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HoloIntelligent: A Deep Learning Framework for Comparative Analysis of Holographic and Bright-Field Imaging in Head and Neck Carcinoma Classification

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ABSTRACT

Head and Neck Cancer (HNC) remains a major global health challenge, with late-stage diagnosis limiting treatment outcomes. Conventional methods, including histopathology and standard imaging, are time-consuming, heavily reliant on expert interpretation, and introduce variability with diagnostic delays. To address these limitations, this study integrates digital holographic imaging with advanced Deep Learning (DL) architectures for automated HNC classification. A novel dataset comprising 3915 holographic images from 291 patients is utilized to evaluate two proposed models: a *Convolutional Block Attention Module (CBAM)-Integrated U-Net classifier* and a custom-designed *HoloIntelligent framework*. Class imbalance is addressed through synthetic oversampling, and performance is evaluated using both discriminative metrics and error-based measures. Both models achieved high classification accuracy, with the CBAM-Integrated U-Net attaining 97.29% and HoloIntelligent achieving 97.63%. HoloIntelligent outperformed the CBAM-Integrated U-Net in classifying both normal and abnormal cases, demonstrating superior discriminative performance on holographic data. To further validate the proposed models, ablation studies were conducted to analyze the contribution of each model component. The study is further strengthened through statistical evaluation and comparative analysis with corresponding bright-field data across multiple baseline models. In addition, the explainability analysis improved the interpretability and credibility of the findings. The study also discusses current limitations, key challenges, and future research directions. Finally, the study concludes with a summary of its major contributions. Overall, the findings demonstrate that HoloIntelligent achieves robust and reliable performance on holographic data, underscoring its potential as a valuable tool for early detection and clinical decision-making in HNC.

1 | Introduction

Cancer remains one of the leading causes of morbidity and mortality worldwide, ranking as the second most common cause of death globally, after cardiovascular disorders [1]. Among the various types of cancer, Head and Neck Cancer (HNC) ranks sixth worldwide in terms of incidence, accounting for more than 650,000 new cases and over 330,000 deaths annually [2]. The burden of cancer is unevenly distributed across sexes; men are generally more affected, with a higher incidence of HNC, particularly