

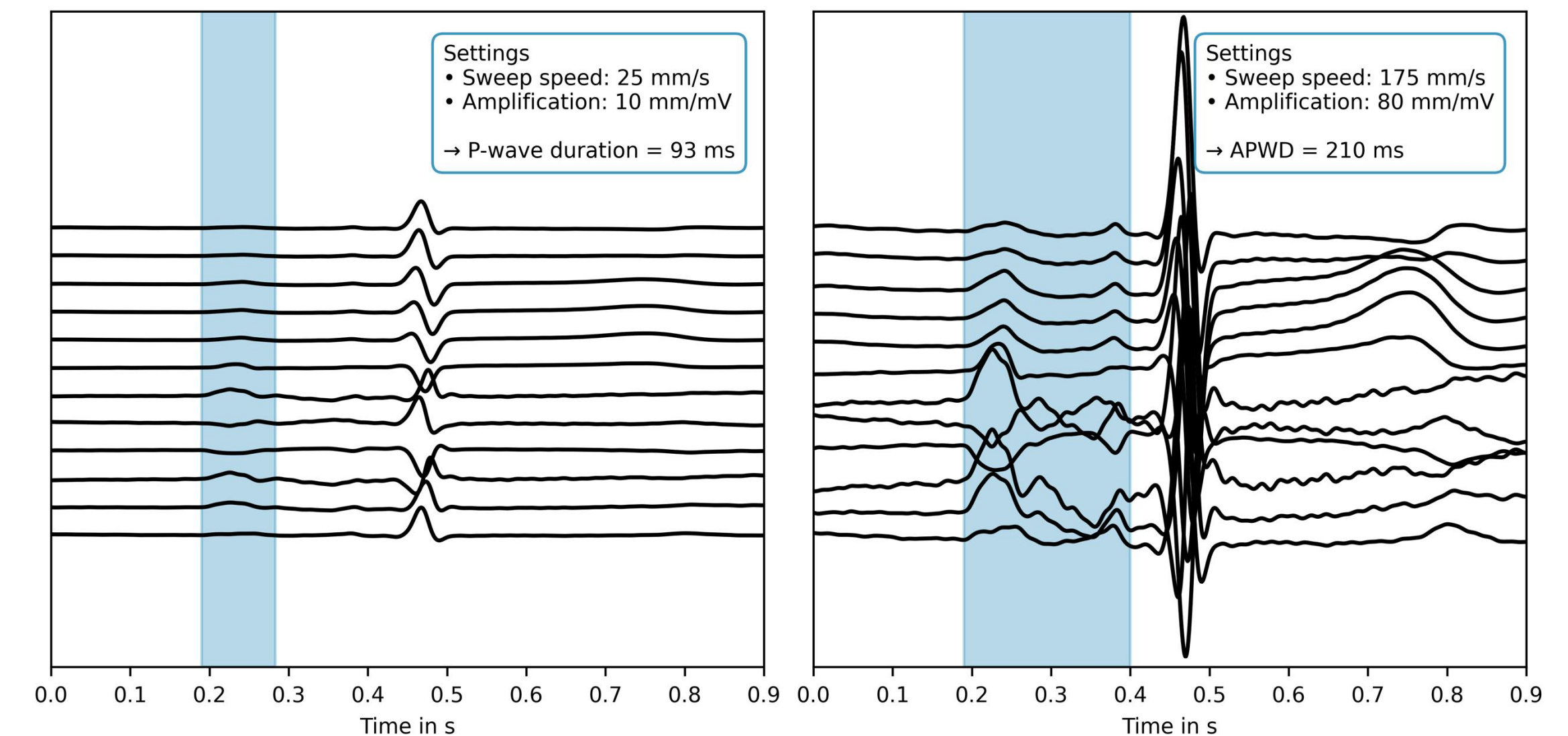
ECG Template-Based Deep Learning for Amplified P-wave Duration Prediction

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Introduction

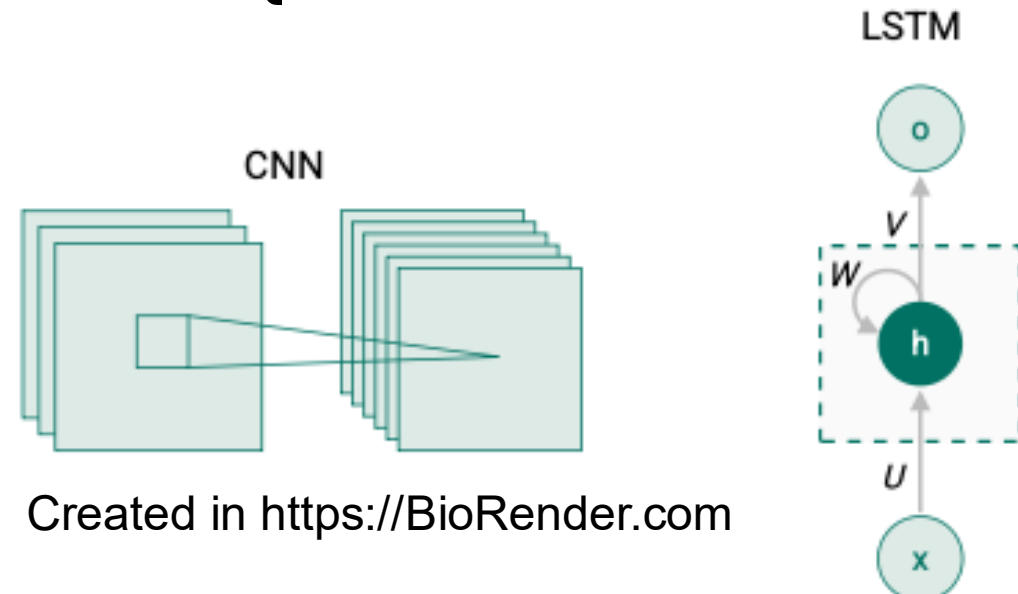
Atrial cardiomyopathy (AtCM) is associated with new-onset atrial fibrillation (AF), heart failure, and a potentially elevated risk of cardioembolic stroke. Atrial conduction delay in patients with AtCM can be non-invasively quantified through the amplified P-wave (APW) duration [1–3]. Currently, however, APW duration analysis depends on manual annotation by trained experts, which restricts its broader clinical applicability. To address this limitation, the present work introduces an automated APW duration algorithm that facilitates reproducible, machine-based analysis, laying the groundwork for large-scale AtCM screening and risk stratification.



Methods

Architectures

- LSTM
 - Bidirectional
 - Hidden dimensions $\in \{16, 32, 64, 128, \mathbf{256}, 512\}$
 - Layer dimensions $\in \{1, \mathbf{2}\}$
- CNN
 - 4-block 1D CNN with kernel sizes $\{9, 7, 5, 5\}$
 - Base $\in \{8, 16, 32, \mathbf{64}, 128, 256\}$



Training setup

- Transfer learning approach
- Pretraining with > 129,000 ECG templates [4,5]
- Fine-tuning with 1,044 ECG templates
- Hyperparameter optimization with Optuna

Labels

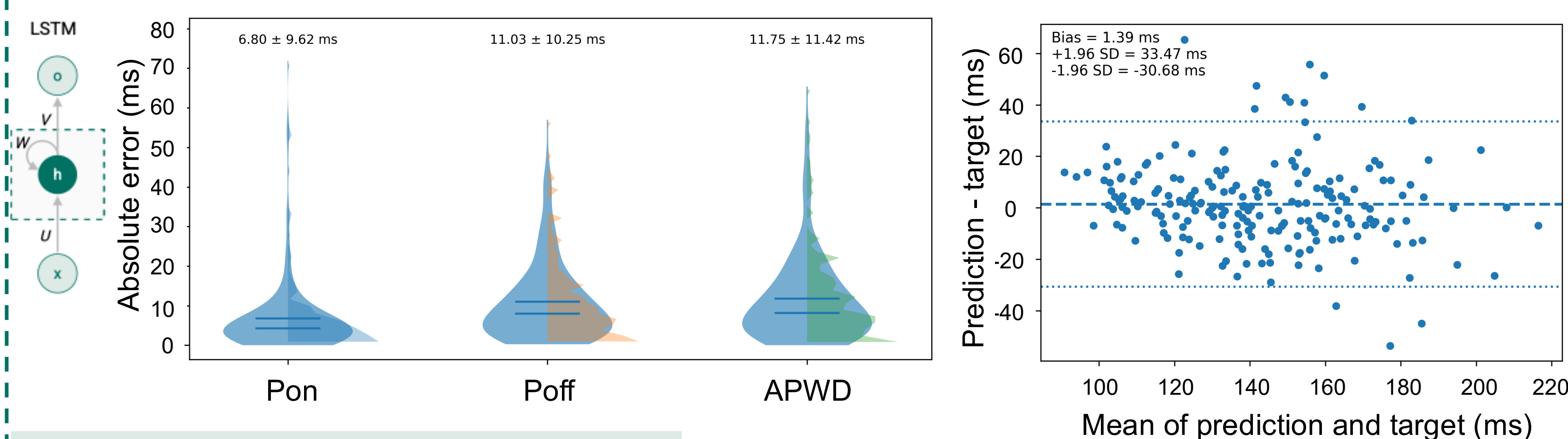
- APW onset
- APW offset
- Pretraining: weak labels generated by ECGdeli [6]
- Fine-tuning: expert labels

Parameters

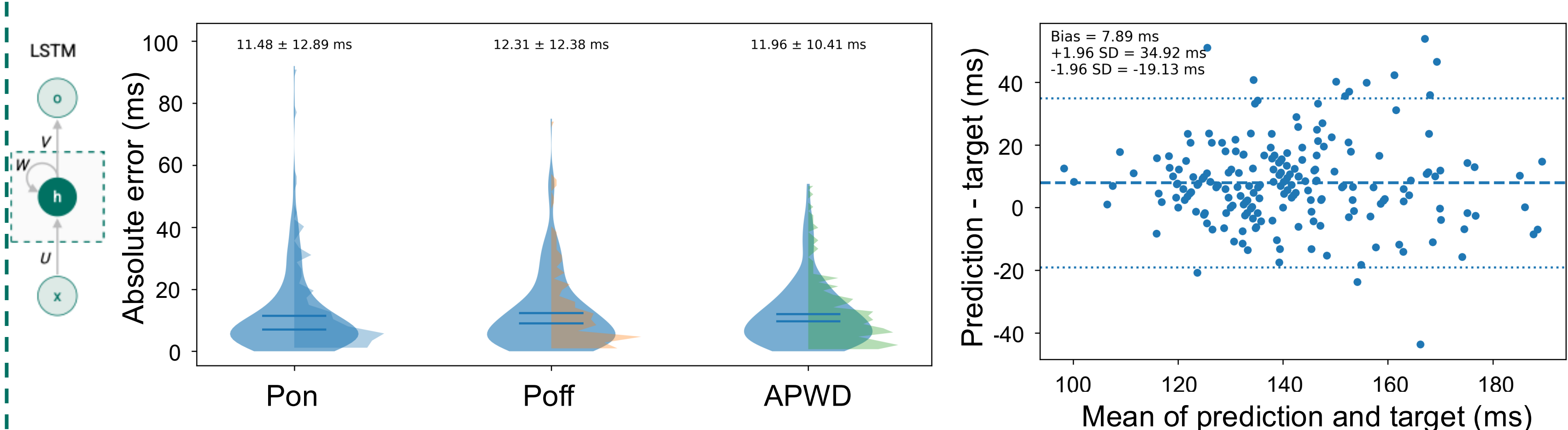
- Pretraining:
 - MSE, early stopping, dropout=0.3, AdamW, weigh decay=1e-2, lr=1e-3, CosineAnnealingLR, masked mean pooling, batch size=64
- Fine-tuning:
 - l1, L2-SP regularization, early stopping, ReduceLROnPlateau, masked mean pooling
- Tuned parameters:
 - dropout, optimizer, scheduler patience, scheduler factor, scheduler min lr, weight decay, lr, batch size, lambda l2, architecture size)

Results

Test set



Independent data set (n=200)



Comparison

	LSTM	CNN
MAE on test set (ms)	6.8 ± 9.62 (Pon) 11.03 ± 10.25 (Poff) 11.75 ± 11.42 (APWD)	18.22 ± 20.33 (Pon) 18.04 ± 21.86 (Poff) 14.11 ± 12.38 (APWD)
Bias on test set (ms)	1.39 [33.47 -30.68] (APWD)	0.32 [37.21 -36.56] (APWD)
MAE on independent data set (ms)	11.48 ± 12.89 (Pon) 12.31 ± 12.38 (Poff) 11.96 ± 10.41 (APWD)	23.39 ± 25.51 (Pon) 22.67 ± 23.21 (Poff) 16.12 ± 11.87 (APWD)
Bias on independent data set (ms)	7.89 [34.92 -19.13] (APWD)	9.82 [44.09 -24.45] (APWD)
# Parameters	2.13 M	0.59 M

Discussion & Conclusion

- Both models generalize well to unseen data
- Outlook: dilated convolutions will be implemented and the performance of a hybrid CNN–LSTM model will be evaluated
- ECG template-based deep learning for amplified P-wave duration prediction shows promise for large-scale atrial cardiomyopathy screening and risk stratification

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