

Automated Early Warning of Acute Heart Failure in *ex vivo* Heart Evaluation Using Hemodynamic Flags

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Aims: In *ex vivo* heart evaluation, an explanted heart is kept beating outside the body by circulating oxygenated solution, allowing assessment of cardiac function. Hearts may develop acute heart failure (AHF), requiring prompt flow reduction to prevent damage. Detection currently relies on continuous visual monitoring. In clinical transplantation, automated monitoring during *ex vivo* perfusion could reduce dependence on human oversight and improve graft safety. We aimed to automate AHF detection using hemodynamic signals from a porcine *ex vivo* system.

Methods: Data from 13 porcine heart experiments were split chronologically into training (10 experiments, 29 events, 17 h 40 min) and test (3 experiments, 5 events, 6 h 55 min) sets. Seven hemodynamic signals (including left ventricular, left atrial, and aortic pressures) were converted to beat-by-beat features, including heart rate (HR), left atrial pressure (LAP), and the maximum rate of ventricular pressure rise. Each feature was expressed as its short-term deviation from a causal baseline. A flag activated when a feature exceeded its threshold, and detection triggered when the weighted flag sum reached a pre-defined count. Three variants—all-feature, reduced (HR and LAP only), and weighted (HR and LAP double-weighted)—were compared by F2 score.

Results: The weighted model generalized best, with F2 scores of 0.80 on training and 0.65 on test data, detecting 90% of events with roughly one false positive per true positive. On extended datasets simulating continued operation, F2 improved to 0.85 and 0.76, detecting all five test events. Median detection latency was 5 s before manual intervention.

Conclusion: A simple flag-based model detects AHF events in an *ex vivo* perfusion system prior to manual intervention. The weighted model’s consistent generalization supports feasibility of automated early warning during *ex vivo* heart evaluation. Next steps include online validation toward clinical *ex vivo* evaluation of human donor hearts.

F2 scores across models and datasets.

Model	Full		Extended	
	Train	Test	Train	Test
All-feat.	0.74	0.59	0.81	0.74
Reduced	0.79	0.36	0.85	0.67
Weighted	0.80	0.65	0.85	0.76