

Temporal Signal Within Vital Signs Precedes Delayed Cerebral Ischemia Diagnosis

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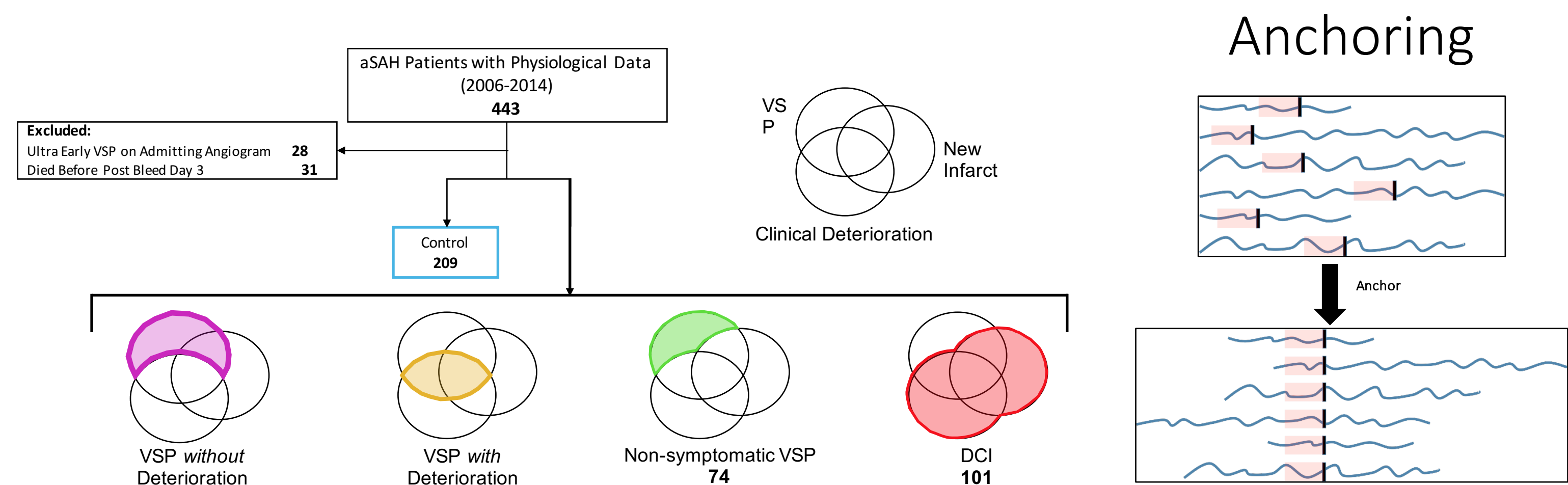
Background

- Subarachnoid hemorrhage (SAH) is a major public health burden, affecting 14.5 per 100,000 Americans.
- Delayed Cerebral Ischemia (DCI) from vasospasm (VSP) has been implicated as the most morbid secondary injury after SAH.
- VSP is the narrowing of cerebral blood vessels, triggered by the unusual presence of blood in the brain after a bleed.
- DCI is a consensus definition used for research, encompassing clinical evidence linked to reduced perfusion after SAH.
- Symptoms can be subtle and develop gradually, typically occurring anywhere between 3 and 14 days post-bleed.
- Current prediction: scales (mFS, Hijdra) rely on one-time imaging findings at admission, and often lacks precision for individuals.
- Current detection: diagnosis relies on noticing subtle symptoms which then triggers ruling out mimics and confirmatory imaging.

We are seeking to develop autonomous, continuous tools to detect complications after SAH—by discovering, evaluating and incorporating the temporal signals imbedded in vital signs.

Methods

Vital signs at 0.2 Hz, age, sex, mFS, WFNS, HH and GCS at NICU admission included for 384 patients admitted with aneurysmal SAH May 2006 to December 2014.

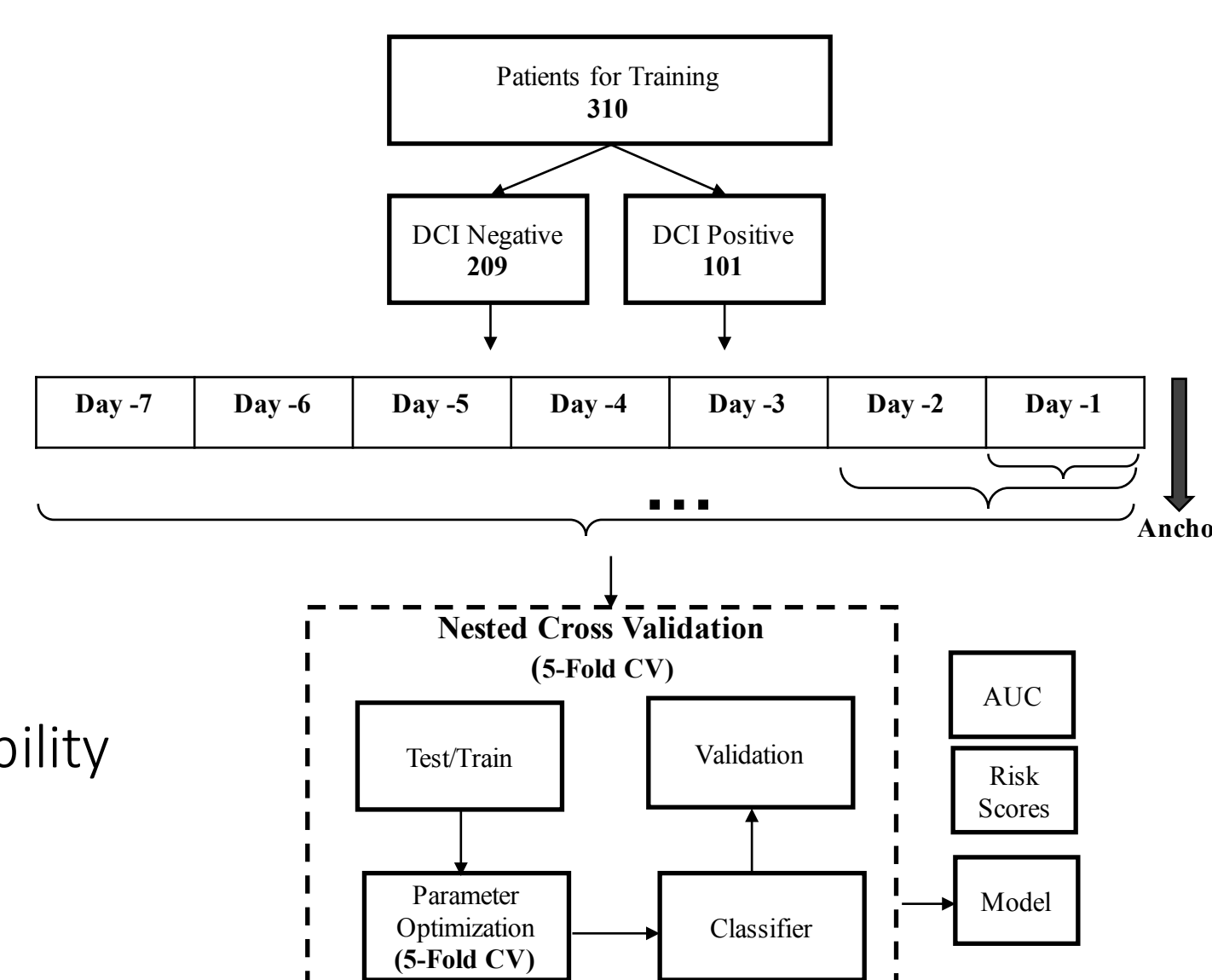


Multilevel Linear Regression (MLM) $Y_{ij} = \alpha_0 + \alpha_1 t_{ij} + \alpha_2 X_{ij} + b_{0i} + \epsilon_{ij}$

Data continuously added from admission until DCI anchor. Longitudinal mixed-effects model allows for inter-patient and intra-patient comparison over time with repeated outcomes.

Ensemble Machine Learning Approach

L2-regularized logistic regression, random forest, and support vector machines

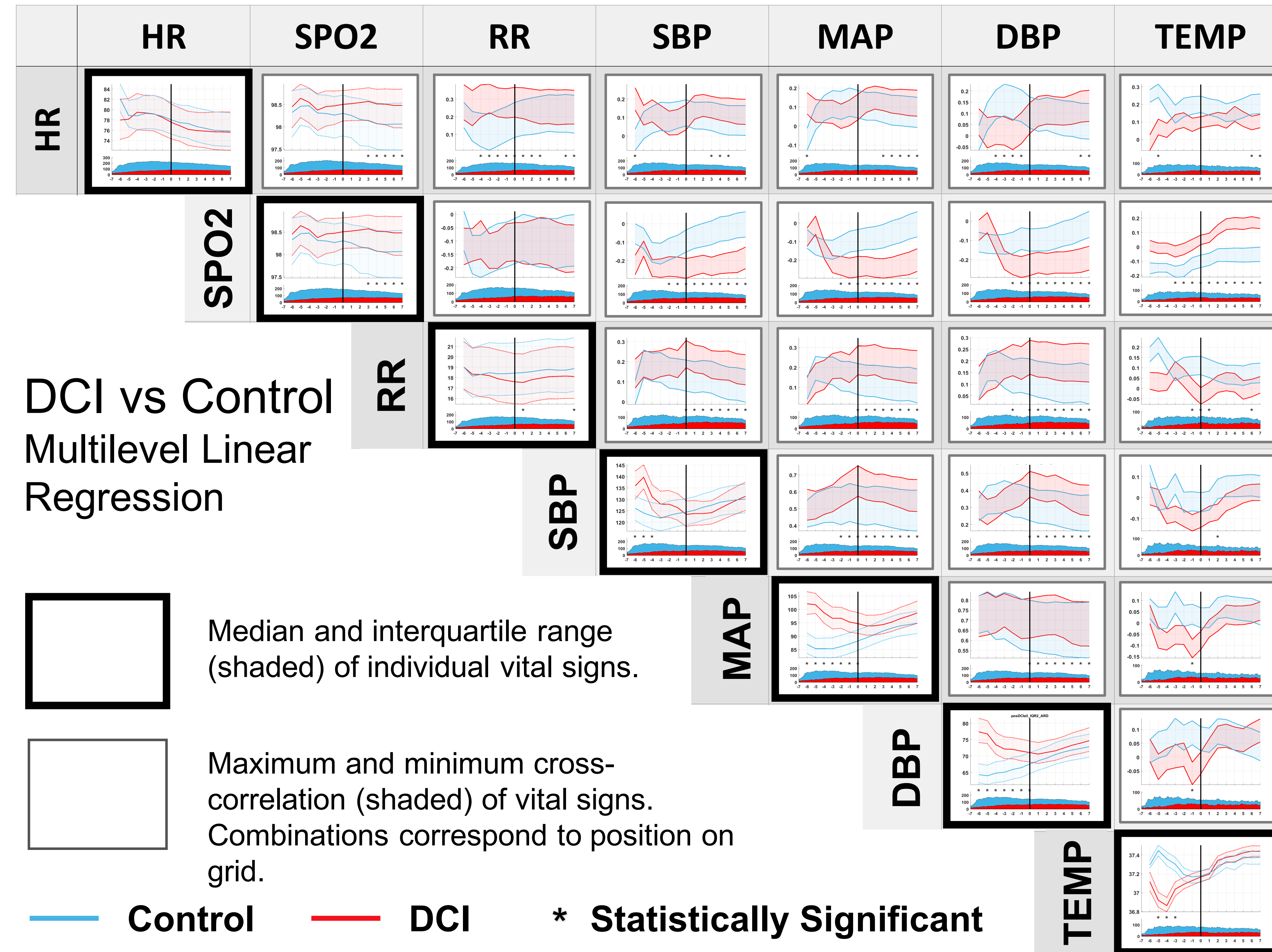


Hourly Risk Scores - Posterior probability

$$p(y_i | x_{it}) = f(w, x_{it})$$

Multilevel Linear Regression

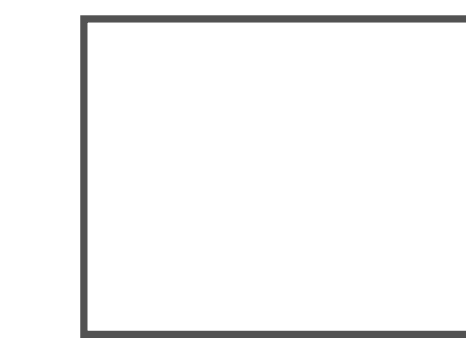
Comparisons of vital signs:



DCI vs Control
Multilevel Linear
Regression



Median and interquartile range (shaded) of individual vital signs.



Maximum and minimum cross-correlation (shaded) of vital signs. Combinations correspond to position on grid.

— Control — DCI * Statistically Significant

Heart rate (HR), respiratory rate (RR), oxygen saturation (SPO2), arterial blood pressure (SBP, DBP, MAP) and temperature (TEMP).

- statistical difference in trajectories of several vital signs and relationships between vital signs prior to DCI diagnosis.
- BPs and TEMP show difference long before anchor, while cross-correlations (HR-RR, DBP; SPO2-SBP, MAP, DBP, TEMP; RR-TEMP, SBP-MAP, TEMP-MAP, DBP) show difference localized to anchor.

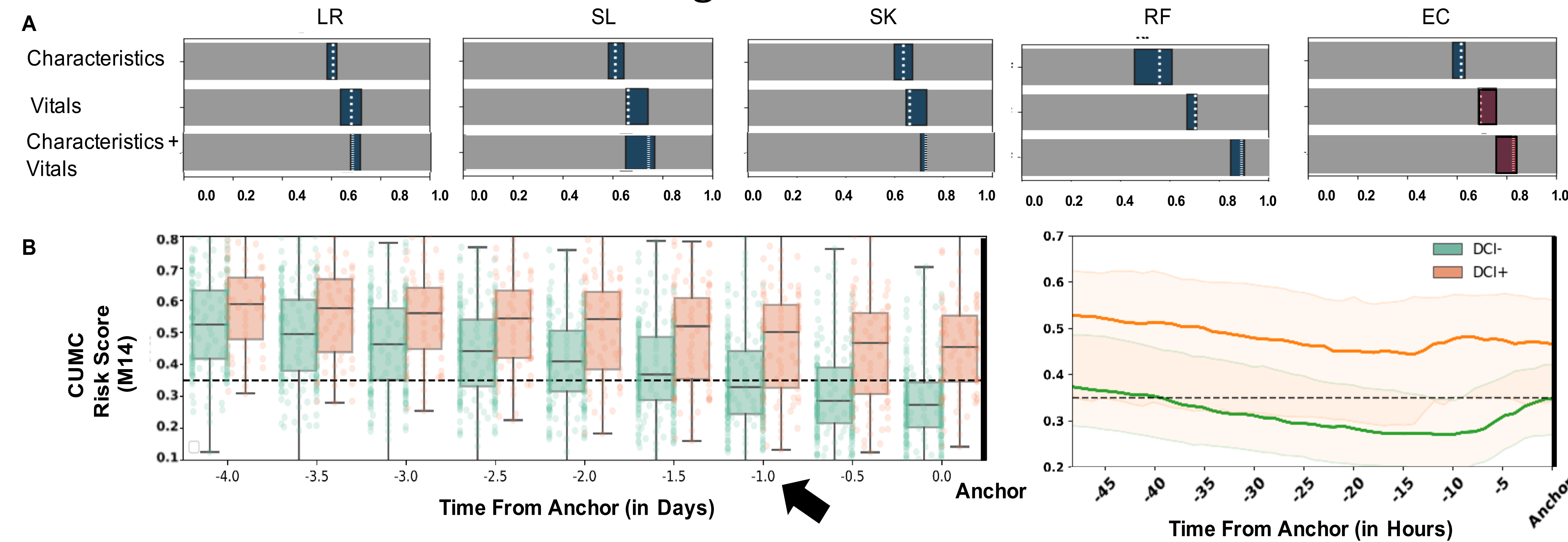
Discussion

Temporal signals in vital signs exist prior to DCI diagnosis. Machine Learning models using vital signs and popular baseline characteristics may be able to enhance identification of patients developing DCI.

A limitation: this study utilizes retrospective data. However, enrollment in this SAH outcomes database and adjudication of DCI was completed prospectively.

Future efforts: improving our models, continuing to validate the models on external and prospective datasets.

Machine Learning Classifiers and Risk Scores



AU-ROCs for 5 classifiers and risk scores based on best performing model (EC with characteristics and vitals).

LR = 0.78 [0.71-0.80], SL = 0.76 [0.75-0.81], SK = 0.76 [0.70-0.78], RF = 0.81 [0.75-0.82] and EC = 0.79 [0.75-0.80]

With optimal threshold of 0.35, we correctly predict 72.6 % of DCI patients and 74.7 % of controls 12 hours prior to anchor. This would translate to 3 true alerts per 2 false alerts.

References

1. Shea AM, Reed SD, Curtis LH, Alexander MJ, Villani JJ, Schulman KA. Characteristics of nontraumatic subarachnoid hemorrhage in the United States in 2003. *Neurosurgery* (2007) 61(6):1131-7.
2. Frontera JA, Fernandez A, Schmidt JM, Claassen J, Wartenberg KE, Badjatia N, et al. Defining vasospasm after subarachnoid hemorrhage: what is the most clinically relevant definition? *Stroke* (2009) 40(6):1963-8.
3. Megjhani M, Terilli K, Weiss M, Savarraj J, Chen LH, Alkhachroum A, Roh DJ, Agarwal S, Connolly ES Jr, Velazquez A, Boehme A, Claassen J, Choi HA, Schubert GA, Park S. Dynamic Detection of Delayed Cerebral Ischemia: A Study in 3 Centers. *Stroke*. 2021 Apr;52(4):1370-1379. doi: 10.1161/STROKEAHA.120.032546.



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