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ORIGINAL ARTICLE

Preliminary reading of antibiogram by microdilution for clinical isolates in urine culture

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Abstract

Purpose We evaluated a modification of automated antibiograms in urine cultures designed to facilitate the early interpretation of minimum inhibitory concentrations (MICs) and accelerate the targeted treatment of urinary tract infections (UTIs),

Methods A prospective study was conducted of 309 isolates (219 *Enterobacteriaceae*, 75 Enterococcus spp., and 15 non-fermenting Gram-negative bacilli (NFGNB), and a retrospective study of 9 carbapenemase-producing clinical isolates from urine cultures. Colonies grown on conventional isolation plates were inoculated in MicroScan Walkaway system panels and incubated for 7 h, using a MicroScan AutoScan-4 plate reader for preliminary MIC determination by turbidimetry. Resulting antibiograms were compared with definitive antibiograms obtained after incubation for 17 h.

Results Preliminary and definitive readings were concordant for 86.7% of Gram-positive cocci isolates (65/75), 61.6% of Enterobacteriaceae (135/219), and 53.3% of NFGNB. The agreement rate was greater than 90% for most antimicrobials against Gram-positive cocci (94.7% or more) and Enterobacteriaceae, (97.2% or more for 10 of 17 antibiotics) except with nitrofurantoin (89%). The agreement rate was 86.7% or more for most antibiotics against NFGNB apart from piperacillin/tazobactam, aztreonam, amikacin, and ciprofloxacin. Gram-negative bacilli showed the highest differences in MIC values between preliminary and definitive readings.

Conclusions A preliminary antibiogram reading may be useful in urine cultures to reduce the delay before targeted antibiotherapy, especially against *Enterobacteriaceae* and Gram-positive cocci, but not in cases of carbapenemase-producing NFGNB. Further local studies are warranted to evaluate the usefulness of this approach in relation to resistance rates.

Keywords Urinary tract infection · Urine culture · MicroScan Walkaway · Rapid antibiogram · Preliminary reading

Introduction

Escherichia coli is the most common causal agent of urinary tract infections (UTIs), including complicated cases (acute cystitis and pyelonephritis). Other UTIs are produced by *Enterobacteriaceae* (especially *Klebsiella pneumoniae*) and Gram-positive cocci (especially *Enterococcus* spp.) [1]. Some pathogens are more likely to be responsible in certain clinical circumstances, as in the case of *Pseudomonas aeruginosa* in immunocompromised patients [2]. Microorganisms other than bacteria can produce UTIs but are not considered in this study.

UTIs are associated with a high morbidity, especially in females, elderly males, and young children, including frequent recurrences and episodes of pyelonephritis and sepsis, with a mortality rate of up to 50% in cases of severe infection and 80% with septic shock [3]. UTIs are also

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associated with kidney damage, prematurity, and the negative effects of chronic antibiotic use, and their treatment is increasingly hampered by the rise in bacterial resistances [1]. The early and effective treatment of UTIs is therefore essential [4]. Phenotypic analysis based on automated microdilution in culture medium is the reference method for preparing antibiograms [5, 6] using turbidometry, photometry, or fluorimetry [7]. Artificial intelligence-based systems include MicroScan Walkaway (Beckman Coulter, Brea, CA), Phoenix (Becton Dickinson, Sparks, MD), and Vitek 2 (BioMérieux, Marcy-L'Etoile, France) [6], which all comprise a database, algorithm/results interpretation guidelines, and interface [8]. However, there is an interval of around 48 h in all systems between the receipt of samples by the microbiology laboratory and the delivery of a definitive antibiogram. It has been proposed to reduce this interval by shortening the incubation step to only 7 h rather than the minimum of 17 h stipulated by manufacturers; If a correct reading of bacterial susceptibilities can obtained, a more rapid detection of resistances could be achieved [6, 7]. This approach can be combined with bacterial identification methods such as mass spectrometry (MALDI-TOF) or genotypic techniques [9].

The objective of this study was to compare a preliminary clinical reading of bacterial isolates from positive urine cultures after the 7-h incubation of MicroScan Walkaway antibiotic susceptibility panels with the conventional clinical reading obtained after 17 h of incubation.

Material and methods

Sample gathering

During July 2022, 309 bacterial isolates from significant urine cultures obtained in different clinical episodes were prospectively gathered from the Microbiology Laboratory of the Virgen de las Nieves University Hospital (HUVN) of Granada for bacterial susceptibility profile identification and analysis. In addition, nine carbapenemase-producing Gram-negative microorganisms from different episodes were retrospectively collected from frozen clinical isolates of previous urine cultures, including three *K. pneumoniae* (producers of OXA-48-, VIM-, and KPC-type carbapenemases, respectively), two *E. coli* (producers of OXA-48-type carbapenemase), two *Enterobacter cloacae* (producers of OXA-48- and VIM-type carbapenemases, respectively), one *Acinetobacter baummanii* (producer of OXA-23-type carbapenemase), and one *Pseudomonas aeruginosa* (producer of VIM-type carbapenemase); the aim was to characterize the performance of rapid reading in high-resistance cases.

Experimental procedure

The samples were inoculated in CPSO chromogenic medium (Biomerieux®, Marcy L'Etoile, France) and Columbia agar with 5% sheep blood (BioMerieux) and incubated 37ºC during 24 h. After that, bacterial colonies were selected and inoculated into a panel of the MicroScan Walkaway system: NC95 for *Enterobacteriaceae*, NC71 for non-glucose-fermenting Gram-negative bacilli (NGF-GNB), and PC38 for Gram-positive cocci. The panel was introduced into the MicroScan WalkAway incubator, extracted from the incubator after 7 h for a preliminary reading in the MicroScan AutoSCAN device by turbidimetry, and then returned to the incubator to complete 17 h of incubation. Next, a definitive reading was obtained for delivery to the clinician. Results of this definitive antibiogram and the antibiogram obtained from the preliminary reading were entered in a database to compare minimum inhibitory concentration (MIC) profiles (in mg/L) and clinical categories (susceptible, intermediate, or resistant) interpreted according to EUCAST 2022 guidelines [10]. Manufacturer's instructions were always followed, and laboratory staff were always blinded to patient symptoms.

Antibiotics used against *Enterobacteriaceae* were ampicillin, piperacillin/tazobactam, cefuroxime, cefotaxime, cefepime, cefixime, imipenem, ertapenem, gentamicin, tobramycin, amikacin, levofloxacin, nitrofurantoin, fosfomycin, trimethoprim/sulfamethoxazole, colistin, and amoxicillin/clavulanic acid. Antibiotics used against *Enterococcus* spp. were ampicillin, vancomycin, teicoplanin, levofloxacin, nitrofurantoin, fosfomycin, trimethoprim/sulfamethoxazole, daptomycin, and linezolid. Those used against NGF-GNB were piperacillin, piperacillin/tazobactam, ceftazidime, cefepime, imipenem, meropenem, aztreonam, tobramycin, amikacin, ciprofloxacin, and colistin.

Data interpretation

Comparisons between the preliminary and definitive readings of the panels revealed: i) agreement in their assignments of clinical category; ii) minor discrepancy, with the classification of isolates as susceptible at 7 h of incubation and intermediate at 17 h (S/I) or as intermediate at 7 h and resistant at 17 h (I/R); iii) major discrepancy, with their classification as susceptible in the preliminary reading at 7 h and resistant in the definitive reading at 17 h (S/R).

Differences between MIC values were compared between isolates for which there was a discrepancy and those for which there was between-reading agreement, given the possibility that readings could assign the same clinical category (S, I, or R) but different MIC values.

Many antibiotics were studied in one bacterial group alone because of their spectrum of action. The following antibiotics were used in at least two groups: ampicillin, piperacillin-tazobactam, cefepime, imipenem, tobramycin, amikacin, levofloxacin, nitrofurantoin, fosfomycin, trimethoprim-sulfamethoxazole, and colistin.

Statistical analysis

IBM SPSS Statistics 19 was used for data analyses. In a descriptive analysis, absolute and relative frequencies were calculated for qualitative variables and central tendency and dispersion measurements for quantitative variables. Fisher's exact test was used to evaluate the relationship of between-reading agreement/discrepancy with type of microorganism; $p < 0.05$ was considered significant.

Table 1 Relationship of bacterial species in the prospective group

MICROORGANISM	Frequency ($n = 309$)	Percentage (%)
Escherichia coli	137	44.3
Enterococcus faecalis	52	16.8
Klebsiella pneumoniae	43	13.9
Enterococcus faecium	15	4.9
Pseudomonas aeruginosa	15	4.9
Proteus mirabilis	10	3.2
Morganella morganii	7	2.3
Citrobacter freundii	6	1.9
Klebsiella oxytoca	5	1.6
Streptococcus agalactiae	5	1.6
Enterobacter cloacae	4	1.3
Klebsiella aerogenes	3	1.0
Citrobacter koseri	3	1.0
Streptococcus grupo bovis	3	1.0
Serratia marcescens	1	0.3
Providencia stuartii	1	0.3
Enterobacter gergoviae	1	0.3

Results

Prospective study

Among the 309 bacterial isolates in the prospective study, 219 were *Enterobacteriaceae* (70.9%), 75 Gram-positive *cocci* (24.3%), and 15 NGF-GNB (4.9%). The most frequently isolated bacterial species was *E. coli* (44.3%), followed by *E. faecalis* (16.8%), *K. pneumoniae* (13.9%), *E. faecium* (4.9%), and *Pseudomonas aeruginosa* (4.9%). Frequencies of remaining species were lower than 4% (Table 1).

Agreement between preliminary (7 h) and definitive (17 h) readings was obtained in 208 isolates (67.3%), major discrepancies were observed in 90 isolates (29.1%) and minor discrepancies in 11 (3.6%). By bacterial group, the agreement rate was 86.7% for Gram-positive cocci, 61.6% for *Enterobacteriaceae* spp., and 53.3% for NFGNB. The major discrepancy rate was 36.1% for *Enterobacteriaceae* spp., 13.3% for NFGNB, and 12% for Gram-positive cocci (12%). The highest minor discrepancy rate was for Gram-negative bacilli (33.3%) (Table 2).

Among antibiotics used against *Enterobacteriaceae*, the major discrepancy rate was 11% for nitrofurantoin, with an agreement rate of 89% (in 195 of 219 isolates); 9.6% for amoxicillin-clavulanic acid, with an agreement rate of 90.4% (in 197 of 218); and below 6% for the remaining antibiotics, with agreement rates above 90%. The highest agreement rates were for levofloxacin (100%), trimethoprim-sulfamethoxazole (98.6%), cefepime (98.2%), and ertapenem (98.2%) (Table 3).

Among antibiotics used against Gram-positive cocci, the major discrepancy rate was 5.3% for levofloxacin, with an agreement rate of 94.7%; 4% for fosfomycin, with an agreement rate of 96%; and below 3% for the remaining antibiotics, with agreement rates above 97%. The agreement rate was 100% for nitrofurantoin, vancomycin, and teicoplanin and 98.7% for linezolid (Table 4).

Among antibiotics used against NFGNB, the major discrepancy rate was 13.3% for both tobramycin and amikacin, with agreement in 13 of 15 isolates. The minor I/R-type discrepancy rate was higher in this group, unlike in

Table 2 Clinical category agreement between antibiogram readings at 7 h and 17 h by microorganism group

MICROORGANISM	*n*	AGREEMENT *n* (%)		
		Total agreement	Minor discrepancy	Major discrepancy
Gram-positive cocci	75	65/75 (86.7)	1/75 (1.3)	9/75 (12.0)
Enterobacteriaceae	219	135/219 (61.6)	5/219 (2.3)	79/219 (36.1)
Nonfermenting Gram-negative bacilli	15	8/15 (53.3)	5/15 (33.3)	2/15 (13.3)
TOTAL	309	208/309 (67.3)	11/309 (3.6)	90/309 (29.1)

Table 3 Agreement between readings at 7 and 17 h by antibiotic: *Enterobacteriaceae*. Prospective group

ANTIBIOTICS	*n*	Data are expressed in frequency (*n*) and percentage (%)						
		Total agreement				Minor discrepancy		Major discrepancy
		S/S	R/R	I/I	Total	S/I	I/R	S/R
Levofloxacin	219	176(80.4)	41(18.7)	2(0.9)	219(100)	-		-
Trimethoprim/sulfamethoxazole	215*	166(77.2)	45(20.9)	1(0.5)	212(98.6)	-		3(1.4)
Ertapenem	218*	213(97.7)	1(0.5)	-	214(98.2)	-		4(1.8)
Cefepime	219	201(91.8)	14(6.4)	-	215(98.2)	-		4(1.8)
Cefotaxime	218*	194(89.0)	19(8.7)	-	213(97.7)	-		5(2.3)
Gentamicin	218*	192(88.1)	21(9.6)	-	213(97.7)	-		5(2.3)
Amikacin	219	210(95.9)	3(1.4)	-	213(97.3)	-		6(2.7)
Colistin	219	194(88.6)	19(8.7)	-	213(97.3)	-		6(2.7)
Cefixime	219	185(85.3)	26(12)	-	211(97.2)	-		6(2.7)
Tobramycin	218*	187(85.8)	25(11.5)	-	212(97.2)			6(2.8)
Imipenem	209*	200(95.7)	-	1(0.5)	201(96.2)	7(3.3)	-	1(0.5)
Cefuroxime	218*	179(82.1)	30(13.8)	-	209(95.9)	-		9(4.1)
Fosfomycin	219	192(87.7)	16(7.3)	-	208(95.0)	-		11(5.0)
Ampicillin	219	65 (29.7)	142(64.8)	-	207(94.5)	-		12 (5.5)
Piperacillin/tazobactam	219	199(90.9)	6(2.7)	2(0.9)	207(94.5)	5(2.3)	2(0.9)	5(2.3)
Amoxicillin/clavulanic acid	218	164(75.2)	33(15.1)	-	197(90.4)	-		21(9.6)
Nitrofurantoin	219	188(85.8)	7(3.2)	-	195(89.0)	-		24(11)

The "total" column is the sum of the previous three columns. S/I: susceptible at 7 h/intermediate at 17 h. I/R: intermediate at 7 h/resistant at 17 h. S/R: susceptible at 7 h/resistant at 17 h

*Antibiotic not tested in all clinical samples

Table 4 Agreement between readings at 7 and 17 h by antibiotic: Gram-positive cocci. Prospective group

ANTIBIOTICS	*n*	Data are expressed in frequency (*n*) and percentage (%)					
		Total agreement			Minor discrepancy		Major discrepancy
		S/S	R/R	Total	S/I	I/R	S/R
Nitrofurantoin	67*	67(100)	-	67(100)	-		-
Vancomycin	75	75(100)	-	75(100)	-		-
Teicoplanin	72*	72(100)	-	72(100)	-		-
Linezolid	75	74(98.7)	-	74(98.7)	1(1.3)	-	-
Daptomycin	75	73(97.3)	-	73(97.3)	-		2(2.7)
Trimethoprim/sulfamethoxazole	72*	44(58.7)	26(34.7)	70(97.2)	-		2(2.8)
Ampicillin	72*	56(77.8)	14(19.4)	70(97.2)	-		2(2.8)
Fosfomycin	75	71(94.7)	1(1.3)	72(96.0)	-		3(4.0)
Levofloxacin	75	46(61.3)	25(33.3)	71(94.7)	-		4(5.3)

The "total" column is the sum of the previous three columns. S/I: susceptible at 7 h/intermediate at 17 h. I/R: intermediate at 7 h/resistant at 17 h. S/R: susceptible at 7 h/resistant at 17 h

* Antibiotic not tested in all clinical samples

Enterobacteriaceae and Gram-positive cocci, being 26.7% for ciprofloxacin and 20% for both piperacillin-tazobactam and aztreonam. The minor S/I-type discrepancy rate was 33.3% for amikacin. The agreement rate was 100% for colistin and 86.7% for cefepime, imipenem, tobramycin, piperacillin, ceftazidime, and meropenem (Table 5).

MIC values were also analyzed by bacterial group. Among *Enterobacteriaceae* (219 isolates), differences in MIC values were most frequent for fosfomycin (54 isolates), followed by amoxicillin-clavulanic acid (45) and cefuroxime (33), and they were least frequent for trimethoprim-sulfamethoxazole (3), followed by gentamicin (5) and ertapenem (5). Finally, the median number of differences in MIC values was compared between early and definitive readings for isolates from different groups, finding more differences with one dilution for all antibiotics apart from piperacillin-tazobactam, ertapenem, trimethoprim-sulfamethoxazole, and amoxicillin-clavulanic acid, which showed more differences with two dilutions (Table S1). In Gram-positive *cocci* (75 isolates), differences in MIC were most frequent for daptomycin (in 43), linezolid (in 38), and vancomycin (in 29) and least frequent for teicoplanin (in 2), nitrofurantoin (in 3), and trimethoprim-sulfamethoxazole (in 5). The median number of differences in MIC values was always with one dilution except for levofloxacin (median of 1.5) (Table S2). In NFGNB (15 isolates), differences in MIC values were most frequent for ceftazidime (in 12) and azithromycin (in 10) and were least frequent for colistin (in 1) and tobramycin (in 2). The median number of differences in MIC values was with one dilution for amikacin and ceftazidime, with two dilutions for cefepime, imipenem, colistin, meropenem, aztreonam, and ciprofloxacin, and with three dilutions for piperacillin, piperacillin-tazobactam, and tobramycin (Table S3).

Group of carbapenemase-producing isolates in general

Carbapenemase-producing Gram-negative bacilli in the prospective and retrospective groups were considered together, summing 12 carbapenemase-producing isolates. There was agreement on clinical category in 2 of the 10 isolates from the *Enterobacteriaceae* group and a minor discrepancy in the 8 remaining isolates. Agreement was obtained in one of the two isolates from NFGNB (*A. baumannii*), while there was a minor discrepancy in the other (*P. aeruginosa*), with no major discrepancies.

Among the 10 carbapenemase-producing isolates ($n = 10$), a major discrepancy was most frequent with nitrofurantoin (5 isolates) and ertapenem (2 isolates), while a minor discrepancy was most frequent with imipenem (4, including 3 I/R) and piperacillin-tazobactam (3, including 2 I/R). Agreement was obtained in 100% of isolates with ampicillin, amoxicillin-clavulanic acid, cefuroxime, cefixime, trimethoprim-sulfamethoxazole, piperacillin, ceftazidime, and aztreonam, but in 50% of isolates with meropenem, ciprofloxacin, and nitrofurantoin (Table 6).

Discussion

The microbiological profile of the UTI samples in this study is comparable to that in previous investigations. Thus, *E. coli* was the most frequent causal agent (44.3%), as reported worldwide [11, 12] and in Spain [13], followed

Table 5 Agreement between readings at 7 and 17 h by antibiotic: nonfermenting Gram-negative bacilli. Prospective group

ANTIBIOTICS	*n*	Data are expressed in frequency (*n*) and percentage (%)						
		Total agreement				Minor discrepancy		Major discrepancy
		S/S	R/R	I/I	Total	S/I	I/R	S/R
Colistin	15	15(100)	-	-	15(100)	-		-
Cefepime	15	-	1(6.7)	12(80.0)	13(86.7)	-	2(13.3)	-
Ceftazidime	15	-	1(6.7)	12(80.0)	13(86.7)	-	2(13.3)	-
Imipenem	15	-	-	13(86.7)	13(86.7)	-	2(13.3)	-
Meropenem	15	12(80.0)	1(6.7)	-	13(86.7)	1(6.7)	1(6.7)	-
Tobramycin	15	12(80.0)	1(6.7)	-	13(86.7)	-		2(13.3)
Piperacillin	15	-	1(6.7)	12(80.0)	13(86.7)	-	2(13.3)	-
Piperacillin/tazobactam	15	-	-	12(80.0)	12(80.0)	-	3(20.0)	-
Aztreonam	15	-	-	12(80.0)	12(80.0)	-	3(20.0)	-
Ciprofloxacin	15	-	1(6.7)	10(66.7)	11(73.3)	-	4(26.7)	-
Amikacin	15	8(53.3)	-	-	8(53.3)	5(33.3)	-	2(13.3)

The "total" column is the sum of the previous three columns. S/I: susceptible at 7 h/intermediate at 17 h. I/R: intermediate at 7 h/resistant at 17 h. S/R: susceptible at 7 h/resistant at 17 h

Table 6 Agreement between readings at 7 and 17 h by antibiotic in the group of carbapenemase-producing microorganisms (prospective plus retrospective group)

ANTIBIOTICS	*n*	Data are expressed in frequency (*n*) and percentage (%)						
		Total agreement				Minor discrepancy		Major discrepancy
		S/S	R/R	I/I	Total	S/I	I/R	S/R
Ampicillin	10*	-	10	-	10/10 (100.0)	-		-
Amoxicillin/clavulanic acid	10*	-	10	-	10/10 (100.0)	-		-
Cefuroxime	10*	1	9	-	10/10 (100.0)	-		-
Cefixime	10*	1	9	-	10/10 (100.0)	-		-
Trimethoprim/sulfamethoxazole	10*	2	8	-	10/10 (100.0)	-		-
Piperacillin	2*	-	2	-	2/2(100.0)	-		-
Ceftazidime	2*	-	2	-	2/2(100.0)	-		-
Aztreonam	2*	-	1	1	2/2(100.0)	-		-
Cefepime	12	2	9	-	11/12(91.7)	-		1 (8.3)
Tobramycin	12	1	10	-	11/12(91.7)	-		1 (8.3)
Amikacin	12	10	1	-	11/12(91.7)	1 (8.3)	-	-
Colistin	12	11	-	-	11/12(91.7)	-		1 (8.3)
Gentamicin	10*	1	8	-	9/10(90.0)	-		1(10.0)
Levofloxacin	10*	3	6	-	9/10(90.0)	1(10.0)	-	-
Fosfomycin	10*	9	-	-	9/10(90.0)	-		1(10.0)
Ertapenem	10*	1	7	-	8/10(80.0)	-		2 (20.0)
Cefotaxime	10*	1	7	-	8/10 (80.0)	-	2 (20.0)	-
Piperacillin/tazobactam	12	-	9	-	9/12(75)	1 (8.3)	2 (16.7)	-
Imipenem	12	6	2	-	8/12 (66.7)	1 (8.3)	3 (25.0)	-
Meropenem	2*	-	1	-	1/2(50.0)	-	1(50.0)	-
Ciprofloxacin	2*	-	1	-	1/2(50.0)	-	1 (50.0)	-
Nitrofurantoin	10*	5	-	-	5/10 (50.0)	-		5 (50.0)

The "agreement" column is the sum of the previous three columns. S/I: susceptible at 7 h/intermediate at 17 h. I/R: intermediate at 7 h/resistant at 17 h. S/R: susceptible at 7 h/resistant at 17 h

* Antibiotic not tested in all clinical samples

by *Enterococcus* spp. (21.7%) and *K. pneumoniae* (13.9%). In the review by Wagenlehner et al. [12], *E. faecalis* was a slightly more frequent cause of non-complicated cystitis in comparison to *K. pneumoniae,* whereas *K. pneumoniae* was more commonly responsible for complicated cystitis (13% of cases), pyelonephritis (13%), and urinary sepsis (10%). However, Andreu et al. [13] found that 6.8% of UTI episodes were caused by *Klebsiella* spp., 6.6% by *Proteus* spp., and 5.5% by *Enterococcus* spp.. In the present study, *K. pneumoniae* was responsible for 5.5% of third-generation cephalosporin-resistant *Enterobacteriaceae* and *E. coli* for 4.1%, lower percentages than reported in other studies for total *Enterobacteriaceae* [7, 14].

Prospective study

The design of this prospective study in urine culture samples was based on the similar investigation by Sánchez et al. in blood culture samples [7]

Agreement by microorganism group

In the present study, the percentage agreement was 86.7% for Gram-positive cocci, 61.6% for *Enterobacteriaceae*, and 53.3% for NFGNB. The percentage of major discrepancies was 12% for Gram-positive cocci, 36.1% for *Enterobacteriaceae* and 13.3% for NFGNB. In the most similar study available [7], 97 isolates of the *Enterobacteriaceae* group (with no NFGNB) were incubated in panels of the MicroScan system for a mean of 7.10 h, obtaining a percentage category agreement with the reading at 17 h of 89.9% and a major discrepancy rate of 6.9%. The higher rates obtained in comparison to the present study are likely due to our adoption of more restrictive criteria, considering a variation in the MIC value of any antibiotic as a minor discrepancy (i.e., non-agreement). The largest number of minor discrepancies was for NFGNB, which may indicate that 7 h of incubation is too short for preliminary readings in this bacterial group. It is not known whether discrepancies between the

studies are influenced by differences between urine and blood cultures.

Agreement by antibiotic type

Among *Enterobacteriaceae*, the lowest total agreement rate was obtained for nitrofurantoin (89%), largely due to a major discrepancy rate of 11%. All other antibiotics had a total agreement rate above 90%, although it was slightly lower for imipenem and piperacillin-tazobactam, mainly due to minor discrepancies. Sánchez et al. [7] observed an agreement rate above 90% for almost all antibiotics tested, recording the lowest rates for amoxicillin-clavulanic acid (78%) and tobramycin (80.4%) and the highest for levofloxacin (95.2%), lower than the respective rates of 90.4%, 97.2%, and 100% in our study. The minor discrepancy rate for *Enterobacteriaceae* (up to 20.9% with amoxicillin-clavulanic acid) was much higher than in our study, while the highest major discrepancy rates were for tobramycin and cefotaxime.

Among Gram-positive cocci, the total agreement rate was 100% for nitrofurantoin, vancomycin, and teicoplanin, while there were major discrepancy rates of 4% for fosfomycin and 5.3% for levofloxacin. The preliminary reading approach appears useful in infections for which nitrofurantoin might be a treatment of choice, such as non-complicated UTIs [15], or in infections due to *E. faecium*, for which beta lactams would be contraindicated in favor of vancomycin, linezolid, or daptomycin [16].

Among NFGNB, the total agreement rate was 100% for colistin but 86.7% or lower for the rest, with tobramycin and amikacin both showing major discrepancies in 13.3% of cases. Accordingly, the preliminary reading appears to be less reliable for NFGNB than for the other bacterial groups, although it may be useful to reduce the delay in treatment in the case of colistin, especially in patients with very limited therapeutic options.

Carbapenemase-producing isolates

Sánchez et al. [7] included three isolates of *E.coli* AmpC, which were all detected by the rapid evaluation method. To date, no studies have added a sample of multiresistant microorganisms. In the carbapenemase-producing Gram-negative bacilli selected for the present investigation, ertapenem showed a major discrepancy rate above 20%, while meropenem had a total agreement rate of 100% in one of two tests, and one minor discrepancy in the other, passing from intermediate to resistant. Imipenem showed a total agreement rate of only 66.7%; however, a total agreement rate of 100% was recorded for amoxicillin-clavulanic, cefuroxime, cefixime, and ceftazidime, allowing detection of resistance to 3rd-generation cephalosporins in the preliminary reading and a more rapid therapeutic response to the possible production of broad spectrum beta lactams and/or carbapenemases.

Limitations

Future studies should not be limited to a single type of clinical sample and should have larger samples of microorganisms, including high-resistance types. A further limitation was the use of a single time point for the early reading at 7 h of incubation. Different time intervals should be tested in future studies to identify the optimal timing of the preliminary reading.

Conclusions

Agreement between readings for the tested antibiotics was above 90% in most cases, both in Gram-positive cocci and *Enterobacteriaceae*, and was above 80% in NFGNB. These findings support the usefulness of an early antibiogram reading in urine cultures to reduce the delay before administration of targeted antibiotherapy. However, wider studies are required in different microbiology laboratories to verify the benefits of this approach in clinical practice.

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Declarations

Ethics approval The study complied with the principles of the Helsinki Declaration. The informed consent of patients was not required, because the biological material was used solely for the standard diagnosis of genital tract infection by attending physicians with no addition to routine procedures, in accordance with WHO ethical guidelines for health-related research in humans. There were no additional samplings or modifications to the laboratory diagnostic protocol. Permission to access and analyze the data was granted by the Clinical Microbiology Management Unit of our hospital.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflicts of interest The authors declare that they have no conflicts of interest.

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