre in the southern Spanish region of Andalusia serving a population of around 440,000 individuals.

**Laboratory studies with results included in the record.** The work procedure in our laboratory and the method used to calculate antibiotic activity have been reported elsewhere[5]. For each bacterial species identified in ≥ 5 isolates/year, the proportion of susceptible organisms was calculated by dividing the number of urinary isolates susceptible to each antibiotic by the number of organisms that were tested against that antibiotic agent (intermediately resistant and resistant organisms were grouped together). The system shows the number of tests that have been performed for each antibiotic and microorganism in order to reduce errors in the interpretation of results. Based on the susceptibility data gathered, the activity of each antibiotic was evaluated on all bacteria isolated during the study period. The following assumptions were made: (1) each of the aforementioned antibiotics is potentially active against *Enterobacteriaceae*; (2) fosfomycin, nitrofurantoin, amoxicillin-clavulanic acid, cefotaxime, and cefuroxime have no activity against non-fermenting gram-negative bacilli, and *Pseudomonas aeruginosa* is intrinsically resistant to co-trimoxazole; (3) among staphylococci, oxacillin predicts the response to all beta-lactam antibiotics; (4) among enterococci, ampicillin predicts the response to amoxicillin-clavulanic acid, piperacillin-tazobactam, and imipenem; furthermore, cefepime, cefotaxime, ceftazidime, cefuroxime, amikacin, gentamicin, tobramycin, and co-trimoxazole, which can be active *in vitro*, are not clinically active against these microorganisms; (5) fluoroquinolone activity can be determined from the activity of ciprofloxacin on Gram-negative bacilli and of levofloxacin on Gram-positive cocci; (6) the activity of fosfomycin on *Enterobacteriaceae* and Gram-positive cocci can be assessed by using the cut-off points recommended by CLSI for this antibiotic against *E. coli* and *Enterococcus faecalis*, respectively; and (7) the activity of nitrofurantoin on *Enterobacteriaceae* can be assessed by using the cut-off points recommended by EUCAST for this antibiotic against *E. coli*.

Finally, the application was designed to include information related to the origin (hospital/community) of the sample and the clinical department of the petitioner, which will be related to the susceptibility patterns of the microorganisms isolated in urine cultures.

**Development of the automatic record.** The application carries out basic descriptive statistical analyses on the results of the urine cultures in the database for the user to subsequently consult and interact with all of the stored information.

**Table 1** Types of tables in the database

| MASTER TABLES | URINE CULTURE TABLES | INTERMEDIATE TABLES |
|---|---|---|
| MIC_ADMIN | MIC_LOAD | MIC_ACTIVITY_ATB |
| MIC_ANTIMICROBIAL | MIC_CULTURE | MIC_CALC_ACTIVITY |
| MIC_MACO_TYPE_PROF | | MIC_INFORMT_ATB |
| MIC_MICROORGANISM | | |
| MIC_SAMPLE | | |
| MIC_ORIGIN | | |
| MIC_DEPARTMENT | | |

**Table 2** Example of a line of the INPUT file

| VARIABLE | MEANING |
|---|---|
| F | Sex (female) |
| dd/mm/yyyy | Date of birth |
| 3017974 | Number of sample for internal use |
| MSC | Sample origin (medical-surgical center) |
| EMGC | Department of origin of the sample (emergency) |
| URICC | Type of sample (clean-catch) |
| dd/mm/yyyy | Date of urine culture |
| 2001 | Isolated microorganism (species code) |
| 42 | Code of antibiotic tested |
| S/I/R | Susceptibility obtained in antibiogram |

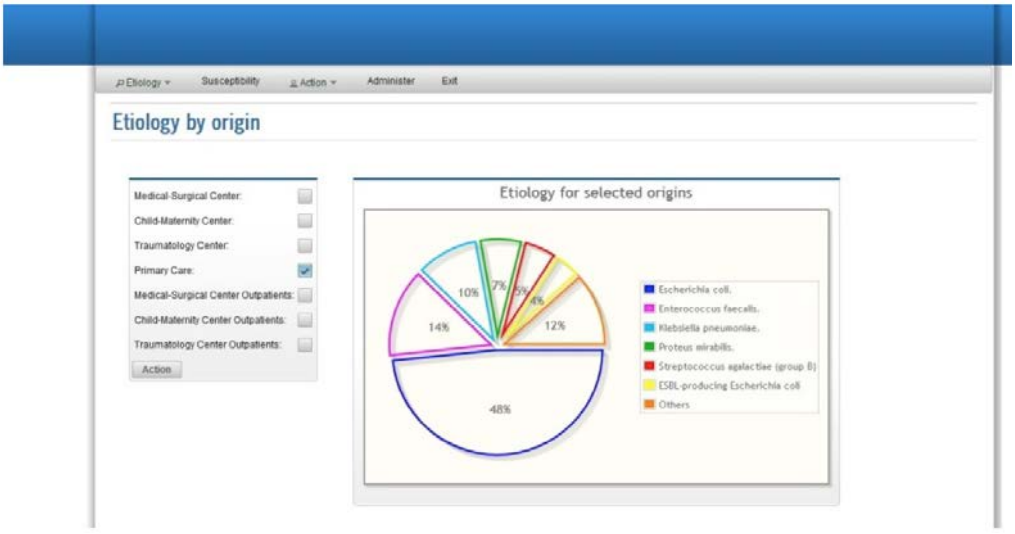


**Figure 1** Screenshot of the General Etiology option

The application database is designed and implemented on Oracle. The tables and the characteristics included in the database are the minimum required to respond to the following clinical questions: 1) What are the most frequent UTI etiologies according to the origin of the clinical sample?; 2) What is the accumulated susceptibility of these isolated microbial species?; and 3) What is the percentage global activity of an antibiotic in suspected UTI cases when the cause of infection is unknown?

Personal data of patients are not stored. The database design comprises 12 tables (table 1), including 7 master tables, using the same coding as in the MicrobDinamyc system. Two tables (MIC_LOAD and MIC_CULTURE) gather all of the data on urine culture results. Three auxiliary tables were created to store the calculations.

Results are automatically uploaded into the database. For this purpose, the administrator first exports data through an option available in the MicrobDynamic system. Subsequently, the exported file is treated with an intermediate program (designated intermediate tool), thereby generating a file (INPUT) to enter our web application. Subsequently, the application processes the INPUT file line-by-line and includes all of the information in the database. The INPUT file fulfils the following rules: 1) the format selected for the file is CSV (comma-separated values), 2) each line of the INPUT file includes 10 variables corresponding to the results of a specific urine culture, and 3) the information in the file is completely anonymous. Table 2 exhibits an example of the variables in each line of the INPUT file.

All information in the database derives from the MicrobDynamic data bank, which is generated from the urine cultures processed in the laboratory and refers to a specific time period. For this purpose, calculation of descriptive statistics by the web application only considers the urine culture results corresponding to the 12 months prior to the consultation by the user. During this time period, it can be guaranteed that an adequate number of susceptibility studies are conducted in our setting to yield sufficiently precise results. The application was developed using Java program language and Oracle database. The development setting was Eclipse IDE. The web application display (.war) was optimized for functioning in Tomcat and WebLogic. The application design followed the DAO (Data Access Object) + DTO (Data Transfer Object) pattern. RichFaces and PrimeFaces Java libraries are used.

**Intermediate tool for data processing.** An intermediate tool was created to obtain a generic and scalable application, given the requirements of the INPUT file. This tool automatically generates the INPUT file based on the data extracted from MicrobDynamic. It was programmed in Visual Basic, which provides automatic data treatment, eliminating variables unnecessary for our web application and presenting all data in the format required by the INPUT file.

## RESULTS

After the web application reads the INPUT file, the urine culture results are automatically included in the application database.

The resulting web application allows clinicians to access and interact with previous results. The database and web application (http://10.104.16.127:8082/jwresitu) reside on the servers of the Virgen de las Nieves University Hospital. Access to the application is restricted by user name and password to the medical staff of the public hospital network of the Andalusian Health Service. No system failures or data losses have happened to date, as verified by a monthly audit in which the web application database is compared with the Microbiology Department database. The data is backed up daily. Each time a new monthly data set is included in the application, the oldest


**Figure 2** | **Screenshot of the Susceptibility of each bacteria (2A) and Screenshot of the Activity of each antibiotic (2B)**

monthly dataset in the system is discarded, and the information related to the 12 months prior to the consultation is then used. The application has an intuitive and user-friendly interface. It has a menu system that permits access to and interaction with the different request options, obtaining a response in the form of a self-explanatory graphic representation of the data. The options in the main menu are *Etiology*, *Susceptibility*, *Action*, *Administer*, and *Exit*.

**Etiology.** The *Etiology* menu (figure 1) offers *General* and *Department* options, allowing the user to consult the etiology of UTIs as a function of the origin of the urine culture. In the *General* option, the physician selects a hospital centre, and the etiology data are calculated for all urine cultures in that centre during the time window. In the *Department* option, the physician selects a hospital department (e.g., urology, gynaecology, nephrology), and the etiology data are calculated for all urine cultures requested by this department during the time window. Using the information in the database, the system counts the microorganisms causing each infection. Finally, it carries out a descriptive analysis of these etiologies and graphically represents the information in a figure that shows the seven most frequent etiologies, including the remainder under the category *Others*.

**Susceptibility.** The *Susceptibility* option on the upper na-

vigation menu provides data on the susceptibility of microorganisms to different antibiotics (figure 2A). The user selects a specific microorganism and then selects Hospital or Community origin in the lower pull-down menu. Figure 2A depicts the microorganisms that can be selected. The application extracts from the database the antibiograms created for the selected origin during the time window. It then selects those corresponding to the microorganism under study and calculates its susceptibility to the different antibiotics. Finally, the application graphically represents the results, only including the antibiotics of interest to the user.

**Action.** After selection of the *Action* option from the upper menu, the *Hospital* or *Community* option must be selected (figure 2B). The application then extracts from the database all antibiograms created for the selected setting during the time window. It then analyzes all cases of non-susceptible strains for each antibiotic and calculates the global accumulated activity for the different antibiotics, producing a graphic representation of the results. The calculation of non-susceptible strains also includes those that are inherently resistant to a given antibiotic, as reported above in *Material and Methods*.

## DISCUSSION

This study describes the development of a web application to assist clinicians in the prescription of antibiotics for UTIs. It provides susceptibility profiles and the most likely etiologies based on a local epidemiologic map of susceptibilities as a function of origin within a healthcare area. This knowledge of the behaviour of different antibiotics against UTIs allows them to be preserved if necessary when a reduction in their effectiveness is detected. This application responds to the need for continuous surveillance identified by our group in a previous study of the susceptibility patterns of antibiotics routinely prescribed for UTI treatment in our area[5]. It may also contribute to a reduction in microbiology laboratory costs by avoiding the need for antibiograms in certain situations[9]. The application offers the user different types of valuable data. Thus, the *Etiology* option gives access to updated information on all UTI-causing microorganisms in the different settings, permitting aetiologies to be reviewed as a function of the hospital department or community origin. This is useful for treatment selection and facilitates the detection of epidemic outbreaks. The *Susceptibility* option provides data on bacterial resistance, key information for selecting the appropriate therapy and supporting compliance with antibiotic policies. The *Action* option provides the clinician with the expected percentage activity of an antibiotic when the UTI-causing microorganism is unknown, information of vital importance in prescribing an empiric treatment.

This web application stands alone and requires no other specific technology or application. Although the present database was designed and implemented with Oracle, any other system can be used through the use of Hibernate for data access abstraction. Moreover, a simple modification of the intermediate data processing tool allows it to be adapted to other microbiology information management systems besides MicrobDynamic. Development of this web application was motivated by the following objectives: (1) to improve the treatment of patients with suspected UTI; (2) to enhance the rational use of antibiotics, reducing costs and undesirable effects; and (3) to increase patient safety. A prospective study is warranted to determine whether its routine implementation meets these objectives. A limitation of this application is that it does not consider the history of the patients, their age, sex or clinical situation, the presence of allergies or other adverse reactions to the antibiotics, or the administration route, tolerability, bioavailability, adverse effects, or cost. These parameters have been included in some tools of this type for other diseases and have demonstrated their usefulness[10]. Finally, it should be borne in mind that many patients with an uncomplicated UTI are treated in the community without carrying out a urine culture, which means that this type of sample is under-represented.

The application is currently functioning in different hospital departments in the Granada health area and is being used to gather epidemiological data. The opinion of physicians on the web platform is also being sought with a view to introducing improvements in the future.

In conclusion, this web application provides clinicians with more reliable knowledge on the possible infectious etiology of urinary tract disease, the antibiotic susceptibility of the most frequent pathogens in a specific setting, and the possible activity of empirically prescribed antibiotics.

## REFERENCES

1. Tena D, González-Praetorius A, González JC, Heredero E, Illescas S, de Baranda CS, et al. Changes in the antimicrobial susceptibility of *Escherichia coli* isolates from community diagnosed urinary tract infections during the period 2003-2007. Multicentre study in Castilla la Mancha (Spain). Rev Esp Quimioter 2010; 23:36–42.
2. Alós JI. Epidemiology and etiology of urinary tract infections in the community. Antimicrobial susceptibility of the main pathogens and clinical significance of resistance. Enferm Infecc Microbiol Clin 2005; 23 Suppl 4:3–8.
3. Andreu A, Planells I. Etiology of community-acquired lower urinary infections and antimicrobial resistance of *Escherichia coli*: a national surveillance study. Med Clin (Barc) 2008; 130:481–6.
4. Gobernado M, Valdés L, Alós JI, García-Rey C, Dal-Ré R, García-de-Lomas J. Antimicrobial susceptibility of clinical *Escherichia coli* isolates from uncomplicated cystitis in women over a 1-year period in Spain. Rev Esp Quimioter 2007;20:68–76.
5. Sorlozano A, Jimenez-Pacheco A, de Dios Luna del Castillo J, Sampedro A, Martinez-Brocal A, Miranda-Casas C, et al. Evolution of the resistance to antibiotics of bacteria involved in urinary tract infections: A 7-year surveillance study. Am J Infect Control 2014;42:1033–8.
6. Garcia Garcia MI, Munoz Bellido JL, Garcia Rodriguez JA. In vitro susceptibility of community-acquired urinary tract pathogens to commonly used antimicrobial agents in Spain: a comparative multicenter study (2002-2004). J Chemother 2007; 19:263–70.
7. Sorlózano Puerto A, Gutierrez Fernández J, Luna del Castillo J de D, Soto Pino MJ, Piédrola Angulo G. In vitro activity of β-lactam

and non-β-lactam antibiotics in extended-spectrum β-lactamase-producing clinical isolates of *Escherichia coli*. Diagn Microbiol Infect Dis 2006;54:135–9.

8. Rodriguez-Maresca M, Sorlozano A, Grau M, Rodriguez-Castaño R, Ruiz-Valverde A, Gutierrez-Fernandez J. Implementation of a computerized decision support system to improve the appropriateness of antibiotic therapy using local microbiologic data. Biomed Res Int 2014; 2014:395434.
9. Miller JM. Cost-saving strategies for diagnostic microbiology laboratories. Clin Microbiol Newsl 2013; 35:195–204.
10. Evans RS, Pestotnik SL, Classen DC, Clemmer TP, Weaver LK, Orme JF, et al. A computer-assisted management program for antibiotics and other antiinfective agents. N Engl J Med 1998; 338:232–8.