SENSITIVE DETECTION OF KIDNEY INJURY BIOMARKER (KIM1) IN URINE SAMPLES USING AN OPTICAL FIBER SEMI-DISTRIBUTED INTERFEROMETER BIOSENSOR

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Kidney injury molecule-1 (KIM-1) has emerged as a reliable biomarker for the early detection of acute kidney injury (AKI) and chronic kidney disease (CKD). However, its translation into clinical diagnostics has been limited by the lack of sensitive, rapid, and non-invasive detection platforms. Conventional approaches, such as ELISA, chromatography, and mass spectrometry, though accurate, remain costly, time-consuming, and unsuitable for point-of-care testing. To address this gap, we developed an innovative optical fiber biosensor based on a semi-distributed interferometer (SDI) for the direct detection of KIM-1 in urine samples. The sensor design integrates a cost- effective splice-and-cleave fabrication strategy using magnesium-silicate nanoparticle-doped enhanced backscattering fiber spliced to a standard single-mode fiber, forming a Fabry–Perot interferometric cavity. Functionalization of the fiber tip with monoclonal anti-KIM-1 antibodies enabled selective binding of the target protein. Surface characterization confirmed robust antibody immobilization, while antibody specificity was validated using dot blot and ELISA assays. The biosensor was interrogated using a dynamic optical fiber Bragg grating system, ensuring high spectral resolution and reproducibility.

Performance evaluation demonstrated an ultralow limit of detection of 13.6 attomolar, with a linear detection range spanning 1 aM to 100 nM. Notably, the sensor exhibited enhanced stability and sensitivity in complex biological matrices, including artificial, abnormal, and human urine, outperforming traditional immunoassays. Clinical proof-of-concept testing in CKD patient urine confirmed its capability to discriminate between pathological and healthy conditions with high accuracy. The biosensor also showed excellent reproducibility across independently fabricated units and sustained functionality under variable matrix compositions.

This study highlights several key advantages of the SDI biosensor: (i) rapid and label-free detection of KIM-1 without the need for sample preprocessing; (ii) ultrahigh sensitivity suitable for early-stage diagnosis; (iii) affordability, with a unit cost of less than one USD; and (iv) compatibility with multiplexing platforms for broader biomarker analysis. These features position the biosensor as a transformative diagnostic tool for non-invasive monitoring of renal injury.