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Real-Time Intradialytic Hypotension Prediction by Hemodialysis Patient Graph with Large Language Model Summaries

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Objectives : To develop a clinical decision support system that represents longitudinal hemodialysis trajectories as a patient-temporal contextual graph, generates evidence-linked large language model (LLM) summaries, and predicts intradialytic hypotension (IDH) with rigorous generalizability assessment.

Methods : Twelve months of data (March 2025–February 2026) from 66 patients (9,206 sessions) were analyzed from a hemodialysis management system (Modunuri®), integrating five streams: minute-level machine logs (2.2 million ORU records), vital signs, laboratory results, dry-weight adjustments, and nursing events. Data were transformed into patient-centric contextual graphs (mean 548 nodes per patient), from which time-horizon subgraphs were retrieved for graph-based RAG summaries via a local LLM. For IDH prediction (SBP < 100 mmHg within 30/60 minutes), 39 features were engineered from 5-minute resampled observations (353,590 points). The dataset was split temporally at September 2025 into training and test sets. Robustness was further assessed via LOPO cross-validation and LOPO restricted to SBP > 110 mmHg observations.

Results : The retrieval-augmented generation (RAG) pipeline generated multi-horizon summaries with explicit node-level evidence citations. For 30-minute IDH prediction, Random Forest area under the curve–receiver operating characteristic (AUC-ROC) was 0.937 on temporal split, 0.914 with systolic blood pressure (SBP) > 110 mmHg filtering, 0.872 ± 0.117 on leave-one-patient-out (LOPO) cross-validation—where each patient was held out entirely to assess generalizability to unseen individuals—and 0.822 ± 0.130 under the most stringent SBP > 110 mmHg + LOPO evaluation. For 60-minute prediction: 0.921, 0.897, 0.848 ± 0.125 , and 0.816 ± 0.119 , respectively. Top features were mean arterial pressure (MAP), SBP change from session start, and ultrafiltration rate.

Conclusions : A patient-temporal contextual graph provides unified infrastructure for both evidence-linked LLM summaries and IDH prediction, maintaining AUC-ROC above 0.82 even under the most stringent validation, supporting clinical utility for early IDH warning.

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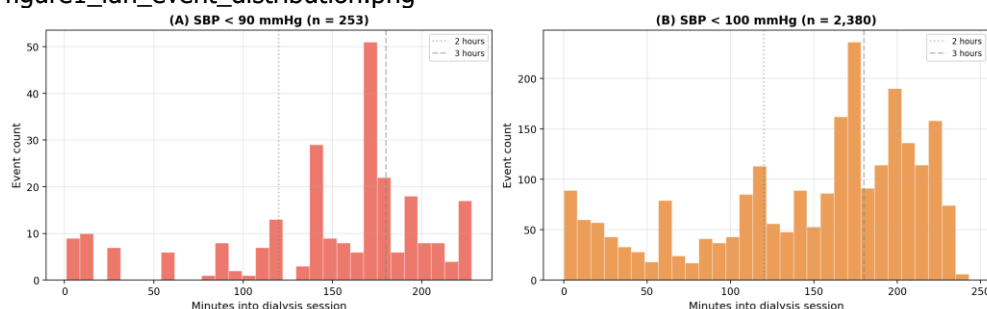


Fig. 1. Temporal distribution of intradialytic hypotension events during hemodialysis sessions. (A) Severe IDH (SBP < 90 mmHg): 253 events concentrated in the later half of sessions (120–240 minutes), consistent with ultrafiltration-induced volume depletion. (B) Borderline IDH (SBP < 100 mmHg): 2,380 events showing a broader temporal distribution with earlier onset, suggesting gradual hemodynamic instability detectable before severe hypotension occurs. Both patterns support the use of SBP < 100 mmHg as the threshold for proactive monitoring to enable earlier clinical intervention. IDH, intradialytic hypotension; SBP, systolic blood pressure.



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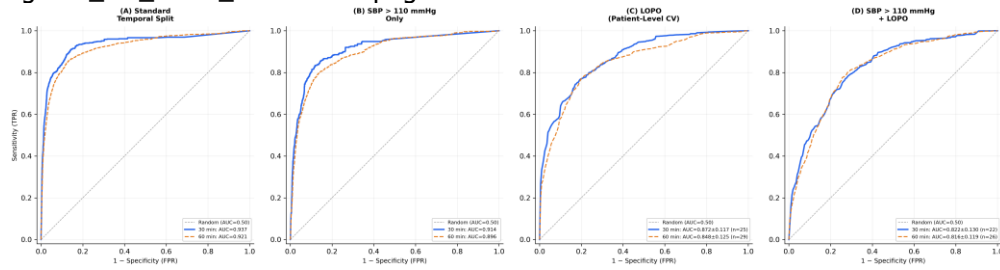


Fig. 2. ROC curves for intradialytic hypotension (IDH, SBP < 100 mmHg) prediction at 30-minute (solid blue) and 60-minute (dashed orange) horizons. (A) Standard temporal train/test split (training before September 2020, testing after). (B) Evaluation restricted to observations with current SBP > 110 mmHg, excluding thrashly predictable cases near the hypotension threshold. (C) Leave-one-patient-out (LOPO) cross-validation showing the mean ROC curve across all patients. (D) The most stringent combined evaluation (SBP > 110 mmHg + LOPO). Random Forest classifiers with 39 features were used throughout. Even under the most conservative assessment (D), AUC-ROC remained above 0.80 for both prediction horizons. IDH, intradialytic hypotension; SBP, systolic blood pressure.