Nanoscale

PAPER

View Article Online
View Journal

Cite this: DOI: 10.1039/d4nr04503c

Ultrasensitive electroanalytical sensing platform using aptamer-conjugated V_2CT_x MXene for the detection of the HER-2 biomarker†

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Received 29th October 2024,
Accepted 31st March 2025

DOI: 10.1039/d4nr04503c

rsc.li/nanoscale

Breast cancer is a leading cause of mortality among women globally, with the human epidermal growth factor receptor-2 (HER-2) serving as a vital biomarker for its diagnosis and management. In this study, an electrochemical aptasensor was developed using V_2CT_x MXene for the sensitive and selective quantification of HER-2. The sensor's electrochemical performance was evaluated through cyclic voltammetry (CV) and square wave voltammetry (SWV) that demonstrated a wide linear detection range of 1 ng mL^{-1} to 100 μg mL^{-1}. The aptasensor achieved an exceptional detection limit of 0.36 ng mL^{-1} and a quantification limit of 1.96 ng mL^{-1} under optimized conditions. Furthermore, the sensor displayed excellent selectivity for HER-2 against other biomarkers and retained stability for 40 days, making it suitable for prolonged use. The high electrochemical response was attributed to the exceptional surface-to-volume ratio and conductivity of the V_2CT_x MXene, enabling efficient aptamer immobilization and signal enhancement. These findings highlight the potential of the developed aptasensor as a non-invasive, reliable, and cost-effective platform for early HER-2 detection, paving the way for improved breast cancer diagnosis and monitoring.

Introduction

Breast cancer is the most serious cancer that affects women's health and lives.[1] It ranks as the second main cause of cancer among women, contributing to 34% of all malignancies and impacting around 2.1–2.3 million people worldwide every year. In 2020, there were 2.261 million new cases of breast cancer and 0.685 million deaths worldwide. By 2025, the number of breast cancer cases in India is expected to increase to 232 000 from the current 205 000.[2] HER-2, also called ErbB-2 (avian erythroblastosis oncogene B), is overexpressed by twenty to thirty percent in breast cancer cells, making it a well-established biomarker to aid in medical supervisory for patients with breast cancer.[3] The person affected with breast cancer typically shows higher HER-2 levels (15–75 ng mL^{-1}) in blood as compared to the levels seen in healthy individuals (2–15 ng mL^{-1}).[4] Therefore, developing a quick, sensitive, label-free, and affordable method for detecting HER-2 levels is necessary.

Current diagnostic techniques, including pathological testing, mammography, sonography, thermography, magnetic resonance imaging (MRI), molecular breast imaging, positron emission tomography (PET), biopsy, and computerized tomography (CT), also known as the "gold standard" for breast cancer diagnosis, can provide scientific and reliable data.[5] However, they have the drawbacks of being time-consuming and invasive, which are not ideal for early cancer detection. The proximity between normal and cancerous cells makes diagnosing and treating breast cancer challenging.[6] Women in rural areas face numerous challenges regarding healthcare and regular checkups. The lack of healthcare facilities often leaves them unaware of symptoms indicative of conditions like breast cancer. Without regular checkups, their health can deteriorate to a critical point where the cancer becomes fatal.[7] The absence of local healthcare facilities forces many women to travel long distances to urban hospitals. Due to the distance and associated costs, many families opt for local, often inadequate, care. Additionally, societal attitudes and taboos further complicate matters, discouraging women from seeking the help they need.[8] These combined factors result in a severe lack of resources and support for women in rural areas. As a result, there is a need for different approaches, non-invasive, portable, and cost-effective screening methods that offer high sensitivity and specificity for point-of-care (POC) diagnosis.

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†Electronic supplementary information (ESI) available. See DOI: https://doi.org/10.1039/d4nr04503c