High-Performance Paper-Based DNA-Conjugated $Ti_3C_2T_x$ Bionanoelectrode for Rapid Point-of-Care Detection of HPV-16

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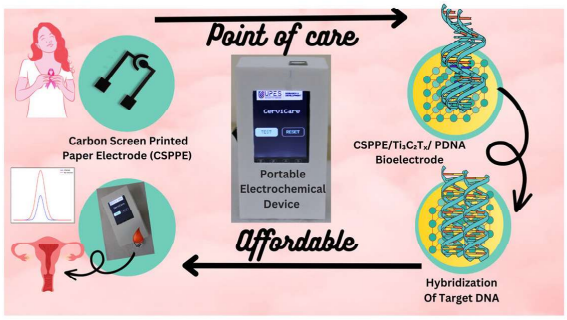
***Abstract*—Cervical cancer remains a significant global health concern, with high-risk human papillomavirus (HR-HPV), particularly the genotype 16, identified as a key etiological factor with a significantly high mortality rate. The conventional diagnostic methods suffer from limitations related to efficiency and affordability, thereby necessitating the development of novel miniaturized biosensing platforms. In this study, we present the creation of an electroanalytical genosensor utilizing $Ti_3C_2T_x$/DNA hybrid screen-printed paper electrode strips for the detection of cervical cancer, based on varying concentrations of HPV-16. The Mxene nanostructures were characterized using X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), Fourier transform infrared (FTIR) spectroscopy, and UV–visible (UV-Vis) spectroscopy. The performance of the bionanoelectrode toward HPV-16 detection was examined using cyclic voltammetry (CV) analysis. The sensitivity and limit of detection (LoD) were calculated to be 1.65 μA/fM/mm^2 and 2.4 fM, respectively, while demonstrating selectivity to HPV-16 DNA and generating a shelf life of ~1 month. The developed bionanoelectrode was further integrated with miniaturized electronics and 3-D printing technology, and the resulting device—Cervicare demonstrated appreciable performance (LoD = 0.02 pM). This indicates significant potential of the developed Cervicare device for implementation in point-of-care (PoC) scenario, toward providing affordable healthcare among the affected populace.**



***Index Terms*— Affordable healthcare, electroanalytical genosensing, human papillomavirus (HPV) 16 cervical cancer, miniaturized electronics, point-of-care (PoC) diagnostics.**

I. Introduction

THE cervical cancer remains a significant global health challenge, contributing substantially to cancer-related fatalities among women worldwide. High-risk human papillomavirus (HR-HPV), particularly genotype 16, is a key causative factor strongly linked to elevated mortality rates [1]. Each year, approximately 5.27 million new cases of cervical cancer are reported globally, with 1.22 million cases occurring in India alone [2]. Recent studies indicate that immune-compromised patients, particularly those affected by COVID-19, may experience accelerated progression of cervical intraepithelial neoplasia, ultimately leading to cancer development [3]. The situation is particularly dire in resource-limited regions, where delays in timely diagnosis often result in severe complications and fatalities [4]. Consequently, there is an urgent need for timely and accurate detection of HR-HPV infections, especially genotype 16, to enable effective cervical cancer screening and facilitate appropriate prevention or treatment strategies.

Current diagnostic approaches have several limitations, including Papanicolaou (Pap) smears, biopsy tests, and colposcopy techniques. These methods often suffer from low specificity and sensitivity, are time-consuming, expensive, and require skilled personnel for operation. Additionally, the imaging-based techniques, such as cytology, are prone to false-positive or false-negative results and may be affected by blood or vaginal discharge [5]. These challenges highlight the pressing need for innovative, portable, and affordable biosens-

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