Synergetic of Surface-Enhanced Raman Spectroscopy and Deep Learning in Antimicrobial Resistance Identification

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Antimicrobial Resistance (AMR) has become one of the global threats causing ten million deaths each year when reaching 2050 (WHO, 2019). To tackle this pandemic, increasing people's awareness of the risk and consequences of the misuse of antimicrobial drugs is a priority. Secondly, to decrease the number of cases, rapid, reliable, and easy-to-use technology should exist to enable identifying the type of bacterial infection properly and recommending the appropriate drug. In this study, Surface-Enhanced Raman Spectroscopy (SERS) combined with deep learning was used to detect and identify antimicrobial resistance with a high-accurate rate. Methicillin-resistant Staphylococcus aureus (MRSA) and methicillin-sensitive Staphylococcus aureus (MSSA), which are common AMR causing several health concerns, were studied and large data were collected for both AMR by SERS and then two deep learning models, U-Net and VGG-16, were employed to classify them. Before classifying our dataset (Uysal et al., 2020), we carried out the U-Net architecture to classify data for MRSA and MSSA collected by (Ho et al., 2019). With an accuracy of 95%, the model had the lead over different models that used the same data. For our data which consists of 9000 spectra for MRSA and 4500 spectra for MSSA, we used 5-fold cross-validation to ensure the efficiency of the models. The U-Net architecture was successfully able to extract the feature map and then classify AMR astonishingly with an accuracy of 98.83 ± 0.13%. The VGG-16 has shown brilliant performance as well with an accuracy of 99.87 ± 0.014%. In brief, this study has demonstrated the important role of the synergy between SERS and deep learning in the identification of bacterial infection and we believe it can be used and extended for several biomedical and food security applications.

**Keywords:** antimicrobial resistance, surface-enhanced Raman spectroscopy, Staphylococcus aureus, deep learning, MRSA, MSSA

REFERENCES

Ciloglu, F.U., Saridag, A.M., Kilic, I.H., Tokmakci, M., Kahraman, M. and Aydin, O., 2020. Identification of methicillin-resistant Staphylococcus aureus bacteria using surface-enhanced Raman spectroscopy and machine learning techniques. Analyst, 145(23). <https://doi.org/10.1039/D0AN00476F>

Ho, C.S., Jean, N., Hogan, C.A., Blackmon, L., Jeffrey, S.S., Holodniy, M., Banaei, N., Saleh, A.A.E., Ermon, S., Dionne, J., 2019. Rapid identification of pathogenic bacteria using Raman spectroscopy and deep learning. Nat. Commun. 10. https://doi.org/10.1038/s41467-019-12898-9

WHO, 2019. New report calls for urgent action to avert antimicrobial resistance crisis [WWW Document]. URL https://www.who.int/news/item/29-04-2019-new-report-calls-for-urgent-action-to-avert-antimicrobial-resistance-crisis (accessed 02.04.2022)