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Foundation Model-Assisted Multi-Instance Learning for Predicting Kidney Function Decline in IgA Nephropathy

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Objectives : This study develops a deep learning-based predictive model for kidney function decline in patients with Immunoglobulin A Nephropathy. By integrating multiple instance learning (MIL) with foundation models (FM) trained on large-scale histopathological datasets, we seek to enhance risk stratification without requiring labor-intensive pixel-level annotations. This approach aims to improve the accuracy and efficiency of digital pathology analysis, enabling early identification of high-risk patients and facilitating timely clinical interventions.
Methods : This study retrospectively collected digital histopathological images of patients with Immunoglobulin A Nephropathy from Seoul National University Hospital. The primary outcome was kidney function decline within a five-year follow-up period. A MIL-based framework processed whole-slide images, selecting the top-10 high-attention patches per slide. We compared three encoders—ResNet50, CONCH, and UNI. ResNet50 was pre-trained on ImageNet, while CONCH and UNI were foundation models trained on large-scale histopathological datasets. CONCH is a vision-language model trained via contrastive learning, whereas UNI is a self-supervised learning model optimized for pathology image representation. For FM-based models, the image encoder was frozen, and only the classifier was trained. Model optimization used the Adam optimizer and weighted cross-entropy loss.
Results : In performance evaluation, UNI achieved the highest C-index (0.872) and AUC (0.875), excelling in ranking-based prediction. In contrast, CONCH demonstrated superior accuracy in binary classification (ACC: 0.842, PPV: 0.786, F1-score: 0.880), making it particularly effective in identifying patients at risk of kidney function decline. These findings suggest that UNI effectively captures gradual disease progression, while CONCH identifies distinct pathological features relevant to short-term prognosis.
Conclusions : Overall, the results highlight the complementary strengths of foundation models in predicting kidney function decline. UNI excels in risk stratification, making it valuable for long-term patient monitoring, while CONCH provides accurate short-term predictions, supporting clinical decision-making. Their integration may enhance precision in personalized nephrology care, optimizing early intervention strategies for high-risk patients.

table1.png

Table 1. Comparison of kidney function decline classification performance according to image encoders.

Encoder	C-index	AUC.	AUC.	ACC.	PPV.	NPV.	F1-score
ResNet50	0.769	0.773	0.773	0.789	0.769	0.833	0.833
CONCH	0.816	0.864	**0.864**	**0.842**	**0.786**	**1.000**	**0.880**
UNI	**0.872**	**0.875**	0.875	0.737	0.750	0.714	0.783

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