UNIVERSITY OF MARYLAND

Benchmarking Wearable Physio-Markers for Stroke Volume Tracking During Hemorrhage and Blood Transfusion in a Swine Model

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PROBLEM

Hemorrhage in Pre-Hospital Care

SCALE [1]

5 million deaths annually

Trauma is one of the leading causes of mortality worldwide

CAUSE [2]

Severe bleeding accounts for 40% of trauma deaths within the first 24 hours

TIMING [3]

90% of battlefield deaths occur in pre-hospital settings

MONITORING GAP [1]

SV/CO monitoring underutilized

Guidelines recommend stroke volume and cardiac output monitoring in shock

[1] ESICM guidelines on circulatory shock and hemodynamic monitoring 2025
[2] The European guideline on management of major bleeding and coagulopathy following trauma: sixth edition
[3] Death on the battlefield (2001-2011): implications for the future of combat casualty care

SV: Stroke Volume. CO: Cardiac Output

Current SV Monitoring Methods Fall Short for Prehospital Use

Invasive

- **Aortic Flow Probes**

Gold-standard accuracy but requires surgery

- **Pulmonary Artery Catheter Thermodilution**

Clinical accuracy but requires central venous access

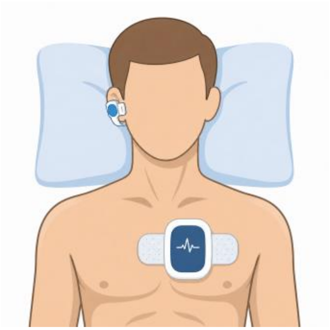
- **Pulse-Contour Systems**

Less invasive but still needs an arterial catheter

Aortic Flow Probe
as Reference SV Measure

Systolic Area under the Arterial Blood Pressure as
ABP-Based Comparator

Multimodal Wearable Approach



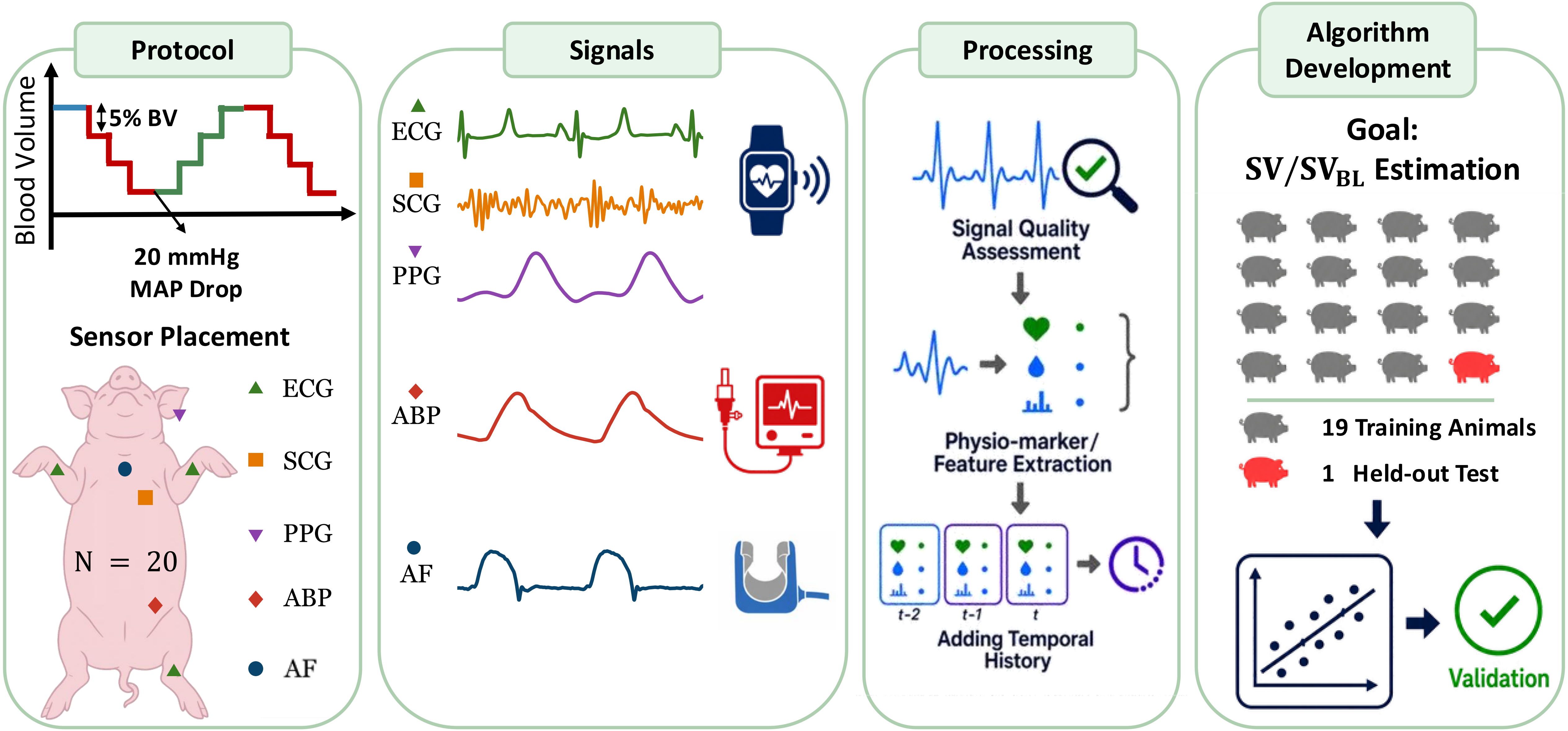
ECG
Cardiac Electrical Activity

SCG
Cardiac Mechanical Activity

PPG
Peripheral Blood Volume Dynamics

ECG: Electrocardiogram. SCG: Seismocardiogram. PPG: Photoplethysmogram. SV: Stroke Volume

Experimental Assessment in a Swine Hemorrhage Model

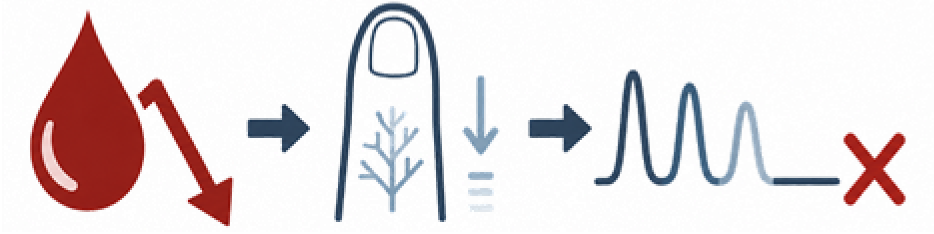


BV: Blood Volume. MAP: Mean Arterial Pressure. ABP: Arterial Blood Pressure. AF: Aortic Flow. BL: Baseline.

Signal Quality Index and Physio-Marker Extraction

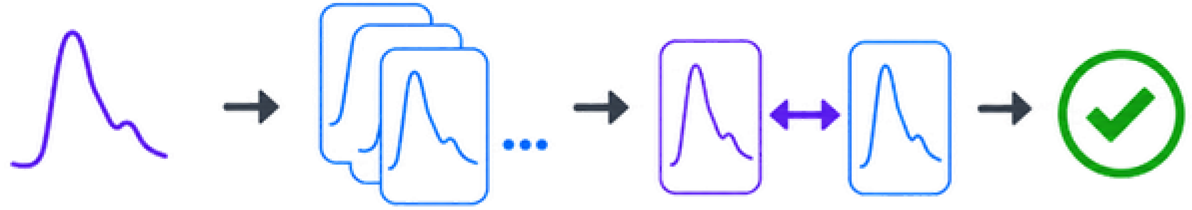
Signal Quality Assessment

Which signals need SQI?



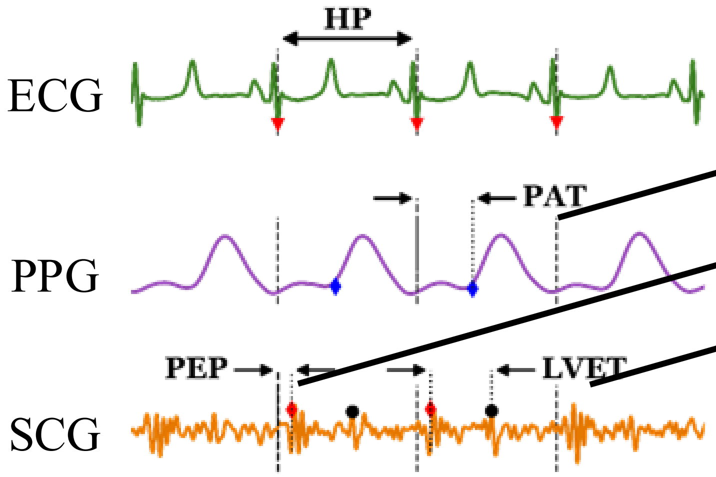
Severe Hemorrhage → Low Peripheral Perfusion → PPG Amplitude Decay

How to calculate the PPG SQI?



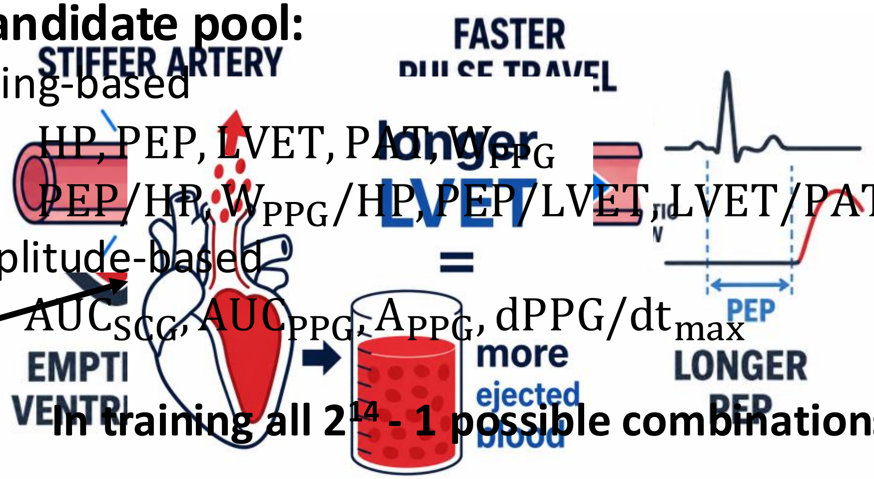
query beat (held-out animal) → other-animal templates → compare query to templates → Final SQI

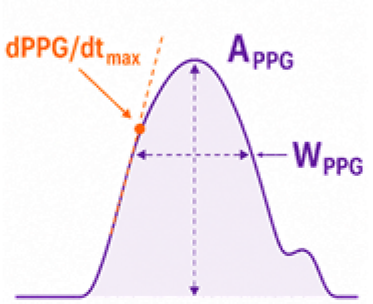
Physio-Marker Candidates



The candidate pool:

- Timing-based
  - HP, PEP, LVET, PAT, W_{PPG}
  - PEP/HP, W_{PPG}/HP, PEP/LVET, LVET/PAT, HP/PAT
- Amplitude-based
  - AUC_{SCG}, AUC_{PPG}, A_{PPG}, $dPPG/dt_{max}$

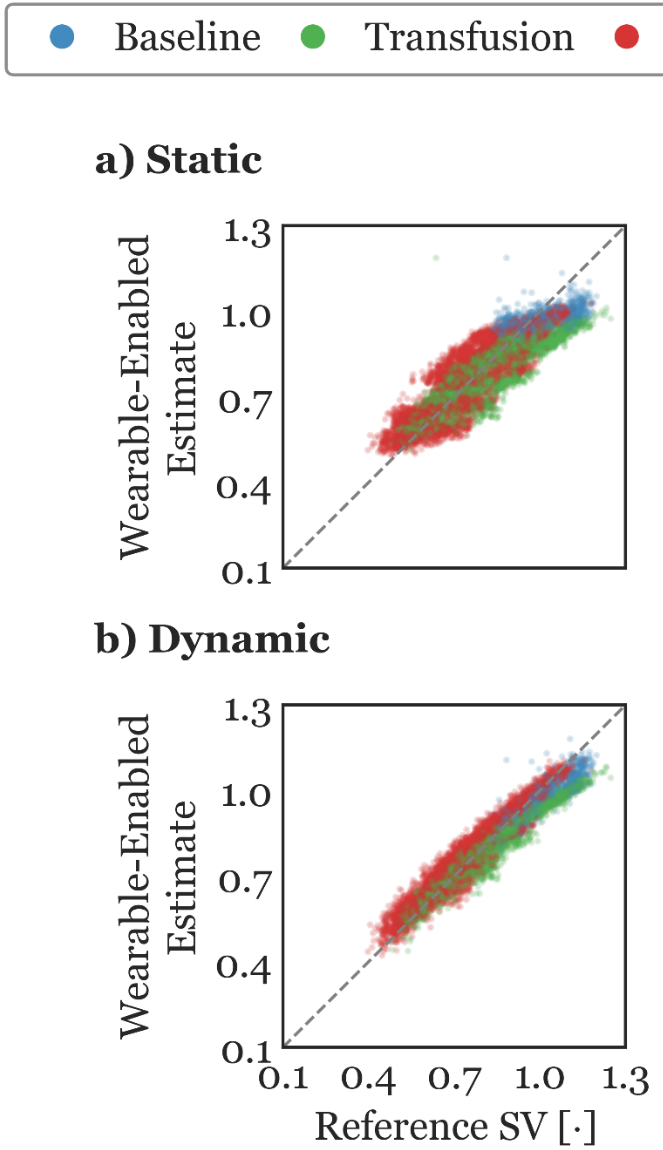




In training all 2^{14} - 1 possible combinations are considered.

SQI: Signal Quality Index. HP: Heart Period. PEP: Pre-Ejection Period. PAT: Pulse Arrival Time. LVET: Left Ventricular Ejection Time.

Performance of Wearable-Enabled Algorithm and ABP-Based Algorithm

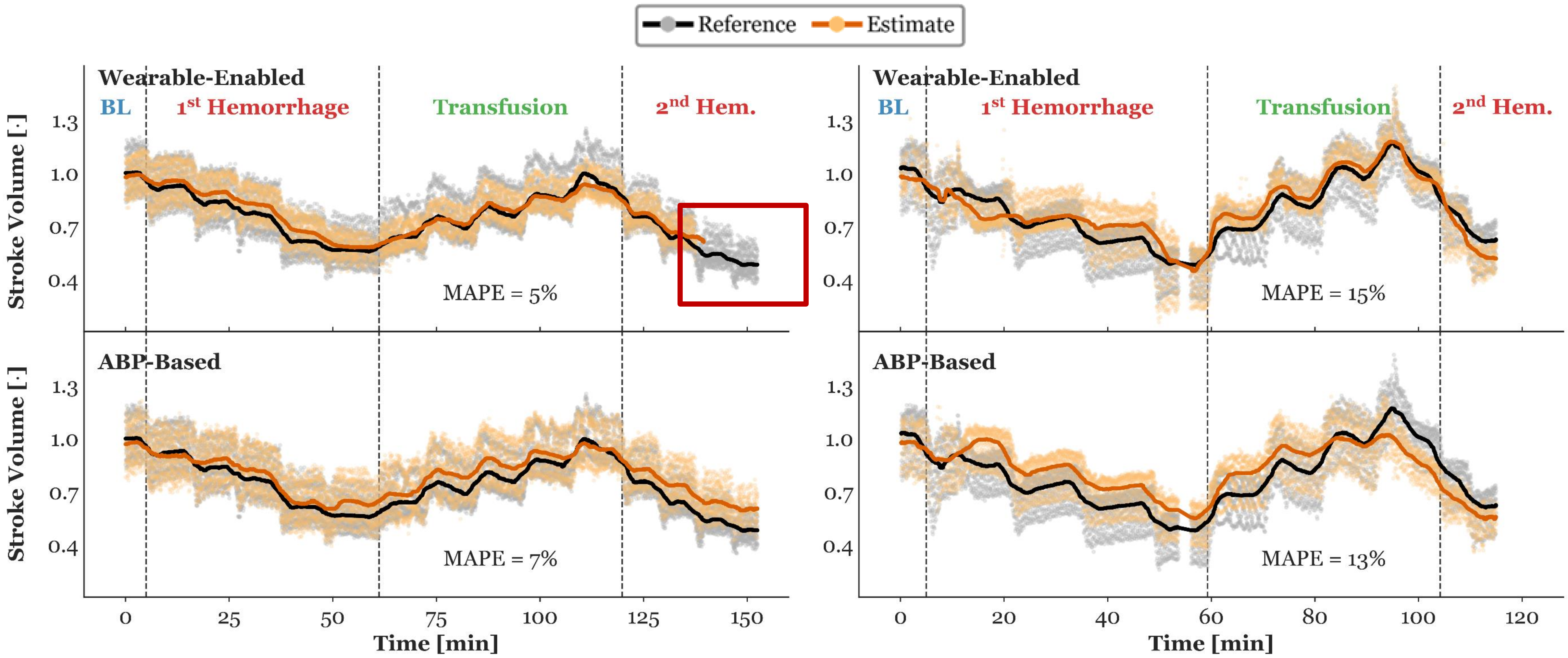


SV: Stroke Volume. BL: Baseline.

Near-Best Case vs Near-Worst Case

Second-Best-Performing Case

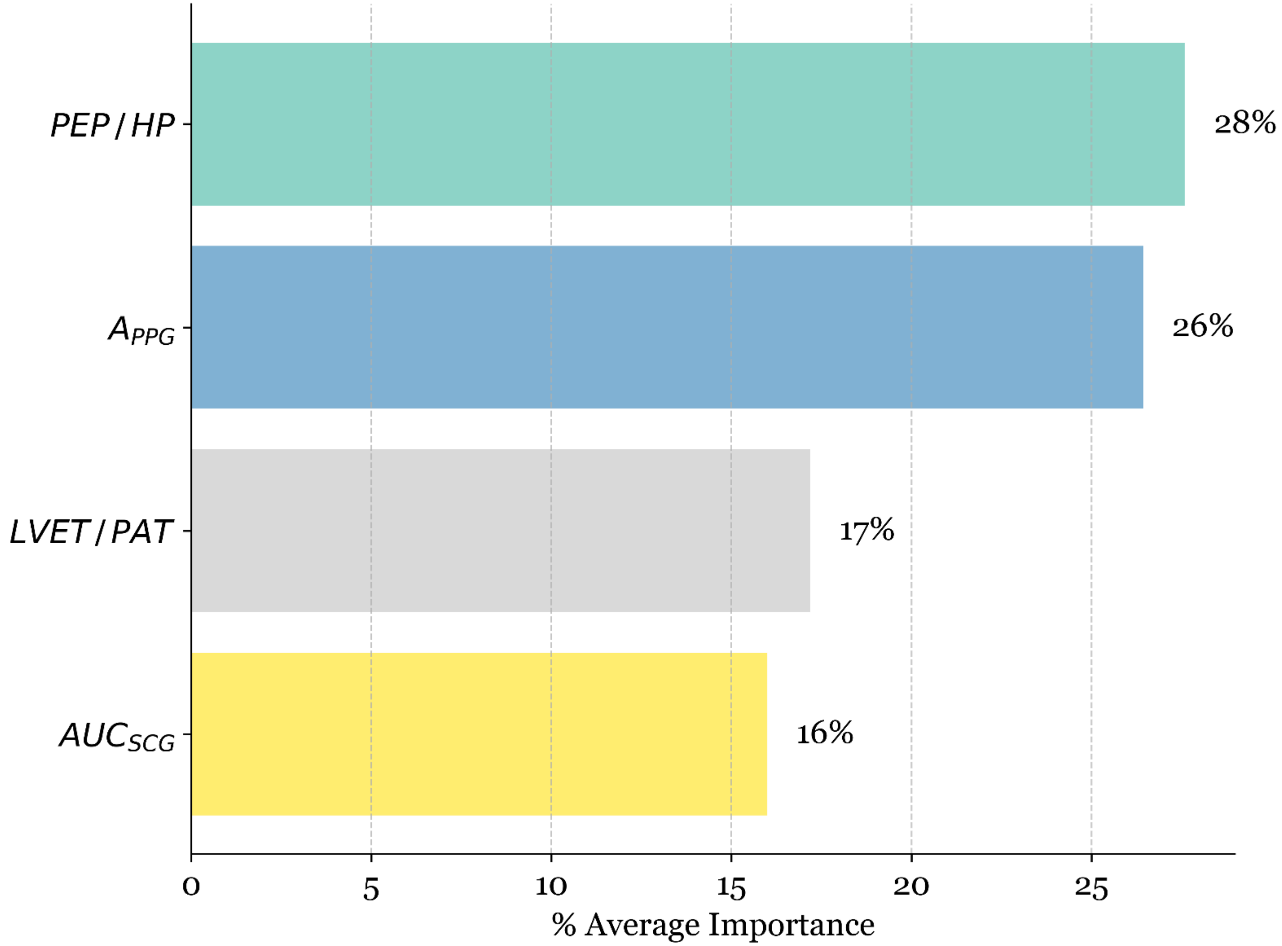
Second-Worst-Performing Case



BL: Baseline. MAPE: Mean Absolute Percentage Error.

Physio-Marker Importance and Modality Contribution

Top Four Physio-Markers ⟶ 87% of Total Feature Importance



	MAPE (%)
ECG-SCG Static	13.9 [10.0, 27.9]
Wearable-Enabled Static	9.7 [6.0, 17.2]
ECG-PPG Static	10.7 [5.3, 30.2]

HP: Heart Period. PAT: Pulse Arrival Time. LVET: Left Ventricular Ejection Time. PEP: Pre-Ejection Period.

LIMITATIONS

TRANSLATION

Findings from anesthetized juvenile female swine may not directly generalize to conscious humans.

CONTROLLED PROTOCOL

The algorithm was evaluated only during controlled hemorrhage and transfusion experiments.

RELATIVE SV

The approach tracks relative SV changes from baseline rather than absolute SV in a new subject.

REAL-TIME USE

Physio-marker extraction was not implemented in real time, especially for SCG.

REAL-WORLD NOISE

Motion artifacts and mechanical noise from prehospital settings were not included in this study.