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Ab.ai – A Novel Automated AI Tool for Reporting Antibiograms

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Abstract. Anti-Microbial Resistance is one of the greatest threats that mankind faces right now due to the inappropriate use of antibiotics. Institution of appropriate antibiotics in right dose for the right patient at right time is the "gamechanger" in fighting AMR. Antibiotic Sensitivity Testing (AST) or antibiogram is done to ascertain the sensitivity profile of the organism. The most widely used method in laboratory practice in India is the Kirby-Bauer's disk diffusion test. There are few shortcomings in the manual interpretation of antibiograms in the form of high inter-operator variability, mandatory requirement of trained microbiologists – which is difficult in low-resource settings and high degree of interpersonal bias due to various factors like stress, workload, and visual acuity. We propose the Ab.ai tool for automating the AST procedures in laboratory. The Ab.ai tool comprises of 3 phases: first for data collection, second for data processing and the third for generation of antibiotic sensitivity reports. Various software packages like OpenCV and EasyOCR are used for the development of the Ab.ai tool. A total of 50 antibiograms of both GPC and GNB are interpreted both by manual and automated method. The manual method is considered the "gold-standard" and the performance of Ab.ai tool was compared against the manual method. The Ab.ai tool achieved an agreement of 98.4% on susceptibility categorization of GPC antibiotics and 97.6% on that of GNB antibiotics against the gold standard manual method. The proposed Ab.ai tool serves as a perfect candidate for automating AST procedures and would prove to be a "game-changer" in battling AMR.

Keywords. Antibiogram, Antibiotic Susceptibility Testing, Anti-Microbial Resistance, Artificial Intelligence, Automated Tool

Introduction

Anti-Microbial Resistance (AMR) is one of the major threats looming in patient care globally [1]. It refers to the development of the adaptive mechanism by the microbes through which it negates the detrimental effects of the antibiotics used to treat the infections caused by them. Antimicrobial Susceptibility Testing (AST) or Antibiogram is a laboratory procedure done to ascertain the susceptibility profile of the microbe i.e., to which antibiotics the microbe would respond. The most widely used method in laboratory practice in India is the Kirby-Bauer's disk diffusion test.

Briefly, the procedure of antibiogram is as follows: the isolated organism is lawn cultured over the Mueller Hinton Agar (MHA) and the commercially available antibiotic

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disks are placed over the MHA with equal spacing between the disks. The culture plates are then incubated overnight. The zone surrounding the antibiotic disks where there is no growth of bacteria is known as the Zone of Inhibition (ZOI) is formed. This is interpreted by a microbiologist according to the Clinical and Laboratory Standards Institute (CLSI) guidelines.

Artificial Intelligence (AI) has revolutionized health care sector in several ways. AI has proved to be an efficient tool in fighting AMR. Potential of Machine Learning in various aspects like predicting resistance from genome data, utilizing this data to frame the antimicrobial stewardship policy and developing newer antibiotics in the long run [1]. An offline mobile application-based AST interpretation system was developed and achieved good performance in terms of overall agreement with susceptibility categorization [2]. AntibiogramJ, an open-source software for automatic interpretation of antibiograms provides an efficient and cost-effective solution for automating the laboratory procedures. This model achieved an impressive agreement of 87% with trained microbiologists [3]. A next gen solution to combat AMR has been proposed in Robotic Antimicrobial Susceptibility Platform (RASP). The RASP was able to perform superiorly than the human technicians in terms of throughput, data resolution and cost parameters [4].

A supervised machine learning based AST automation software, Antilogic was developed for interpretation of AST. Antilogic achieved an impressive agreement against the validation set [5]. An innovative Automatic Identification Algorithm (AIA) has been developed for automating the process of reporting of AST. Various antibiotics were tested through this automated tool. However, several challenges were faced in this trial like imperfect seeding of microorganisms, partial action of antibiotics, overlapping zone of inhibition, formation of secondary halos, etc. [6]. Machine Learning models were developed to predict the antibiotic resistance of bacteria causing primary and secondary pyoderma infections. Various antimicrobial families used to treat Skin and Soft Tissue Infections (SSTIs) were analyzed and a non-linear relationship is found to exist in predicting the antimicrobial resistance [7]. The key factor for incorporation of these AI technologies in clinical practice is its "explainable" nature. The scientific basis of usage of AI and Machine Learning Technologies in battling AMR should be demonstrated with clear evidence, paving way for its incorporation into clinical practice and public health measures [8].

Gaps identified in the manual AST procedures are as follows: high inter-operator variability, mandatory requirement of trained microbiologists – which is difficult in low-resource settings and high degree of interpersonal bias due to various factors like stress, workload and visual acuity.

1. Methods

The proposed architecture of the automated Ab.ai tool is depicted in Figure 1. The study was approved by the Institutional Ethics Committee (Reg No. 199(5)2022). Various software packages like OpenCV and EasyOCR are used for the development of the Ab.ai tool.

OpenCV: Computer Vision Library, a software library used for applications pertaining to computer vision which is available as open source.

EasyOCR: An Optical Character Recognition package based on Python.

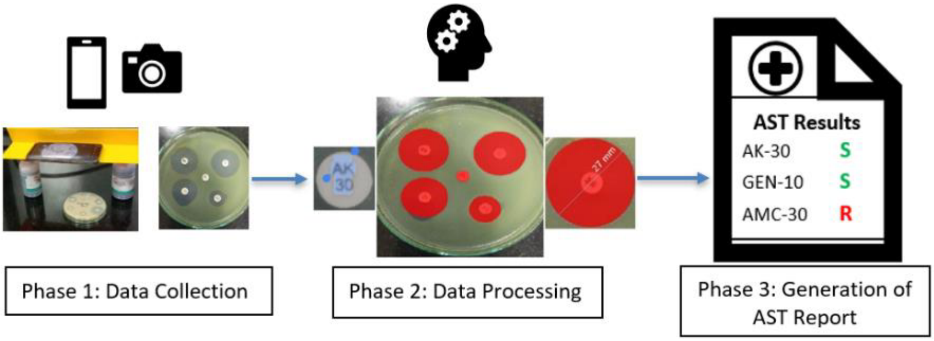

Figure 1. Architecture of the proposed automated Ab.ai tool

The Ab.ai tool comprises of 3 phases: first for data collection, second for data processing and the third for generation of antibiotic sensitivity reports.

1.1. Phase 1: Data Collection – Capturing of Antibiogram Images

The data collection phase deals with the capturing the images of antibiogram plates. The organism which was streaked in the culture plate would also be provided as input. Images of 50 antibiogram plates which consists a total of 250 antibiotics (25 plates streaked with Gram Positive Cocci (GPC) and 25 plates streaked with Gram Negative Bacilli (GNB)) were captured using Redmi Note 8 smartphone which possess a Quad camera with resolution of 48 Mega Pixel. The GPCs used in this study are Staphylococcus aureus and Enterococcus species (Enterococcus faecalis and Enterococcus faecium) and the antibiotics used are Penicillin G, Cephalexin, Cefotaxime, Co-Trimoxazole, Erythromycin, Cefoxitin, Ciprofloxacin, Clindamycin, Vancomycin and Linezolid. The GNBs used in this study are Pseudomonas aeruginosa and Escherichia coli and the antibiotics used are Amoxycillin Clavulanic Acid, Amikacin, Gentamicin, Ciprofloxacin, Cephalexin, Cefotaxime Clavulanic Acid, Ceftazidime Clavulanic Acid, Piperacillin Tazobactam, Imipenem, Tetracycline, and Cefepime. The images were taken at a standard distance of 15 cm from the culture plates. These images are then transferred to the Personal Computer for further processing.

1.2. Phase 2: Data Processing – Analysis of Antibiograms

This data processing phase revolves around analyzing the antibiogram images. The images of the antibiogram plates were processed using the OpenCV and EasyOCR packages. The main aim of this phase is to identify the antibiotic disks and to measure the diameter of the Zone of Inhibition (ZOI).

Recognition of the Antibiotic Disks: The antibiotic disks along with the ZOI were segmented from the antibiogram images using segmentation techniques. This segmented image was then processed using the EasyOCR package. The symbol of the antibiotic and its disc concentration were read from the segmented images. The symbols were then compared with the database to find the full antibiotic name.

Measurement of the diameter of the Zone of Inhibition (ZOI): The AI model was trained to delineate the ZOI from the adjacent zones with microbial growth. The diameter of the ZOI was then measured.

1.3. Phase 3: Generation of Antibiotic Sensitivity Report

This phase deals with the assimilation of the data gathered from Phase 2. The Zone size interpretative chart for the Antibiotic sensitivity testing based on the CLSI guidelines is maintained in the MySQL database. The antibiotic, its disc concentration and the diameter of the ZOI for the particular organism would be matched with the database and the report is then generated.

2. Results

The data processing phase identified the various antibiotics and their respective ZOI. The sample image of antibiogram plate streaked with Pseudomonas aeruginosa is shown in Figure 2 (A). The output showed segmentation of the ZOI, identification of the symbol, disc concentration of antibiotic and measurement of its diameter as in Figure 2 (B).

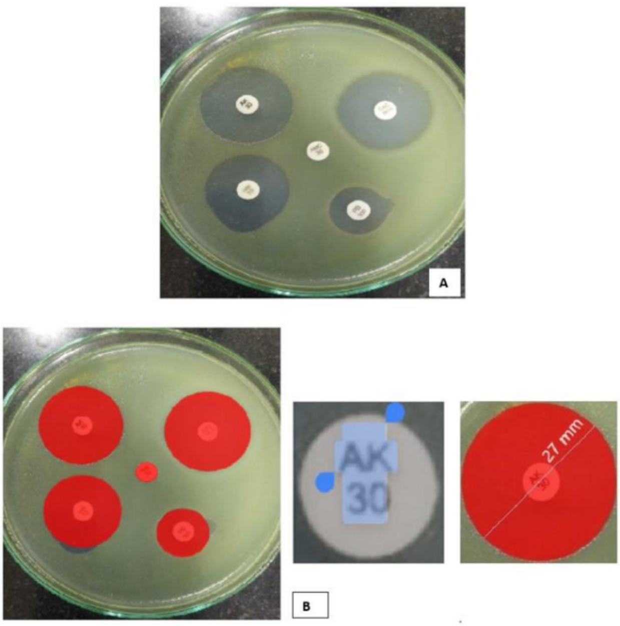

Figure 2. (A) Image of antibiogram plate streaked with Pseudomonas aeruginosa (B) Segmentation of ZOI, Identification of symbol and disc concentration of the antibiotic and measurement of diameter of ZOI

Analysis of performance of the Ab.ai tool

The 50 antibiogram plates which consists a total of 250 antibiotics were interpreted by 2 microbiology trainees and each of them individually interpreted the susceptibility of the antibiotics as Sensitive, Intermediate or Resistant according to CLSI guidelines. Discrepancies between the interpretations of the trainees were further resolved by a senior microbiologist. Thus, the interpretations provided by the microbiologist through manual method are considered to be the gold-standard. The performance of the Ab.ai tool was compared against the manual method and the results shown in Table 1. The sample antibiotic sensitivity report generated by the Ab.ai tool is shown in Figure 3.

Table 1. Performance evaluation of the automated Ab.ai tool against the manual method. Interpretation of 125 antibiotics for GPC and GNB each by trainees, manual and automated method are shown.

	Gram Positive Cocci (GPC)			Gram Negative Bacilli (GNB)		
	Sensitive	**Intermediate**	**Resistant**	**Sensitive**	**Intermediate**	**Resistant**
Trainee 1	48	24	53	50	26	49
Trainee 2	49	22	54	52	24	49
Manual (Trainees + Sr. Microbiologist)	49	24	52	51	25	49
Automated (Ab.ai)	48	24	53	53	24	48

Department of Microbiology - Sample Antibiotic Sensitivity Report*

Method: Automated Ab.ai Tool

Symbol	Antimicrobial Agent	Disc Content – Conc.	Diameter of ZOI	Grading – Sensitive /Intermediate/Resistant
AK-30	Amikacin	30 mcg	27 mm	Sensitive
GEN-10	Gentamicin	10 mcg	23 mm	Sensitive
CAC-30	Ceftazidime/Clavulanic Acid	30 mcg	28 mm	Sensitive
AMC-30	Amoxycillin/Clavulanic acid	30 mcg	6 mm	Resistant
PB-300	Polymyxin B	300 units	15 mm	Sensitive

*Only for research purposes, not used in routine laboratory practice

Figure 3. Sample antibiotic sensitivity report for the sample shown in Figure 2.

3. Discussion

The Ab.ai tool has proved to be successful in interpreting the antibiograms. The AI model has been able to accurately identify the symbol and disc concentration of the antibiotics. Figure 2 (B) shows an example of accurate segmentation of the ZOI. However, it is found that in some instances the AI model hasn't accurately segmented the region. This has been attributed to the irregular margins of the ZOI and streaks of growth presenting over the ZOI.

Interobserver variability is evident from the difference in interpretations of antibiotics by the 2 trainees for both GPC and GNB groups as depicted in Table 1. The interpretations of automated Ab.ai tool is compared with the manual method. The Ab.ai tool achieved an agreement of 98.4% on susceptibility categorization of GPC antibiotics and 97.6% on that of GNB antibiotics against the gold standard manual method. Hence, the Ab.ai tool is found to perform superiorly than AntibiogramJ [2]. These results point out towards the success of the Ab.ai tool.

4. Conclusion

AMR is a major clinical hazard. Institution of appropriate antibiotics in right dose for the right patient at right time is the "gamechanger" in fighting AMR. The proposed Ab.ai tool serves as a perfect candidate for automating AST procedures. The key pros of this tool are alleviation of inter-observer variability and helps to automate AST in low resource settings even in absence of trained microbiologists.

Future scope of the study

- The study utilized only 50 antibiograms. Hence, evaluating the performance of the Ab.ai tool with much larger number of antibiograms would make the tool more robust. This could be done considering large samples of various species of GPC and GNB and a wide range of antibiotics including both first- and second-line drugs. Furthermore, this exercise could be expanded to multicentric setup wherein antibiotic resistance patterns could even be analyzed globally.
- The images used in this study were captured using a single smartphone camera. Analyzing the antibiograms captured using different cameras would be critical in eliciting any bias and if found, suitable corrective measures could be taken.

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