

Analysis of the Comparative Workflow and Performance Characteristics of the VITEK 2 and Phoenix Systems

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The VITEK 2 (bioMérieux, Marcy L'Étoile, France) and the Phoenix systems (BD Diagnostic Systems, Sparks, Md.) are automated instruments for rapid organism identification and susceptibility testing. We evaluated the workflow, the time to result, and the performance of identification and susceptibility testing of both instruments. A total of 307 fresh clinical isolates were tested: 141 *Enterobacteriaceae*, 22 nonfermenters, 93 *Staphylococcus* spp., and 51 *Enterococcus* spp. Manipulation time was measured in batches, each with seven isolates, for a total of 39 batches. The mean (\pm standard deviation [SD]) manipulation time per batch was 20.9 \pm 1.8 min for Phoenix and 10.6 \pm 1.0 min for VITEK 2 ($P < 0.001$). Mean (\pm SD) time to result for all bacterial groups was 727 \pm 162 min for Phoenix and 506 \pm 120 min for VITEK 2 ($P < 0.001$). Concerning identification, Phoenix and VITEK 2 yielded the same results for nonfermenters (100%), staphylococci (97%), and enterococci (100%). For 140 *Enterobacteriaceae* strains evaluated, 135 (96%) were correctly identified by Phoenix and 137 (98%) by VITEK 2 ($P = 0.72$). The overall category agreement for all isolates was 97.0% for both instruments. The minor error rate, major error rate, and very major error rate for all bacterial isolates tested were 3.0, 0.3, and 0.6 and 2.8, 0.2, and 1.7 for Phoenix and VITEK 2, respectively (P values of 0.76, 0.75, and 0.09). The VITEK 2 system required less manual manipulation time and less time than the Phoenix system to yield results.

Automated identification and susceptibility test systems significantly advanced clinical microbiology. Fast and reliable results which improve clinical outcomes and the reduction of costs have been noted by several authors (2, 3, 5). Various systems have been presented during the last years, such as the Vitek Classic (bioMérieux, Marcy L'Étoile, France), the more automated VITEK 2 (bioMérieux) and Microscan Walkaway (Dade-Behring MicroScan, Sacramento, CA), and the recently developed Phoenix system (BD Diagnostic Systems, Sparks, Md.).

Fast results provided by these instruments are not only due to short incubation times for identification (ID) and antimicrobial susceptibility testing (AST) of bacterial isolates but also to hands-on time for setting up the different devices. We compared the different manipulation steps required by the VITEK 2 and Phoenix systems for setting up bacterial isolates for ID and AST. Additionally, the time to result was recorded for each system. The workflow analysis was the main focus of this evaluation; however, efficient workflow must generate accurate results. Therefore, performance characteristics with regard to ID and AST were also investigated. ID results were compared to API systems (bioMérieux), and AST results were compared to standard broth microdilution as recommended by the National Committee for Clinical Laboratory Standards (NCCLS) (14).

(The findings of this study were partly presented at the 103rd Gen. Meet. Am. Soc. Microbiol., abstr. C-250, 2003.)

MATERIALS AND METHODS

Bacterial isolates. A total of 307 fresh clinical isolates comprising 141 strains of the family *Enterobacteriaceae*, 22 nonfermenting gram-negative bacilli (NFGNB), 93 *Staphylococcus* spp., and 51 *Enterococcus* spp. were tested in this study (Table 1). The clinical strains were collected in the routine lab of the Laboratory Group Heidelberg from various specimens (blood cultures, wound specimens, tracheal aspirates, and urine).

The collection included various phenotypes with special resistance mechanisms: 11 *Enterobacteriaceae* isolates with extended-spectrum beta-lactamases (ESBL), 18 methicillin-resistant *Staphylococcus aureus* (MRSA) isolates, and 18 methicillin-resistant coagulase-negative *Staphylococcus* spp. Prior to testing, each isolate was subcultured twice on Columbia agar with 5% defibrinated sheep blood (Unipath, Wesel, Germany). Manipulation time was measured in batches, each with seven isolates. Thirty-nine (39) batches, comprising a total of 273 isolates, were tested. For all 307 isolates time to results (TTR) and ID and AST performance was evaluated.

Phoenix. For the Phoenix system, the combined ID and AST NMIC/ID 14 panel for gram-negative bacilli and the PMIC/ID 13 panel for gram-positive cocci were used. The setup of the panels was performed according to the manufacturer's instructions. The Phoenix ID broth was inoculated with bacterial colonies from Columbia blood agar and adjusted to a 0.5 to 0.6 McFarland standard using the Crystal Spec Nephelometer (BD Diagnostic Systems). After supplementing the AST broth with one drop of indicator dye, 25 μ l of the ID suspension was transferred to the AST broth to achieve a final inoculum density of 1.5×10^8 CFU/ml. The ID and the AST broths were poured into the respective side of the panel placed on the Phoenix inoculation station. The inoculated panels were closed and placed into the transport caddy, and, after entering the accession number, the panels were placed into the Phoenix instrument.

VITEK 2. For ID testing with VITEK 2, the ID-GPC card was used for gram-positive cocci and the ID-GNB card was used for gram-negative rods. For AST, the AST-P 523 panel was used for gram-positive cocci and the AST-N021 card was used for gram-negative bacilli. A sufficient number of colonies was suspended in sterile saline (0.45%) and adjusted to a 0.5 McFarland turbidity standard using the DensiChek Densitometer (bioMérieux). The inoculated tube was placed in a cassette on the VITEK 2 Smart Carrier Station. The sample number was entered and associated with an ID and AST card. The sample accession numbers and card identification bar code numbers were scanned, and the information was stored on the cassette memory chip. The SCS cassette with the cards and the test tubes was placed on the VITEK 2 instrument where the inoculation of the AST cards was automatically performed by the instrument.

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TABLE 1. Isolates tested

| Isolate ^a | n |
|------------------------------------------|-----|
| <i>Escherichia coli</i> (ESBL pos.)..... | 4 |
| <i>Escherichia coli</i> (ESBL neg.)..... | 26 |
| <i>Klebsiella</i> spp. (ESBL pos.)..... | 7 |
| <i>Klebsiella</i> spp. (ESBL neg.)..... | 29 |
| <i>Proteus</i> spp. | 16 |
| <i>Providencia</i> spp. | 5 |
| <i>Serratia</i> spp. | 15 |
| <i>Citrobacter</i> spp. | 9 |
| <i>Enterobacter</i> spp. | 17 |
| <i>Morganella morganii</i> | 8 |
| Other <i>Enterobacteriaceae</i> | 5 |
| <i>Pseudomonas</i> spp. | 14 |
| <i>Acinetobacter</i> spp. | 8 |
| Total..... | 163 |
| MRSA..... | 31 |
| MSSA ^b | 18 |
| <i>S. epidermidis</i> | 22 |
| <i>S. haemolyticus</i> | 8 |
| <i>S. lugdunensis</i> | 2 |
| <i>S. simulans</i> | 3 |
| <i>S. sciuri</i> | 1 |
| <i>S. saprophyticus</i> | 1 |
| <i>S. capitis</i> | 1 |
| Other CoNS ^c | 6 |
| <i>E. faecalis</i> | 50 |
| <i>E. faecium</i> | 1 |
| Total..... | 144 |

^a pos., positive; neg., negative.

^b MSSA, methicillin-sensitive *S. aureus*.

^c CoNS, coagulase-negative staphylococci.

Antibiotics. The following antimicrobial agents were tested: for *Enterobacteriaceae* and NFGNB, ampicillin, piperacillin, piperacillin-tazobactam, meropenem, ceftazidime, ceftazidime, cefepime, and levofloxacin; for staphylococci, penicillin, oxacillin, erythromycin, clindamycin, teicoplanin, vancomycin, rifampin, ofloxacin, gentamicin, tetracycline, and cotrimoxazol; for enterococci, teicoplanin, vancomycin, and tetracycline.

Reference system. For ID, the API 20 E, ID 32 GN, API 32 Staph, and API 32 Strep systems (bioMérieux) were used as comparator systems. Frozen microdilution panels (Biotest AG, Dreieich, Germany) were used as the reference method for AST. These panels were set up according to NCCLS guidelines (14).

Detection of special resistance mechanisms. MRSA were detected by Oxascreen Agar (BD Diagnostic Systems). Additionally, the presence of the *mecA* gene was determined by an in-house PCR test using the following primers: 5'-ACA TCT ATT AGG TTA TGT TGG-3' and 5'-TAT ATT CTT CGT TAC TCA TGC-3'. Gel electrophoresis was performed for the detection of the 492-bp amplification products. The ESBL resistance mechanism was detected using the combined disk methods recommended by NCCLS (14).

Quality control. The following reference strains were used for AST according to NCCLS guidelines (13): *Escherichia coli* ATCC 25922, *E. coli* ATCC 35218, *Pseudomonas aeruginosa* ATCC 27853, *S. aureus* ATCC 29213, *Enterococcus faecalis* ATCC 29212, *S. aureus* ATCC 43300, and *Klebsiella pneumoniae* ATCC 700603.

Workflow. The average manipulation time required to set up each system was determined for 39 batches of seven organisms each. Two skilled technicians were involved in the practical procedure. Using a stopwatch, all steps were timed by an observer not involved in the testing process. The following steps associated with the workflow were included: preparation of bench and devices, adjustment of McFarland standard of 0.5 to 0.6 with bacterial inoculum, setup of VITEK 2 cards and Phoenix panels, loading of the system, entry of accession numbers, and the follow-up work. The details associated with the manipulation steps are provided in Table 2. Considering that the procedures of both systems are not exactly identical, similar workflow steps were directly compared, whereas differing steps are mentioned separately. Additionally, the time for maintenance of both instruments was measured twice during the study of approximately two months.

Data analysis. For workflow analysis the average time to perform each step was calculated over the 39 batches. After completing analysis to determine an appropriate statistical approach a one-way analysis of variance test was applied to compare the workflow times of the two systems. AST data indicated a similar

TABLE 2. Average manipulation time of VITEK 2 and Phoenix (calculated for 39 batches, each with seven isolates)

| Workflow | VITEK 2 | | Phoenix | |
|---------------------|------------------------------------------------------------------------------|----------|------------------------------------------------------------------------------------------|----------|
| | Step(s) | Time (s) | Step(s) | Time (s) |
| Preprocessing | Organize bench with supplies | 19 | Organize bench with supplies | 19 |
| | Label purity plates | 15 | Label purity plates | 16 |
| | Label tubes with saline ^a | 44 | Label ID broth ^a | 56 |
| | Dispense saline | 12 | | |
| Inoculum adjustment | Make suspension and check with DensiChek or vortex | 230 | Inoculate ID broth and check with crystal spec or vortex | 462 |
| Panel preparation | Inoculate purity plate | 47 | Inoculate purity plate | 67 |
| | Open package | 63 | Drop indicator in AST broth | 67 |
| | | | Transfer 25 µl from ID to AST broth | 137 |
| | | | Open package and label panels | 107 |
| | | | Place ID and AST broth in inoculation station and inoculate panels with ID and AST broth | 96 |
| | | | Close the panels | 32 |
| | | | Put panels in transport caddy | 17 |
| System loading | Enter accession no., read barcode on SCS ^b , put card on SCS rack | 138 | Enter accession number and put panels in Phoenix | 113 |
| | Put carrier in VITEK2 | 9 | | |
| Postprocessing | Put purity plates in incubator | 46 | Put purity plates in incubator | 46 |
| | Remove panels from instrument and throw away | 13 | Remove panels from instrument and throw away | 17 |
| Total per batch | | 636 | | 1,252 |

^a Labeling was done for the study but is optional for routine procedures.

^b SCS, smart carrier station.

TABLE 3. Maintenance of instruments

| Interval | Automated instrument | | | |
|--------------|-------------------------------------------|--------------|------------------------------------------|--------------|
| | VITEK 2 | | Phoenix | |
| | Step | Time (min:s) | Step | Time (min:s) |
| Daily | | | Temperature | 00:15 |
| | | | Calibration of CrystalSpec | 00:25 |
| Every 3 days | Filling of tips and changing of NaCl bags | 02:00 | | |
| Weekly | Cleaning of optic system | 07:00 | | |
| Monthly | Calibration of DensiCheck | 00:11 | Signal lamps, acoustic and visual alarms | 01:13 |
| | Cleaning carousel, boats, optical devices | 15:00 | | |

approach was reasonable to assess differences between the average TTR for the VITEK 2 and Phoenix systems. Thus, a one-way analysis of variance test with multiple comparisons was used. To examine the accuracy of clinical interpretations, the rates of correct ID were compared for each organism group. For AST, category agreement (CA), minor errors (mE), major errors (ME), and very major errors (VME) were calculated as defined by the U.S. Food and Drug Administration guidance document for each organism group (4). Differences between correct ID, CA, and error rates were evaluated for significance using Fisher's exact test.

RESULTS

Workflow. The results of the different steps of the manipulation time are shown in Table 2. The steps associated with the workflow of each system were timed for 39 batches of seven organisms. The mean time ± standard deviation (SD) of 20.9 ± 1.8 min per batch for Phoenix was significantly longer than 10.6 min ± 1.0 min per batch for VITEK 2 (P < 0.001). The mean time to prepare one isolate using the Phoenix system was 3.0 min and for VITEK 2 was 1.5 min, resulting in a time savings of 1.5 min per organism. The mean values of the two measurements of the instrument maintenance are included in Table 3. Over a 30-day period the Phoenix instrument required 21.2 min for maintenance and the VITEK 2 required 63.2 min.

TTR. TTR data of the completed ID and AST results are included in Table 4. Mean (±SD) AST results for *Enterobacteriaceae*, NFGNB, staphylococci, and enterococci were available in 701 ± 154 min, 851 ± 134 min, 775 ± 161 min, and 660 ± 145 min with the Phoenix instrument; with VITEK 2 results were obtained in 451 ± 76 min, 679 ± 178 min, 514 ± 123 min, and 566 ± 71 min, respectively. For each bacterial group the mean TTR was significantly greater for Phoenix when compared to VITEK 2 (all P values were <0.001). The overall mean (±SD) TTR for the Phoenix system was 727 ± 162 min,

significantly higher than the result of 506 ± 120 min for the VITEK 2 system. Analysis of the TTR differences from pairing by organisms for all strains indicated that the overall mean difference between results was 221 min longer for Phoenix (P < 0.001).

ID. Of the 141 *Enterobacteriaceae* strains tested, 135 (96%) were correctly identified by the Phoenix system and 137 (98%) were correctly identified by the VITEK 2 system; both systems identified 100% of the 22 NFGNB tested (Table 4). For staphylococci, both systems achieved an accuracy of 97% for 93 isolates tested. Two strains (one *Enterobacteriaceae* isolate, one *Staphylococcus* spp.) could not be resolved by the API reference method and were therefore not used for evaluation. For 51 enterococci, both systems correctly identified 100% of the isolates to the species level. Two of the species required motility tests to resolve correct ID of the isolates.

AST. The overall category agreement for all isolates was 97.0% for both instruments. The minor error rates, major error rates, and very major error rates for all bacterial isolates tested were 3.0, 0.3, and 0.6 and 2.8, 0.2, and 1.7 for Phoenix and VITEK 2, respectively (P values of 0.76, 0.75, and 0.09). The AST results of all single antimicrobials and organisms included in this study are shown in Table 5. The 11 ESBL-producing *Enterobacteriaceae* isolates were correctly detected by Phoenix; VITEK 2 missed one *K. oxytoca* isolate. The oxacillin resistance mechanism was correctly detected by both systems.

DISCUSSION

The main purpose of this study was to compare the setup workflow for the Phoenix and the VITEK 2 systems. However, in addition to efficient workflow, the TTR and reliability of the AST and ID results are also of importance. Therefore, the accuracy of ID and the AST performance parameters were calculated and are discussed.

Workflow. An important issue when conducting workflow comparative studies is the experience of the technicians with each system. Our technicians were well trained and experienced in the operation of both systems, as several previous studies have been performed with both of these systems (7 and U. Eigner, A. Caganic, D. Schuhmacher, R. Englert, and A. M. Fahr, Abstr. 99th Gen. Meet. Am. Soc. Microbiol. 1999, abstr. C-85, 1999, and A. M. Fahr, U. Wild, and U. Eigner, Abstr. 13th Eur. Cong. Clin. Microbiol. Infect. Dis. 2003, abstr. P-755, 2003). In this study, the mean time to set up one bacterial isolate was 3.0 min for the Phoenix system and 1.5 min for the VITEK 2 system (P < 0.001). The longer hands-on time for the

TABLE 4. Identification results for VITEK 2 and Phoenix

| Bacterial group | No. of isolates tested | % of IDs | | | |
|---------------------------|------------------------|-----------------|------------|------------------|------------|
| | | VITEK 2 | | Phoenix | |
| | | Concordant | Discordant | Concordant | Discordant |
| <i>Enterobacteriaceae</i> | 140 ^a | 98 ^c | 2 | 96 ^d | 4 |
| Nonfermenters | 22 | 100 | 0 | 100 | 0 |
| Staphylococci | 92 ^a | 97 | 3 | 97 | 3 |
| Enterococci | 51 | 100 | 0 | 100 ^b | 0 |

^a One isolate was not solved by the reference method.
^b Motility test solved two discrepancies.
^c Three isolates incorrect for genus.
^d Three isolates incorrect for genus, two isolates incorrect only for species.

TABLE 5. Susceptibility test results for VITEK 2 and Phoenix

| Bacterial group | Antibiotic(s) | No. of isolates tested ^a | | | | Total no. of isolates | VITEK 2 | | | | | | | | Phoenix | | | | | |
|---------------------------|-------------------------|-------------------------------------|-------|-----|-------|-----------------------|---------|------|-----|------|-------|-------|------|----|---------|-----|------|-------|------|------|
| | | S | I | R | n | | | | % | | | | n | | | % | | | | |
| | | | | | mE | | ME | VME | CA | mE | ME | VME | CA | mE | ME | VME | CA | | | |
| <i>Enterobacteriaceae</i> | Ampicillin | 24 | 4 | 113 | 141 | 1 | | 0.7 | 0.0 | 0.0 | 99.3 | 3 | 1 | | 2.1 | 4.2 | 0.0 | 97.2 | | |
| | Piperacillin | 90 | 11 | 40 | 141 | 4 | 2 | 2.8 | 0.0 | 5.0 | 95.7 | 4 | | | 2.8 | 0.0 | 0.0 | 97.2 | | |
| | Piperacillin-tazobactam | 121 | 8 | 12 | 141 | 11 | | 7.8 | 0.0 | 0.0 | 92.2 | 7 | 1 | | 5.0 | 0.8 | 0.0 | 94.3 | | |
| | Cefazolin | 42 | 7 | 92 | 141 | 9 | 4 | 6.4 | 0.0 | 4.3 | 90.8 | 4 | | 2 | 2.8 | 0.0 | 2.2 | 95.7 | | |
| | Cefepime | 134 | 1 | 6 | 141 | 2 | 1 | 1.4 | 0.0 | 16.7 | 97.9 | 3 | | | 2.1 | 0.0 | 0.0 | 97.9 | | |
| | Cefuroxim | 60 | 16 | 65 | 141 | 3 | | 2.1 | 0.0 | 0.0 | 97.9 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Cefotaxime | 124 | 4 | 13 | 141 | 5 | | 3.5 | 0.0 | 0.0 | 96.5 | 8 | | | 5.7 | 0.0 | 0.0 | 94.3 | | |
| | Ceftazidime | 125 | 4 | 12 | 141 | 6 | | 4.3 | 0.0 | 0.0 | 95.7 | 5 | | | 3.5 | 0.0 | 0.0 | 96.5 | | |
| | Meropenem | 141 | 0 | 0 | 141 | | | 0.0 | 0.0 | 0.0 | 100.0 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Ciprofloxacin | 113 | 3 | 25 | 141 | 3 | | 2.1 | 0.0 | 0.0 | 97.9 | 7 | | | 5.0 | 0.0 | 0.0 | 95.0 | | |
| | Levofloxacin | 114 | 9 | 18 | 141 | 13 | | 9.2 | 0.0 | 0.0 | 90.8 | 9 | | | 6.4 | 0.0 | 0.0 | 93.6 | | |
| | Gentamicin | 120 | 4 | 17 | 141 | 5 | | 3.5 | 0.0 | 0.0 | 96.5 | 6 | | | 4.3 | 0.0 | 0.0 | 95.7 | | |
| | Total | | 1,208 | 71 | 413 | 1,692 | 62 | 0 | 7 | 3.7 | 0.0 | 1.7 | 95.9 | 56 | 2 | 2 | 3.3 | 0.2 | 0.5 | 96.5 |
| Nonfermenters | Piperacillin | 13 | 2 | 7 | 22 | | | 0.0 | 0.0 | 14.3 | 95.5 | 1 | | | 4.5 | 0.0 | 0.0 | 95.5 | | |
| | Piperacillin-tazobactam | 18 | 0 | 4 | 22 | 1 | | 4.5 | 0.0 | 0.0 | 95.5 | 2 | | | 9.1 | 0.0 | 0.0 | 90.9 | | |
| | Cefepime | 17 | 3 | 2 | 22 | 4 | | 18.2 | 0.0 | 0.0 | 81.8 | 5 | | | 22.7 | 0.0 | 0.0 | 77.3 | | |
| | Cefotaxime | 5 | 6 | 11 | 22 | 3 | | 13.6 | 0.0 | 0.0 | 86.4 | 4 | 1 | | 18.2 | 0.0 | 9.1 | 77.3 | | |
| | Ceftazidime | 14 | 4 | 4 | 22 | 5 | 1 | 22.7 | 0.0 | 25.0 | 72.7 | 3 | 1 | | 13.6 | 0.0 | 25.0 | 81.8 | | |
| | Meropenem | 17 | 2 | 3 | 22 | 4 | 1 | 18.2 | 0.0 | 33.3 | 77.3 | 6 | | | 27.3 | 0.0 | 0.0 | 72.7 | | |
| | Ciprofloxacin | 11 | 2 | 9 | 22 | 2 | | 9.1 | 0.0 | 0.0 | 90.9 | 1 | | | 4.5 | 0.0 | 0.0 | 95.5 | | |
| | Levofloxacin | 11 | 4 | 7 | 22 | 3 | | 13.6 | 0.0 | 0.0 | 86.4 | 4 | | | 18.2 | 0.0 | 0.0 | 81.8 | | |
| | Gentamicin | 16 | 0 | 6 | 22 | 1 | | 4.5 | 0.0 | 0.0 | 95.5 | 2 | | | 9.1 | 0.0 | 0.0 | 90.9 | | |
| | Total | | 122 | 23 | 53 | 198 | 23 | 0 | 3 | 11.6 | 0.0 | 5.7 | 86.9 | 28 | 0 | 2 | 14.1 | 0.0 | 3.8 | 84.8 |
| Staphylococci | Penicillin | 31 | 0 | 62 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Oxacillin | 57 | 0 | 36 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | | 1 | | 0.0 | 1.8 | 0.0 | 98.9 | | |
| | Vancomycin | 93 | 0 | 0 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Teicoplanin | 93 | 0 | 0 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | 1 | | | 1.1 | 0.0 | 0.0 | 98.9 | | |
| | Ofloxacin | 55 | 0 | 38 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | 1 | | | 1.1 | 0.0 | 0.0 | 98.9 | | |
| | Ciprofloxacin | 56 | 0 | 37 | 93 | 1 | | 0.0 | 1.8 | 0.0 | 98.9 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Tetracycline | 82 | 0 | 11 | 93 | | 1 | 0.0 | 0.0 | 9.1 | 98.9 | 1 | | 1 | 1.1 | 0.0 | 9.1 | 97.8 | | |
| | Gentamicin | 74 | 0 | 19 | 93 | 1 | | 1.1 | 0.0 | 0.0 | 98.9 | 1 | 1 | | 1.1 | 1.4 | 0.0 | 97.8 | | |
| | Erythromycin | 42 | 1 | 50 | 93 | 3 | | 3.2 | 0.0 | 0.0 | 95.7 | 2 | | | 2.2 | 0.0 | 0.0 | 97.8 | | |
| | Clindamycin | 63 | 0 | 30 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | 1 | 1 | | 1.1 | 1.6 | 0.0 | 97.8 | | |
| | Cotrimoxazol | 81 | 11 | 1 | 93 | | 1 | 0.0 | 1.2 | 0.0 | 97.8 | | 1 | | 0.0 | 1.2 | 0.0 | 98.9 | | |
| | Rifampicin | 92 | 1 | 0 | 93 | | | 0.0 | 0.0 | 0.0 | 100.0 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| | Total | | 819 | 13 | 284 | 1,116 | 4 | 2 | 3 | 0.4 | 0.2 | 1.1 | 99.2 | 7 | 4 | 1 | 0.6 | 0.5 | 0.4 | 98.9 |
| | Enterococci | Vancomycin | 51 | | | 51 | | | 0.0 | 0.0 | 0.0 | 100.0 | 2 | | | 3.9 | 0.0 | 0.0 | 96.1 | |
| Teicoplanin | | 51 | | | 51 | | | 0.0 | 0.0 | 0.0 | 100.0 | | | | 0.0 | 0.0 | 0.0 | 100.0 | | |
| Tetracycline | | 19 | | 32 | 51 | | | 0.0 | 0.0 | 0.0 | 100.0 | 1 | | | 2.0 | 0.0 | 0.0 | 98.0 | | |
| Total | | 121 | 0 | 32 | 153 | 0 | 0 | 0 | 0.0 | 0.0 | 0.0 | 100.0 | 3 | | | 2.0 | 0.0 | 0.0 | 98.0 | |
| All | | 2,270 | 107 | 782 | 3,159 | 89 | 4 | 13 | 2.8 | 0.2 | 1.7 | 97.0 | 94 | 6 | 5 | 3.0 | 0.3 | 0.6 | 97.0 | |

^a Abbreviations: S, susceptible; I, intermediate; R, resistant.

Phoenix instrument was mainly due to the additional manual steps of transferring 25 µl of ID broth to AST broth, dropping of the indicator dye into the AST broth, inoculating the panels with the respective broth, closing the panels, placing the panels in the transport caddy, and entering the panels into the instrument. Additionally, setting up the McFarland standard with CrystalSpec was more time-consuming compared to DensiChek. According to BD Diagnostic Systems this will be improved with a new version in the near future.

Meyer et al. performed a timed workflow study comparing the Phoenix instrument with the Microscan Walkaway-96

(W. A. Meyer III, D. Lockwood, W. Brasso, and J. Reuben, Abstr 100th Gen. Meet. Am. Soc. Microbiol. 2000, abstr. C-309, 2000). The following workflow steps were measured to process 50 isolates: logging of isolates into ID and AST system (3.3 min), manual labeling of the panels (7.7 min), inoculation of panels (14.6 min), and the loading of the panels into the instrument (3.8 min). These selected values were similar to our respective manipulation steps. Unfortunately the inoculum preparation time was not evaluated in this study due to the significant differences between the processes normally associated with overnight ID and AST analysis (Microscan) and

“rapid” ID and AST analysis (Phoenix). Therefore, the final results are not comparable to our evaluation, where the differences between both instruments were mainly due to specimen inoculum preparation procedures.

Our result of 1.5 min for setting up one isolate for the VITEK 2 instrument is in accordance with other investigators, considering the fact that each study design is slightly different. Larone et al. reported 1.3 min technical hands-on time to set up one isolate with VITEK 2 compared to 1.7 min for VITEK classic and 1.9 min for Microscan (D. H. Larone, L. J. Tucci, and D. O. Samide, Abstr. 100th Gen. Meet. Am. Soc. Microbiol. 2000, abstr. C-279, 2000). Goessens et al. calculated a mean operating time of 0.9 min per specimen for VITEK 2 and 2.3 min for Microscan Walkaway (W. H. F. Goessens, A. H. J. A. Van Vliet, and H. A. Verbrugh, Abstr. 9th Eur. Cong. Clin. Microbiol. Infect. Dis. 1999, abstr. P-0822, 1999). Abele-Horn et al. reported a time frame of 15.0 to 20.0 min for inoculum preparation and setting up 20 species with the VITEK 2 instrument (0.8 to 1.0 min per isolate), in comparison to 30.0 to 40.0 min with API systems and agar diffusion tests (1.5 to 2.0 min per isolate) (1).

Comparing both instruments, W. S. Seto reported 2.4 min and 2.0 min from initiation of inoculum preparation to loading into the machine with Phoenix and VITEK 2, respectively (personal communication). Silver et al. compared the Phoenix with the VITEK 2 instrument for 325 isolates of staphylococci and also stated that Phoenix required more preparation time than VITEK 2 without showing any detailed data (D. M. Silver, L. Louie, and A. E. Simor, Abstr. 102nd Gen. Meet. Am. Soc. Microbiol. 2002, abstr. C-132, 2002).

TTR. In this study, TTR was determined when the results of all antibiotics on one card or panel were final. The mean TTR evaluated for the different bacterial groups were significantly longer for Phoenix in comparison to VITEK 2. To our knowledge no other direct studies had been published on comparative TTR results between both instruments. The results available are from separate studies for each instrument, therefore a comparison with this study is not valid.

For complete ID and AST results with the Phoenix system, Donay et al. required 7.5 h, 16.0 h, 13.0 h, 10.5 h, and 11.0 h for *E. coli*, all NFGNB isolates, *P. aeruginosa* (exclusively), *S. aureus*, and *E. faecalis*, respectively (6). Endimiani et al. reported an average TTR of 14.8 h \pm 1.6 h for NFGNB and a lower TTR of 13.0 h \pm 1.8 h for *Acinetobacter baumannii* (7).

With regard to VITEK 2, the results reported in this study were almost in accordance with other evaluations. In a previous study we collected AST TTR for 3,143 fresh clinical isolates reported by VITEK 2 in our routine laboratory (A. M. Fahr, U. Eigner, D. Bertsch, M. Kirstahler, M. Holfelder, and A. Turnwald-Maschler, Abstr. 13th Eur. Cong. Clin. Microbiol. Infect. Dis. 2003, abstr. P-760, 2003). The mean TTR for all bacteria tested was 8.1 h, with 7.2 h for *Enterobacteriaceae*, 12.1 h for *P. aeruginosa*, 6.9 h for *S. aureus*, and 9.0 h for enterococci. Similar TTR results for VITEK 2 were reported by other working groups (12, 15).

For ID and AST, several studies have compared either the Phoenix or VITEK 2 system with reference methods (1, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17).

ID. Both systems were equally good at identifying all four bacterial groups examined (96% to 100%). Similar results for

the Phoenix instrument were reported by Stefaniuk et al. and Fahr et al., whereas Donay et al. found results of 89.4% and 86.2% for NFGNB and enterococci (6, 8, 16). For VITEK 2, correct ID results of 95% and 97.8% were reported for routine strains and 88.5% for a challenge set of gram-negative organisms (9, 13, 15). Comparing both systems Gross et al. found a concordance of 96% for gram-negative and gram-positive isolates (R. Gross, U. Hörling, and G. Peters et al, Abstr. 12th Eur. Cong. Clin. Microbiol. Infect. Dis. 2002, abstr. P-703, 2002).

AST. For all bacterial groups the CA was >95% for both instruments, only for NFGNB we observed a CA of 84.8% for Phoenix and 86.9% for VITEK 2. For both instruments similar results were obtained for mE and ME, whereas VITEK 2 had a larger but not significant VME rate compared to Phoenix for *Enterobacteriaceae*, NFGNB, and staphylococci. For the Phoenix system similar CA of >95% are reported for *Enterobacteriaceae*, staphylococci, and enterococci with a low VME rate of <1.5% (6, 8, 16). For *P. aeruginosa*, Donay et al. reported a CA of 75.8% with a VME rate of 0.3% for Phoenix (6). For VITEK 2 comparable results with our study were reported for gram-negative isolates (12, 13). For 138 *Enterobacteriaceae* tested Pérez-Vázquez et al. observed an essential agreement of 97.8% with a VME rate of 6.1%, mainly due to piperacillin (15). Good performance in detecting *vanA*, *vanB*, and *vanC1* resistance mechanisms in enterococci was stated by van den Braak et al. for VITEK 2 (17). Comparing both instruments, Gross et al. showed comparability between Phoenix and VITEK 2 of 94% for all bacterial groups tested (R. Gross et al., 12th Eur. Cong. Clin. Microbiol. Infect. Dis. Abstr. 2002, abstr. P-704, 2002).

In conclusion, the mean setup time for one bacterial isolate was significantly longer with Phoenix when compared to VITEK 2, whereas VITEK 2 required more maintenance time than Phoenix. TTR for all bacterial groups was shorter with VITEK 2 when compared to the Phoenix system, so more results will be available with the VITEK 2 instrument on the same day. VITEK 2 had a larger VME rate than the Phoenix system, the difference being not significant. CA, mE, ME, and correct ID rates were equally good for both systems.

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