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Research and Development of Image Recognition AI to Estimate Bacterial Species Using Gram Stain Findings in Urine Specimens

Contact :
isao.miyatsuka@carbgem.com
+81-3-6431-8148
CarbGeM Inc. (Tokyo/JAPAN)

S. Maeta[1], K. Yamamoto[2], G. Ohji[3], N. Ohmagari[2], A. Moriya[2], K. Ebisawa[3], M. Kusuki[3], K. Ohnuma[3], M. Nakada[1], **I. Miyatsuka**[1]

[1]CarbGeM Inc., Japan, [2]National Center for Global Health and Medicine Hosp., Japan, [3]Kobe Univ. Hosp., Japan

Revised Abstract

Due to improvements in the model, the accuracy has changed since the abstract submission.

Background: In the treatment of bacterial infections, proper administration of antimicrobial agents is very important, not only because it improves patient prognosis, but also because it reduces the development of bacterial resistance. Urine gram stain is a useful test for initial antimicrobial selection, but it requires a certain degree of skill to decipher. Therefore, we developed an image analysis system for Gram stain images of urinary and verified whether it is possible to estimate the species of bacteria in order to facilitate the initial selection of antimicrobial agents, regardless of the level of proficiency.

Methods: Slides and bacterial species identification information from an anonymized Gram stain registry at two medical institutions, National Center for Global Health and Medicine (NCGM) and Kobe University Hospital (KUH), were used for the study. Urine culture specimens of 1290 cases were included. Mock-specimens were used for rare bacteria. A total of 12,321 images were generated by capturing the observation field of view of an optical microscope with a smartphone. A total of 17 categories of bacteria were used for classification: 15 categories that frequently occur in urine samples + no bacteria + multiple bacteria. The data were divided into training data and test data at a ratio of 8 to 2 for each category, and a deep learning algorithm was trained using the training data.

Results: The macro-average recall (sensitivity) and accuracy for the test data were 74% and 77%, respectively. The results showed the possibility of performing bacterial species classification with an accuracy of over 70% using only Gram stained images via image recognition AI. In particular, the seven categories of GNR, GNC, GPR, GPC, yeast bacteria, non-bacteria, and multiple bacteria are predicted to have 94% accuracy, 95% for the macro average recall.

Conclusion: The research has shown that it is possible to classify bacterial species to a certain extent only by observing the Gram stain images. Since the accuracy varies by bacterial species, we aim to improve the accuracy of classification by adding more cases, and also by devising learning methods for the species with lower accuracy. We are planning to make comparisons with specialists in the future, and are currently working to achieve an accuracy that will allow us to show that AI is non-inferior to specialists.

Bacterial species estimation procedure by AI

Figure 1. Assumed flow for estimating bacterial species using AI. After Gram staining of urine specimen, the slide is observed under a microscope with a 100x objective lens and a 10x eyepiece.

Classification category

Class	Detailed Category	Broad Category
UGC_01	*Candida* spp.	yeast
UGC_02	GPC cluster	GPC
UGC_03	*Enterococcus faecalis*	GPC
UGC_04	*Enterococcus faecium*	GPC
UGC_05	*Streptococcus agalactiae*	GPC
UGC_06	other GPC	GPC
UGC_07	*Corynebacterium* spp.	GPR
UGC_08	*Enterobacter cloacae*	GNR
UGC_09	*Escherichia coli*	GNR
UGC_10	*Klebsiella oxytoca*	GNR
UGC_11	*Klebsiella pneumoniae*	GNR
UGC_12	*Pseudomonas aeruginosa*	GNR
UGC_13	other GNR Enterobacteriaceae	GNR
UGC_14	other GNR Glucose non-fermenting bacteria	GNR
UGC_15	GNC	GNC
Multiple	There are more than two types of bacteria in broad category.	-
None	No bacteria.	-

Tabel 1. Classification Category Table. 15 categories that frequently occur in urine samples + no bacteria + multiple bacteria. Initially, the seven broad categories (Yeast, GPC, GPR, GNR, GPC, Multiple , None) are classified using AI.
If the AI's prediction result is GPC or GNR, it is further classified into a detailed category using a dedicated AI.

Bacterial species estimation performance

	precision	sensitivity	f1-score	specificity	support
GNC	100.00%	95.24%	97.56%	100.00%	42
GNR	95.19%	98.93%	97.02%	96.85%	1219
GPC	85.69%	95.86%	90.49%	96.58%	556
GPR	90.20%	96.84%	93.40%	99.67%	95
Multiple	93.52%	77.06%	84.49%	98.50%	693
None	99.72%	99.16%	99.44%	99.96%	359
yeast	97.46%	100.00%	98.71%	99.83%	192
macro average	94.54%	94.73%	94.45%	98.77%	3156
accuracy					93.57%

Table 2. Results of AI estimation for test data in 7-category.

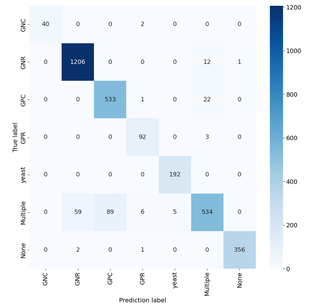

Figure 2. Confusion matrix for test data. Very few mistakes are made within GNR, GPC, Yeast, GNC, GPR. Often, multiple bacteria are mistaken for single bacteria (GNR, GPC), and single bacteria are mistaken for multiple bacteria.

	precision	sensitivity	f1-score	specificity	support
UGC_01	97.46%	100.00%	98.71%	99.83%	192
UGC_02	77.95%	96.12%	86.09%	98.10%	206
UGC_03	67.90%	50.46%	57.89%	99.15%	109
UGC_04	75.00%	68.97%	71.86%	99.35%	87
UGC_05	54.23%	85.56%	66.38%	97.88%	90
UGC_06	69.23%	70.31%	69.77%	99.35%	64
UGC_07	90.20%	96.84%	93.40%	99.67%	95
UGC_08	59.34%	52.94%	55.96%	98.79%	102
UGC_09	64.85%	81.06%	72.05%	91.17%	528
UGC_10	70.24%	67.82%	69.01%	99.19%	87
UGC_11	46.11%	49.11%	47.56%	96.75%	169
UGC_12	66.00%	75.86%	70.59%	98.89%	87
UGC_13	26.09%	13.87%	18.11%	97.72%	173
UGC_14	96.67%	79.45%	87.22%	99.94%	73
UGC_15	100.00%	95.24%	97.56%	100.00%	42
Multiple	93.52%	77.06%	84.49%	98.50%	693
None	99.72%	99.16%	99.44%	99.96%	359
macro average	73.79%	74.11%	73.30%	98.48%	3156
accuracy					76.71%

Table 3. . Results of AI estimation for test data in 17-category.

Conclusion : Our image identification AI can classify test data from Gram-stained images into seven categories with an average sensitivity of over 90%. In addition, an average sensitivity of more than 70% was achieved in 17 categorical classifications. This classification results indicate that AI may be able to identify Gram-stained images, which may also facilitate initial antimicrobial selection. Future tests comparing specialists and AI are planned.