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Original Research Article

Evaluation of diagnostic accuracy of latex agglutination test and E-test for the detection of methicillin-resistant *Staphylococcus aureus*

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ABSTRACT

Background: This study was undertaken to compare the phenotypic methods of latex agglutination test and e-test with polymerase chain reaction for the detection of methicillin-resistant *Staphylococcus aureus*.
Methods: Two hundred pus samples obtained from different clinical disciplines were subjected to the latex agglutination test and minimum inhibitory concentration by e-test (Oxacillin and Vancomycin) as per the standard guidelines. The comparison was made with polymerase chain reaction as the reference test. The diagnostic accuracy of each method was reported in terms of sensitivity, specificity, positive predictive value, and negative predictive value.
Results: The sensitivity of latex agglutination test was found to be 100% whereas e-test for Oxacillin was found to be 96.67% sensitive. Higher specificity for e-test was reported (99.41%) when compared to the latex agglutination test (97.65%).
Conclusions: Latex agglutination and e-tests are tests are relatively simpler, rapid, and easy-to-perform methods when compared to polymerase chain reaction. The present study reported high sensitivity and specificity values for both the tests, and therefore supports usage of the stated methods as screening tools for methicillin-resistant *S. aureus*. However, more multi-centric studies are recommended to precisely determine the diagnostic accuracy of these phenotypic methods.

Keywords: E-test, Latex agglutination, Methicillin-resistant Staphylococcus aureus, MRSA, Oxacillin, *Staphylococcus aureus*, Vancomycin

INTRODUCTION

Staphylococcus aureus is gram-positive bacteria responsible for a wide range of community and hospital-acquired infections. Conventional treatment for staphylococcal infections using antibiotics such as penicillin and its derivatives has been successful in the past. However, the increase in the incidence of antimicrobial resistance in the present times could lead to failure of the drug regimen and therefore is a cause of grave concern.[1] Presently, *S. aureus* has developed resistance to a group of antibiotics such as methicillin, isoxazolyl penicillin-like oxacillin, cloxacillin, and dicloxacillin. The strains of *S. aureus* that are resistant to this group of antibiotics are referred to as Methicillin-Resistant *Staphylococcus aureus* (MRSA).[2]

The prevalence of MRSA has risen worldwide during the last two decades. While 33% of the population is colonized with staphylococcus, approximately 1% is colonized with MRSA.[3] Most frequent healthcare-acquired MRSA infections include surgical wound infections, urinary tract infections, and, bloodstream and catheter-related infections. Community-acquired infections include skin soft tissue infections and necrotizing pneumonia.[4,5] Methicillin resistance requires the presence of

chromosomally localized *mecA* and is acquired by horizontal transfer of a mobile genetic island designated staphylococcal cassette chromosome *mec* (SCC*mec*).[6] Penicillin-binding protein 2a (PBP2a or PBP 2') is encoded by gene *mecA*, an enzyme that helps crosslink the peptidoglycans in the bacterial cell wall. The low affinity of PBP 2a for β-lactams results in resistance to isoxazolyl penicillin such as oxacillin, cloxacillin, flucloxacillin, dicloxacillin, cephalosporins, and carbapenems.[7] The possibility of the emergence and spread of MRSA in healthcare facilities is a major concern in the present scenario. Therefore, the detection of MRSA is of paramount importance to prevent the spread of MRSA in healthcare facilities. For this reason, the development of sensitive, reliable, and cost-effective rapid tests for the detection of MRSA is crucial. The development of phenotypic methods such as the cefoxitin disk diffusion test, oxacillin resistance screening agar base, CHROM agar MRSA, latex agglutination, and e-test has been revolutionary in addressing the concerns of rapid and accurate detection of MRSA. There have been multiple studies reporting a satisfactory diagnostic accuracy of these phenotypic methods, thus making them a reliable tool for screening MRSA in a large population.[8]

Polymerase chain reaction (PCR) is the gold standard for the detection of MRSA which involves the identification of the *mec*A gene in isolated strains.[9] However, the challenges associated with PCR such as the requirement of specialized equipment, higher cost, and limited sensitivity in cases of low MRSA levels make it difficult to use as a screening tool on a larger sample. Latex agglutination test is an easy-to-perform phenotypic test that has been found to approach the same reliability as seen with PCR.[10] It qualitatively tests for PBP2', a mecA gene product in the MRSA cell membrane. Additionally, E-test has also been reported as a reliable alternative to conventional agar or broth dilution methods for the detection of MRSA.[11] However, more evidence is required for the translation of these useful phenotypic methods into routine clinical practice. Therefore, this study aims to evaluate the diagnostic accuracy of the latex agglutination method and E-test method of detection of MRSA and compare it with the gold standard PCR.

METHODS

This in-vitro study was conducted in the department of microbiology of a central government medical institute and its associated hospitals. Pus samples received from various clinical disciplines for microbiological evaluation were subjected to the study. 200 strains of *S. aureus* were isolated. Patients' consent was not sought since the isolates were obtained as a part of routine patient care. As the first part of this study, phenotypic methods such as the oxacillin disk diffusion test, cefoxitin disk diffusion test, CHROM agar MRSA, and oxacillin resistance screening agar base test were evaluated for their diagnostic accuracy with PCR as the reference standard.[12] This study explores the accuracy of latex agglutination test and e-test in detecting MRSA strains.

Identification of isolates

Preliminary gram staining and inoculation of pus samples on blood agar and MacConkey agar were conducted to obtain a primary insight into the likely organism present. Colonies of *S. aureus* were identified by the following methods and tests. Gram stain: gram-positive cocci arranged in grape-like clusters, culture on blood agar: smooth glistening, opaque, and beta-hemolytic colonies**,** MacConkey agar: pinkish-orange colonies, catalase test: catalase positive, and coagulase test (slide and tube coagulase tests).

MRSA screen-slide latex agglutination test (Denka Seiken, Co., LTD. Japan)

PBP2' extraction

Four drops of extraction reagent 1 were added into a micro-centrifuge tube. 4-5 large colonies with a diameter of 2.5 mm, isolated from fresh, 18–24-hour cultures grown on blood agar plates at 35°C were suspended in the tube. The tube was capped and placed into a boiling water bath at 95-100°C and heated for 3 minutes. 1 drop of extraction reagent 2 was added into the tube, mixed well, and centrifuged at 3000 ppm with a 15 cm rotor radius. The supernatant was used as the test specimen.

Latex agglutination

For each specimen, two circles were allotted and labeled on the test card, one as a test and the other as a control. 50 ul of the specimen was placed onto each of the test and the control circles. To the test circle, 1 drop of sensitized latex was added and to the control circle, 1 drop of control latex was added. With separate mixing sticks, each reagent was thoroughly mixed with the specimen over the area of the circle. The test card was rotated by the mechanical rotator for 3 minutes. It was placed on the bench and the agglutination pattern was read by eye (Figure 1). The latex agglutination test classified the strains as MRSA or methicillin-resistant *S. aureus* (MSSA) based on the presence of PBP 2' (Table 1).

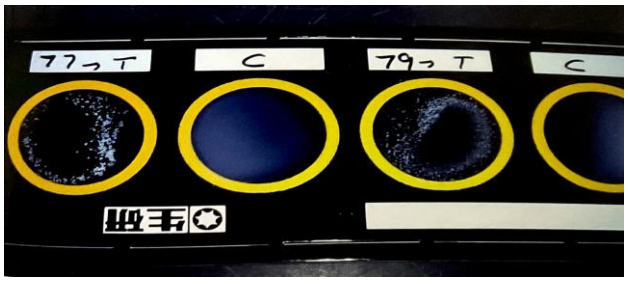

Figure 1: MRSA-screen latex agglutination test. Strain number 77 and 79 with strong agglutination (3+) are MRSA.

Table 1: Interpretation of the latex agglutination procedure.

Type of agglutination	Test latex	Control latex	Interpretation	Report
Strong agglutination (3+)	Positive	Negative	PBP2' positive	MRSA
Agglutination against a slightly turbid background (2+)	Positive	Negative	PBP2' positive	MRSA
Slight agglutination against turbid background (1+)	Positive	Negative	PBP2' positive	MRSA
No agglutination	Negative	Negative	Negative	MSSA

Minimum inhibitory concentration by E-test

E-test (Epsilometer test)

The minimum inhibitory concentration (MIC) values of oxacillin and vancomycin were determined by the e-test (AB-BIODISK, Solna, Sweden). The E-test comprises a thin impervious test carrier (5×50 mm plastic strip) with a continuous exponential gradient of antibiotics immobilized on one side and a reading cum interpretive scale on the other. The test was performed as per the instructions of the manufacturer. Mueller Hinton agar (Hi-Media) supplemented with 2% NaCl (for MIC of oxacillin but not for vancomycin) was employed. A suspension of the organism in 0.85% NaCI adjusted to equal the turbidity of a 0.5 McFarland opacity standard was used to swab the surface of the plates. The inoculated plates were allowed to dry before the E-test strips were applied. E-test strips containing the following antibiotics were used: Oxacillin (range: 0.016-256 ug/ml), and Vancomycin (range: 0.016-256 ug/ml) (Figure 2).

The plates were incubated at 35°C in ambient air for 24 hours and the MIC values were read as the intersection of the inhibition eclipse with the MIC scale in the test strip. Interpretation of the results was done following the National Committee for Clinical Laboratory Standards [NCCLS] breakpoints. *S. aureus* ATCC 29213 reference strain was included as a control.

Polymerase chain reaction

The procedure for PCR was the same as that performed in the previous study.[11]

Figure 2: E-test for oxacillin and vancomycin. MIC value for this strain is ≥256 ug/ml for oxacillin and 2 ug/ml for vancomycin.

RESULTS

A total of two hundred confirmed clinical isolates of *S. aureus* were obtained from the pus samples. The *mec*A PCR assay allowed us to classify 30 isolates as *S. aureus mec*A-positive i.e., MRSA (15%), and 170 as *S. aureus mec*A-negative i.e. MSSA (85%). The distribution of MRSA according to various clinical disciplines has been presented in detail in the previous part of this study. All free coagulase-producing *S. aureus* strains were subjected to the MRSA-screen latex agglutination test and e-test for the detection of methicillin resistance. The number and percentage of methicillin-resistant and methicillin-sensitive strains isolated by this method in comparison with PCR are given in the table (Table 2).

The distribution of *S. aureus* isolates according to the MIC of oxacillin and Vancomycin by E-test is given in the table (Table 3). Ninety-three (46.5%) strains with a MIC value of 0.5 ug/ml, 31 (15.5%) strains with a MIC value of 1 ug/ml and 46 (23%) strains with a MIC value of 2 ug/ml were classified as MSSA. Five strains (2.5%) with a MIC value of 4 ug/ml, 4 (2%) strains with a MIC value of 8 ug/mI, 4 (2%) with a MIC value of 16g/ml, 6 (3%) with MIC value of 32 ug/ml, 7 (3.5%) with MIC value of 64ug/ml and 4 (2%) with MIC value of 256 ug/ml were classified as MRSA. Out of five strains with a MIC value of 4 ug/ml, one was false positive. For MRSA strains, MIC_{50} was 324g/ml and MIC_{90} was 256 ug/ml.

E-test for vancomycin was put up for all the strains of *S. aureus*. 105 (52.5%) strains had a MIC value of 0.5 ug/ml, 77(38.5%) had a MIC of 1 ug/ml, 16 (8.0%) had a MIC value of 2 ug/ml and only 2 (1.0%) had MIC of 4 ug/ml. Therefore, all the strains were sensitive to vancomycin. No vancomycin-intermediate strains with MIC values ranging between 8-16 ug/ml and vancomycin-resistant strains with MIC values more than or equal to 32 ug/ml were found. The comparison of latex agglutination and e-tests with PCR as the reference standard produced latex agglutination as the more sensitive method (100%). However, e-test was found to be more specific (99.41%). A detailed description of the accuracy of these tests regarding their sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) has been presented in the table (Table 4). The figure depicts the comparison of the latex agglutination test and the E-test (Figure 3).

Table 2: Classification of *S. aureus* strains by different methods.

Method of detection	Total sample screened	MRSA		MSSA	
		Number	Percentage	Number	Percentage
Latex Agg.	200	34	17.0	166	83.0
E-test-Ox	200	30	15.0	170	85.0
PCR	200	30	15.0	170	85.0

Latex agg.=MRSA-screen latex agglutination test, e-test-ox=e-test for oxacillin, PCR=polymerase chain reaction

Table 3: Mic of oxacillin and vancomycin for *S. aureus* isolates by e-test.

MIC value (ug/ml)	Oxacillin		Vancomycin	
	Number of isolates	Percentage	Number of isolates	Percentage
0.5	93	46.5	105	52.5
1.0	31	15.5	77	38.5
2.0	46	23	16	8.0
4.0	5	2.5	2	1.0
8.0	4	2.0	0	0.0
16.0	4	2.0	0	0.0
32.0	6	3.0	0	0.0
64.0	7	3.5	-	-
128.0	0	0.0	-	-
256.0	4	2.0	-	-

Table 4: Accuracy of latex agglutination and e-test in the detection of MRSA.

Method of detection of MRSA	True +ve	True -ve	False +ve	False -ve	Total	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Latex agglutination	30	166	4	0	200	100	97.65	88.24	100
E-test for oxacillin	29	169	1	1	200	96.67	99.41	96.67	99.41

+Ve: positive, -ve: negative

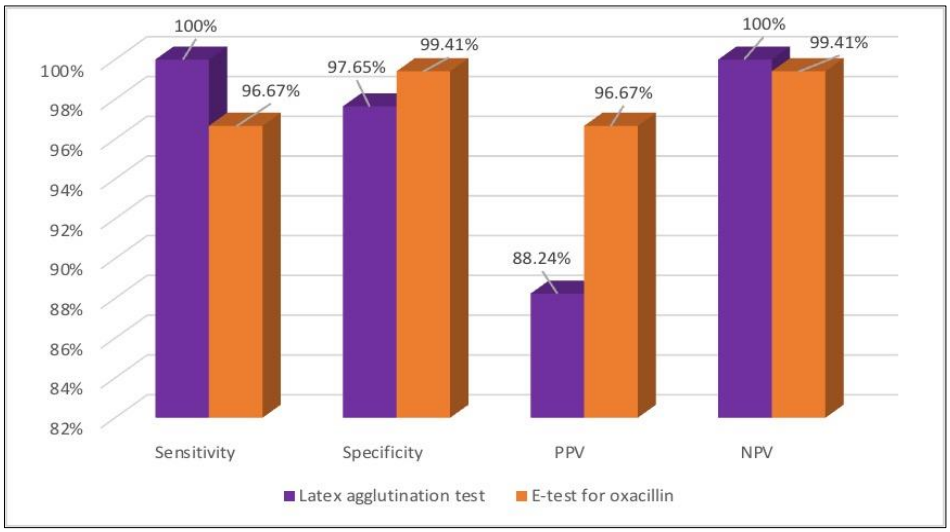

Figure 3: Comparison of sensitivity, specificity, PPV, and NPV for latex agglutination test and e-test.

DISCUSSION

S. aureus is a highly infectious bacterium capable of causing an array of life-threatening infections, and its property to survive adverse conditions makes it even more life-threatening.[13] Antimicrobial chemotherapy for this species keeps evolving since MRSA has now overcome most of the therapeutic agents developed.[14] Common antibiotics used against MRSA include vancomycin, daptomycin, ceftaroline and linezolid. However, the frequent use of the first-line drug vancomycin has now produced several resistant strains namely vancomycin

intermediate-resistant *S. aureus* (VISA) and vancomycin-resistant *S. aureus* (VRSA).[15] Therefore, the recent rise in the number and level of heterogeneity of resistant strains necessitates the requirement of screening tools to detect these strains and prevent their further spread in the community.

PCR, a rapid molecular-based assay has been utilized in detecting MRSA for a long time. It detects the presence of a specific mecA gene or its product PBP2', and is considered the gold standard for MRSA confirmation.[16] PCR reduces the time required for various culture methods by up to 5 days to identify an outbreak enabling improved prevention and control.[17] However, one of the disadvantages of this technique is the complexity of the typing system since the SCC *mec* region is variable and newer types are permanently being defined.[18] Additionally, the requirement of standard reference laboratories and the expensive nature of this confirmatory test makes it even more difficult to be performed in developing centers. Therefore, this study aims to explore the latex agglutination test and E-test which are cost-effective and simple methods for the detection of MRSA.

Latex agglutination screen test is a novel, valuable tool in the ongoing battle against MRSA. It is a qualitative slide latex agglutination test that detects PBP2', a *mec*A gene product present in the cell membrane of MRSA. It consists of a latex reagent sensitized with a monoclonal antibody against PBP2' together with reagents in rapidly extracting PBP2' from the bacterial membranes of MRSA.[19] The classic criterion for the identification of *S. aureus* is that the organism can clump in plasma via the activity of extracellular free coagulase. Free coagulase is thought to interact with prothrombin in plasma to produce staphylothrombin, which converts prothrombin into an active form that releases fibrinopeptide's from fibrinogen, forming fibrin clots.[20,21]

The sensitivity and specificity for the MRSA-Screen latex agglutination test usually range from 24% to 100% and 93% to 100% respectively.[22] In the present study, the sensitivity and specificity were 100% and 97.65% respectively. The latex agglutination test labeled 34/200 (17%) as MRSA whereas 30/200 (15%) were positive by PCR. Hence, it was able to correctly identify (true positives) all *mec*A positive strains but gave 4 false-positive results. The positive predictive value and negative predictive value were 88.24%, and 100% respectively. Velasco et al in a study found the MRSA-Screen latex agglutination test was 100% sensitive and 96% specific when compared to PCR.[23] In another study, the overall sensitivity and specificity of the latex agglutination test were found to be 100% and 91.7% respectively.[24] Further, overall sensitivity ranged from 99.2% to 100% and specificity ranged from 98.8% to 100% in a study.[25]

Variation in the sensitivity of MRSA screen latex agglutination has been found with change in the reading time. The sensitivity of 76%, when read at 3 minutes improved to 100% when the reaction was read at 15 min. The probable cause for this, is the increase in the agglutination time. Further, it has also been found that if the strains are induced by incubation in the presence of a 5 ug methicillin disk before testing, to increase the level of PBP2a expression, or a large inoculum is used, the sensitivity of detection is increased without sacrificing specificity. However, one recent study reported increased sensitivity on increasing agglutination time but specificity decreased when the agglutination time exceeded ≥15 min.[26] It is recommended that any strain showing agglutination after 10 minutes should be tested for the *mec*A gene using PCR. Although further refinements may be necessary for the MRSA-Screen test, it appears to be potentially useful.

MRSA latex agglutination is easy to perform, highly reliable produces rapid results with a processing time of around 15 to 20 minutes, and is amenable to the processing of a large number of samples. It has been said to approach the accuracy of PCR for *mec*A concerning sensitivity and specificity.[27] It can be easily incorporated into the clinical diagnostic laboratory since it requires minimal equipment and training. The test has a major advantage over other phenotypic methods of not being influenced by the various levels of expression of resistance, a parameter which highly heterogeneously resistant isolates tend to render classical and automated methods less accurate. It can accurately differentiate borderline phenotypic resistance in methicillin isolates from MRSA isolates.[16] When applied to overnight primary culture agar media, the MRSA-Screen test shortens the delay for the detection of MRSA to one day, versus two-three days for the conventional methods; a potentially significant improvement for both directed antibiotic therapy and epidemiological measures.[28] However, there are certain limitations to this phenotypic method. The probability of false-negative results although rare could result if the strain produces low amounts of PBP2'. Moreover, this test cannot be used to detect mecA in coagulase-negative staphylococci or on a direct specimen such as a blood culture.

E-test for oxacillin, labeled 170/200 (85%) *S. aureus* strains as MSSA (MIC<4 ug/ml). Although the number of MRSA isolates was the same as that of PCR, in 5 borderline cases with a MIC value of 4 ug/ml, 1 strain was negative by PCR. Hence it gave 1 false-positive and 1 false-negative result. The sensitivity, specificity, positive predictive value, and negative predictive value of MIC by E-test were 96.67%, 99.41%, 96.67%, and 99.41% respectively. In a study comparing latex agglutination, oxacillin resistance screening agar base, and E-test for the detection of MRSA with PCR as the reference standard, E-test was found to be a reliable method for the detection of methicillin resistance with a maximum sensitivity of 95.9%.[20] A similar study by Felten et al found that very-low-level MRSA, or class1 MRSA, is often misdiagnosed as MSSA.[29] They compared the distributions of MICs of oxacillin and cefoxitin by the E-test (AB Biodisk), and those of moxalactam by dilutions in agar for MRSA and

MSSA isolates. E-test for oxacillin was found to be 91.6% sensitive and 100% specific.

Velasco et al found the E test for oxacillin to be 94.1% sensitive and 100% specific when compared with PCR after 24 hours of incubation.[23] The sensitivity was found to increase to 98% after 48 hours of incubation. They found that methods based on E-test, as well as microdilution with oxacillin, were often not reliable at detecting some strains that harbor the mecA gene. 3 out of 51 clinical strains that were positive for the mecA gene yielded false-negative results with an E-test for oxacillin and microdilution. This is explained by the absence or reduced expression of the mecA-encoded protein, PBP2'. In the present study, although the sensitivity of latex agglutination (100%) was more than E-test (96.67%), the test was found to be more specific (99.41%) than latex agglutination (97.65%). Further, E-test is better than any other agar-based method tested in our previous study.[12] It was able to detect 4 borderline cases (MIC value of 4-6 ug/ml) which were missed by oxacillin resistance screening agar base. Being agar-based, E-test has been shown to correlate best with the reference agar dilution as it is affected by test conditions in a similar way. E-test for vancomycin put up for the strains of *S. aureus* in the study revealed MIC value ≤4 ug/ml for all. These were labeled as vancomycin-sensitive *S. aureus*. No vancomycin-intermediate sensitive strains [MIC 8-16 ug/ml] and vancomycin-resistant strains [MIC value ≥32 ug/ml] were found. A similar finding was reported by Finan et al.[30] The advantages of the E-test over other MIC methods are its ease of setup, easier interpretation, and ability to study a wider range of MIC values at a time which is not possible in agar and broth dilution methods.

Limitations

The disadvantage of test is its cost. Studies by Sasirekha et al and Karami et al considered the E-test as the most reliable way to detect MRSA.[31,32] E-test is very straightforward to carry out as a disc diffusion test and is almost as precise as PCR for mecA. However, despite its high sensitivity and specificity, it is an expensive test to perform. Additionally, different studies have reported that the Oxacillin MIC strip can be sensitive to temperature change which can affect the results and lead to unreliable readings. Furthermore, the strip for E-test has a limited shelf life and its potency diminishes on storing incorrectly or for too long.[33]

The present study involved isolates from a single healthcare center. Increasing prevalence of MRSA worldwide and a rise in multi-drug resistant strains of *S. aureus*, necessitates a multicentric study with large sample size for establishing an early and accurate detection method, thus ensuring its efficient management while preventing the development of more resistant strains.

CONCLUSION

MRSA-screen latex agglutination test is a simple, rapid, easy-to-perform, and highly reliable phenotypic method to detect MRSA with a reported sensitivity of 100% as per the present study. This test can be used in routine laboratories where PCR is not available as it detects PBP2', the direct product of the mecA gene. E-test using Oxacillin and Vancomycin offer other alternatives for detecting MRSA strains with even higher specificity than Latex agglutination. Although expensive, the simplicity of the procedure approaching that of disk diffusion methods, and easy interpretation make it a promising screening tool for MRSA. With the increasing prevalence of MRSA worldwide, a multi-centric study involving a wider range of staphylococcal species is recommended to precisely determine the accuracy of these phenotypic methods thus ensuring early detection and efficient management while preventing the development of more resistant strains.

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REFERENCES

1. Lowy FD. Antimicrobial resistance: the example of Staphylococcus aureus. J Clin Invest. 2003;111(9):1265-73.
2. Turner NA, Sharma-Kuinkel BK, Maskarinec SA, Eichenberger EM, Shah PP, Carugati M, et al. Methicillin-resistant Staphylococcus aureus: an overview of basic and clinical research. Nat Rev Microbiol. 2019;17:203-18.
3. Centers for Disease Control and Prevention. MRSA and the workplace. Available at: https://www.cdc.gov/niosh/topics/mrsa/default.html. Accessed on 11 May 2022.
4. Siddiqui AH, Koirala J. Methicillin Resistant Staphylococcus Aureus. In: StatPearls. Treasure Island (FL): StatPearls Publishing. 2022.
5. Gajdács M. The Continuing Threat of Methicillin-Resistant Staphylococcus aureus. Antibiotics. 2019;8(2):52.
6. Katayama Y, Ito T, Hiramatsu K. A new class of genetic element, staphylococcus cassette chromosome mec, encodes methicillin resistance in Staphylococcus aureus. Antimicrob Agents Chemother. 2000;44(6):1549-55.
7. Lowy FD. Antimicrobial resistance: the example of Staphylococcus aureus. J Clin Invest. 2003;111:1265-73.
8. Datta P, Gulati N, Singla N, Rani Vasdeva H, Bala K, Chander J, Gupta V. Evaluation of various methods for the detection of meticillin-resistant Staphylococcus aureus strains and susceptibility patterns. J Med Microbiol. 2011;60(11):1613-6.
9. Baddour MM, AbuElKheir MM, Fatani AJ. Comparison of mecA polymerase chain reaction with

phenotypic methods for the detection of methicillin-resistant Staphylococcus aureus. Curr Microbiol. 2007;55(6):473-9.
10. Sakoulas G, Gold HS, Venkataraman L, DeGirolami PC, Eliopoulos GM, Qian Q. Methicillin-resistant Staphylococcus aureus: comparison of susceptibility testing methods and analysis of mecA-positive susceptible strains. J Clin Microbiol. 2001;39(11):3946-51.
11. Akpaka PE, Kissoon S, Rutherford C, Swantson WH, Jayaratne P. Evaluation of methods and costs for detecting methicillin-resistant Staphylococcus aureus isolates from clinical specimens at regional hospitals in Trinidad and Tobago. West Indian Med J. 2008;57(1):24.
12. Gupta N, Manoj JA, Shrivastava PK, Sharma A. Comparison of Different Phenotypic Methods of Detection of Methicillin-Resistant Staphylococcus aureus with Polymerase Chain Reaction. J Microbiol Infect Dis. 2022;12(03):116-26.
13. Musini A, Kandula P, Giri A. Drug Resistance Mechanism in Staphylococcus aureus. innovations in Biotechnology for a Sustainable Future. Springer, Cham. 2021;355-76.
14. Viertel TM, Ritter K, Horz HP. Viruses versus bacteria—novel approaches to phage therapy as a tool against multidrug-resistant pathogens. J Antimicrob Chemotherapy. 2014;69(9):2326-36.
15. Liu WT, Chen EZ, Yang L, Peng C, Wang Q, Xu Z, Chen DQ. Emerging resistance mechanisms for 4 types of common anti-MRSA antibiotics in Staphylococcus aureus: A comprehensive review. Microb Pathogenesis. 2021;156:104915.
16. Pournajaf A, Ardebili A, Goudarzi L, Khodabandeh M, Narimani T, Abbaszadeh H. PCR-based identification of methicillin-resistant Staphylococcus aureus strains and their antibiotic resistance profiles. Asian Pac J Trop Biomed. 2014;4:S293-7.
17. Stürenburg E. Rapid detection of methicillin-resistant Staphylococcus aureus directly from clinical samples: methods, effectiveness and cost considerations. Ger Med Sci. 2009;7:06.
18. Szabó J. Molecular methods in the epidemiology of Methicillin-resistant Staphylococcus aureus (MRSA): advantages, disadvantages of different techniques. J Med Microbiol Diagnosis. 2014;3(3):1.
19. Alipour F, Ahmadi M, Javadi S. Evaluation of different methods to detect methicillin resistance in Staphylococcus aureus (MRSA). J Infect Public Health. 2014;7(3):186-91.
20. van Griethuysen A, Pouw M, van Leeuwen N, Heck M, Willemse P, Buiting A, Kluytmans J. Rapid slide latex agglutination test for detection of methicillin resistance in Staphylococcus aureus. J Clin Microbiol. 1999;37(9):2789-92.
21. Smole SC, Aronson E, Durbin A, Brecher SM, Arbeit RD. Sensitivity and specificity of an improved rapid latex agglutination test for identification of methicillin-sensitive and-resistant Staphylococcus aureus isolates. J Clin Microbiol. 1998;36(4):1109-12.
22. El-Ageery SM, Abou El-Khier NT. Comparison of Conventional Mannitol Salt Agar with Oxacillin, Penicillin-Binding Protein 2a Latex Agglutination, and mecA PCR for Detection of Methicillin Resistance in Staphylococcus aureus. Egyptian J Med Microbiol. 2014;23(1).
23. Velasco D, del Mar Tomas M, Cartelle M, Beceiro A, et al. Evaluation of different methods for detecting methicillin(oxacillin) resistance in Staphylococcus aureus. J Antimicrob Chemother. 2005;55:379-82.
24. Nordin N, Hussin NS, Hanafiah A, Sulong A. Staphylococcal aureus bacteremia: Clinical characteristic & evaluation of Prolex Staph Xtra latex agglutination test in the rapid identification of Staphylococcus aureus Malaysian J Pathology. 2021;43(3).
25. Villard O, Cimon B, Franck J, Fricker-Hidalgo H, Godineau N, Houze S, et al. Network from the French National Reference Center for Toxoplasmosis. Evaluation of the usefulness of six commercial agglutination assays for serologic diagnosis of toxoplasmosis. Diagnostic microbiology and infectious disease. 2012;73(3):231-5.
26. Swenson JM, Williams PP, Killgore G, Hara CM, Tenover FC. Performance of eight methods, including two new rapid methods, for detection of oxacillin resistance in a challenge set of Staphylococcus aureus organisms. J Clin Microbiol. 2001;39(10):3785-8.
27. Marlowe EM, Linscott AJ, Kanatani M, Bruckner DA. Practical therapeutic application of the Oxoid PBP2'latex agglutination test for the rapid identification of methicillin-resistant Staphylococcus aureus in blood cultures. Am J Clin Pathol. 2002;118(2):287-91.
28. Cavassini M, Wenger A, Jaton K. Blanc D, Bille J. Evaluation of MRSA Screen, a Simple Anti-PBP 2a Slide Latex Agglutination Kit, for Rapid Detection of Methicillin Resistance in Staphylococcus aureus. J Clin Microbiol. 1999;37(5):1591-9.
29. Felten A, Grandry B, Lagrange PH, Casin I. Evaluation of three techniques for detection of low-level methicillin-resistant Staphylococcus aureus (MRSA): a disk diffusion method with cefoxitin and moxalactam, the Vitek 2 system, and the MRSA-screen latex agglutination test. J Clin Microbiol. 2002;40(8):2766-71.
30. Finan JE. Molecular mechanisms of vancomycin resistance in Staphylococcus aureus. Virginia Commonwealth University. 2002.
31. Mathews AA, Thomas M, Appalaraju B, Jayalakshmi J. Evaluation and comparison of tests to detect methicillin resistant S. aureus. Indian J Pathol Microbiol. 2010;53(1):79-82.
32. Karami S, Rahbar M, Yousefi J. V. Evaluation of Five Phenotypic Methods for Detection of Methicillin Resistant Staphylococcus aureus (MRSA). Iranian J Pathol. 2011;6(1):27-31.

33. Gupta M, Kaore N, Gupta A. Comparative evaluation of MIC by E-test and Cefoxitin disc diffusion for detection of Methicillin Resistant Staphylococcus aureus (MRSA). Indian J Microbiol Res. 2016;3(4):407-10.

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