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Prediction of Recurrence of Atrial Fibrillation after Catheter Ablation Using an Artificial Intelligence on Electrocardiogram

Jinsun Park, MD

Division of Cardiology, Asan Medical Center,
University of Ulsan College of Medicine, Seoul, Republic of Korea

Jinsun Park, MD[1], Sanghoon Choi[2], Kyungmin Choi[2], So-Young Yang MD[1], Hyun-Jung Oh MD[1], Min Soo Cho MD[1], Jun Kim MD[1], Gi-Byoung Nam MD[1], Kee-Joon Choi MD[1], Segyeong Joo[2] and **Myung-Jin Cha MD**[1]

[1]Division of Cardiology, Asan Medical Center, University of Ulsan College of Medicine,

Seoul, Republic of Korea

[2]Department of Biomedical engineering, Asan Medical Institute of Convergence Science and Technology, Asan Medical Center, University of Ulsan College of Medicine,

Seoul, Republic of Korea.

Disclosure

The authors have no financial conflicts of interest to disclose concerning the presentation

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BACKGROUND

Significance of atrial fibrillation

- Atrial fibrillation (AF) is an important arrhythmia of many reasons.
- AF is the most commonly observed clinical arrhythmia.
- The lifetime risk for AF 1 in 3 individuals, and this prevalence is expected to increase significantly in the next decades because of the aging of the population.
- In addition, it is more important that the patients with AF was associated higher morbidity and mortality compared to those without AF. The risk of stroke by an average of 5-fold.

Benjamin EJ et al. Circulation. 2019;139(10):e56-e528.

Treatment of AF

- Catheter ablation is a well-established rhythm control strategy, which is currently recommended for symptomatic patients with drug-refractory paroxysmal and persistent AF.

- However, despite the ablation is effective, there are still approximately 50% of patient who have AF recurrences 2 years after the procedure.

- Therefore, follow-up monitoring, the continuous use and duration of antiarrhythmic drugs, and post-recurrence treatment are key issues in follow-up after AF catheter ablation.

- Even after the procedure, **the burden of AF** on patients, societal health, and the health care economy continues significantly.

Morillo CA et al. JAMA. 2014;311(7):692-9

Predictor of recurrence of AF using ECG pameters

- Most AF recurrences are related to pulmonary vein (PV) re-conduction, to extra-PV foci, or to pre-existing atrial fibrosis leading to intra- and/or inter-atrial conduction delays (**atrial remodelling**).

- Atrial remodeling is both electrical and structural; it causes slow electrical conduction and enlargement of the atria. → **Changes in the morphology of the P wave in ECG!**

- Predictors to discriminate who will benefit from ablation and who will be needed more intensive antiarrhythmic drug therapy after ablation are beneficial to save money, time and effort.

- Using ECG parameters as a predictor is very useful, as it is low-cost, feasible and can yield a lot of information

Artificial intelligence

- We hypothesized that by using machine learning in the form of deep neural networks, we could predict the recurrence of AF after catheter ablation by analyzing subtle patterns related to recurrence in the standard 12-lead ECG.

Current studies..

An artificial intelligence-enabled ECG algorithm for the identification of patients with atrial fibrillation during sinus rhythm: a retrospective analysis of outcome prediction

Zachi I Attia, Peter A Noseworthy*, Francisco Lopez-Jimenez, Samuel J Asirvatham, Abhishek J Deshmukh, Bernard J Gersh, Rickey E Carter, Xiaoxi Yao, Alejandro A Rabinstein, Brad J Erickson, Suraj Kapa, Paul A Friedman*

Summary

Background Atrial fibrillation is frequently asymptomatic and thus underdetected but is associated with stroke, heart failure, and death. Existing screening methods require prolonged monitoring and are limited by cost and low yield. We aimed to develop a rapid, inexpensive, point-of-care means of identifying patients with atrial fibrillation using machine learning.

Methods We developed an artificial intelligence (AI)-enabled electrocardiograph (ECG) using a convolutional neural network to detect the electrocardiographic signature of atrial fibrillation present during normal sinus rhythm using standard 10-second, 12-lead ECGs. We included all patients aged 18 years or older with at least one digital, normal sinus rhythm, standard 10-second, 12-lead ECG acquired in the supine position at the Mayo Clinic ECG laboratory between Dec 31, 1993, and July 21, 2017, with rhythm labels validated by trained personnel under cardiologist supervision. We classified patients with at least one ECG with a rhythm of atrial fibrillation or atrial flutter as positive for atrial fibrillation. We allocated ECGs to the training, internal validation, and testing datasets in a 7:1:2 ratio. We calculated the area under the curve (AUC) of the receiver operatoring characteristic curve for the internal validation dataset to select a probability threshold, which we applied to the testing dataset. We evaluated model performance on the testing dataset by calculating the AUC and the accuracy, sensitivity, specificity, and F1 score with two-sided 95% CIs.

Findings We included 180 922 patients with 649 931 normal sinus rhythm ECGs for analysis: 454 789 ECGs recorded from 126 526 patients in the training dataset, 64 340 ECGs from 18 116 patients in the internal validation dataset, and 130 802 ECGs from 36 280 patients in the testing dataset. 3051 (8·4%) patients in the testing dataset had verified atrial fibrillation before the normal sinus rhythm ECG tested by the model. A single AI-enabled ECG identified atrial fibrillation with an AUC of 0·87 (95% CI 0·86–0·88), sensitivity of 79·0% (77·5–80·4), specificity of 79·5% (79·0–79·9), F1 score of 39·2% (38·1–40·3), and overall accuracy of 79·4% (79·0–79·9). Including all ECGs acquired during the first month of each patient's window of interest (ie, the study start date or 31 days before the first recorded atrial fibrillation ECG) increased the AUC to 0·90 (0·90–0·91), sensitivity to 82·3% (80·9–83·6), specificity to 83·4% (83·0–83·8), F1 score to 45·4% (44·2–46·5), and overall accuracy to 83·3% (83·0–83·7).

Interpretation An AI-enabled ECG acquired during normal sinus rhythm permits identification at point of care of individuals with atrial fibrillation.

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See **Comment** page 812

*Contributed equally

Department of Cardiovascular Medicine (Z I Attia MS, P A Noseworthy MD, Prof F Lopez-Jimenez MD, Prof S J Asirvatham MD, A J Deshmukh MBBS, Prof B J Gersh MB ChB, S Kapa MD, Prof P A Friedman MD), **Department of Health Sciences Research** (X Yao PhD), **Department of Neurology** (Prof A A Rabinstein MD), **Department of Radiology** (Prof B J Erickson MD), **Mayo Clinic, Rochester, MN, USA; and Department of Health Sciences Research, Mayo Clinic, Jacksonville, FL, USA** (Prof R E Carter PhD)

Correspondence to: Prof Paul Friedman, Department of Cardiovascular Medicine, Mayo Clinic, Rochester, MN 55905, USA **friedman.paul@mayo.edu**

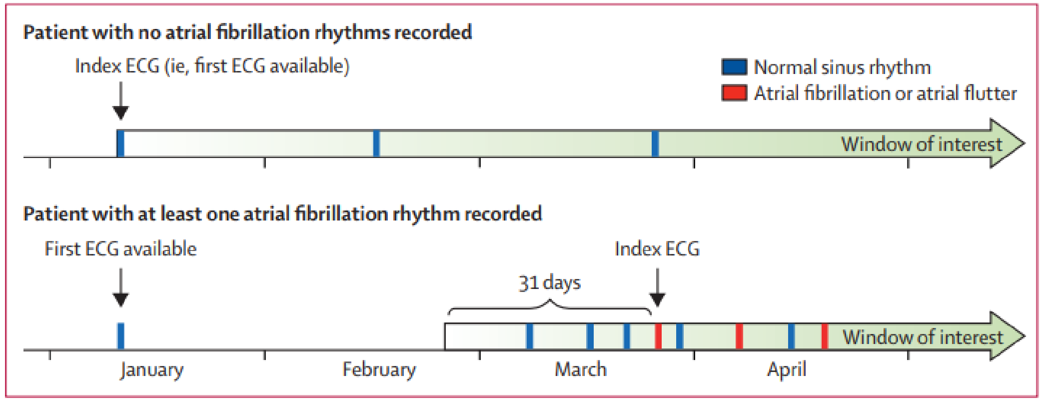

Figure 1: ECG selection and windows of interest for patients with multiple ECGs

Attia, Z. I et al. The Lancet, 2019; 394(10201), 861-867.

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Current studies..

Extensible artificial intelligence model predicts post-ablation AF recurrence using coronary sinus electrogram

D. Huang[1], Z. Zhang[1], K. Lin[1], Z. Zuo[1], Q. Chen[2], D. Qian[3], W. Zhu[2], J. Li[1]

[1]*Shanghai Sixth People's Hospital of Shanghai Jiaotong University, Shanghai, China;* [2]*Zhongshan Hospital, Fudan University, Shanghai Institute of Cardiovascular Diseases, cardiology, Shanghai, China;* [3]*School of Biomedical Engineering,Shanghai JIaotong university, Shanghai, China*

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Background: Atrial fibrillation (AF) is a major public health problem with significant adverse outcomes and catheter ablation is a widely adopted treatment. The CABANA trial showed that catheter ablation reduced AF recurrence to a greater extent than medications. However, some of patients who underwent this procedure still experience relapse. Here, we present an innovative way to identify this subgroup using an artificial intelligence (AI) -assisted coronary sinus electrogram.

Hypothesis: Our hypothesis is that credible features in the electrogram can be extracted by AI for prediction, therefore rigorous drug administration, close follow-up or potential second procedure can be applied to these patients.

Methods: 67 patients from two independent hospitals (SPH & ZSH) with non-valvular persistent AF undergoing circumferential pulmonary vein isolation were enrolled in this study, 23 of which experienced recurrence 6 months after the procedure. We collected standard 2.5-second fragments of coronary sinus electrogram from ENSITE NAVX (SPH) and Carto (ZSH)system before the ablation started. A total of 1429 fragments were obtained and a transfer learning-based ResNet model was employed in our study. Fragments from ZSH were used for training and SPH for validation of deep convolutional neural networks (DCNN). The AI model performance was evaluated by accuracy, recall, precision, F-Measure and AUC.

Results: The prediction accuracy of the DCNN in single center reached 96%, while that in different ablation systems reached 74.3%. Also, the algorithm yielded values for the AUC, recall, precision and F-Measure of 0.76, 86.1%, 95.9% and 0.78, respectively, which shows satisfactory classification results and extensibility in different cardiology centers and brands of electroanatomic mapping instruments.

Conclusions: Our work has revealed the potential intrinsic correlation between coronary sinus electrical activity and AF recurrence using DCNN-based model. Moreover, the DCNN model we developed shows great prospects in the relapse prediction for personalized post-procedural management.

Artificial intelligence-predicted poor responders to catheter ablation for atrial fibrillation

Park JW.[1]; Kwon OS.[1]; Shim JM.[2]; Yu HT.[1]; Kim TH.[1]; Uhm JS.[1]; Kim JY.[1]; Choi JI.[2]; Joung BY.[1]; Lee MH.[1]; Kim YH.[2]; Pak HN.[1]

[1]Yonsei University Health system, Seoul, Korea (Republic of)
[2]Korea University, Cardiovascular Center, Seoul, Korea (Republic of)

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Introduction: Although atrial fibrillation (AF) catheter ablation is effective for rhythm control, in some patients it is hard to maintain sinus rhythm in spite of repeated AF catheter ablation (AFCA) procedures and anti-arrhythmic drugs (AADs). We explored the pre-procedural predictors for poor responders to AFCA and tested whether artificial intelligence (AI) assists the prediction of poor responders in the independent cohort by determining the invasive parameters.

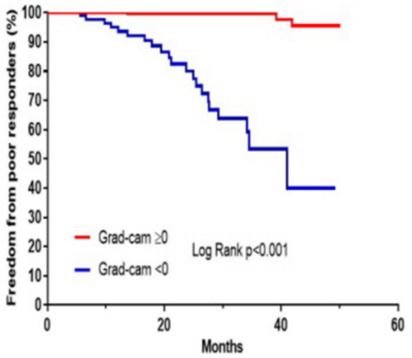
Methods: Among 1,214 patients who underwent AFCA and regular rhythm follow-up for 56.2 ± 33.8 months (59 ± 11 years, 73.5% male, 68.6% paroxysmal AF), we differentiated 92 poor responders as defined as those with sustained AF despite repeat AFCAs, AADs, or electrical cardioversion. Using the Youden index, we identified advanced LA remodeling with lower LA voltage under 1.109mV. AI model, which was derived from development cohort using medical record, was applied to predict LA voltage <1.109mV in the independent cohort (n = 634, poor responders = 24) using a grad-cam score.

Results: The patients with lower LA voltage under 1.109mV showed significantly poorer rhythm outcomes (Log-rank p < 0.001). We determined invasive parameter LA voltage by using the multiple variables (age, female sex, AF type, CHA2DS2VASc score, LA dimension, E/em, hemoglobin, PR interval) and achieved relatively good prediction power of AI for LA voltage <1.109mV (AUC = 0.734, sensitivity 0.729, specificity 0.643) in the test cohort. In the independent cohort, the AI model showed good discrimination power for poor responders (AUC 0.751, p < 0.001) by estimating LA voltage, which is an invasive variable. The patients with predicted lower LA voltage (grad-cam score <0) showed poorer rhythm outcome after active rhythm control (Log-rank p < 0.001)

Conclusions: The patients with advanced atrial remodeling with low LA voltage, which can be predicted by an AI, showed significantly higher recurrence of AF after AFCA with AADs or cardioversion. AI may assist to select these poor responder patients before the AFCA procedure.

Abstract Figure.

Figure. KM curve for poor responders according to Grad-Cam score in independent cohort



Huang D et al. European Heart Journal. 2020;41(Supplement_2):ehaa946. 0560.
Park J et al. EP Europace. 2021;23(Supplement_3):euab116. 228.

Objectives

- By using artificial intelligence (AI), we sought to evaluate the prediction of 1-year recurrence of AF using ECG during sinus rhythm immediate after the procedure.

METHODS

Data sources and study population

- Using the data from the ASAN-AF ablation registry, we identified patients with AF who successfully treated with ablation either radiofrequency catheter ablation or cryoballoon ablation between Jan 01, 2010, and May 2022.

- Among the patients in the registry, we included patients with sinus rhythm, standard 10-second, 12 lead ECG acquired in the supine position at 1 to 3 days after index procedure. → Asan medical Center Muse System (GE Healthcare, USA), for training, all sinus rhythm ECGs during 1 to 3 days after the procedure was used.

- Minimal exclusion criteria:
  - Patients without sinus rhythm immediate after ablation.
  - Documented paced rhythm on ECG during periprocedural period was excluded.

Identifying study groups

- Two groups: those who recurred atrial fibrillation after index procedure, and those who maintained sinus rhythm without recurrence.

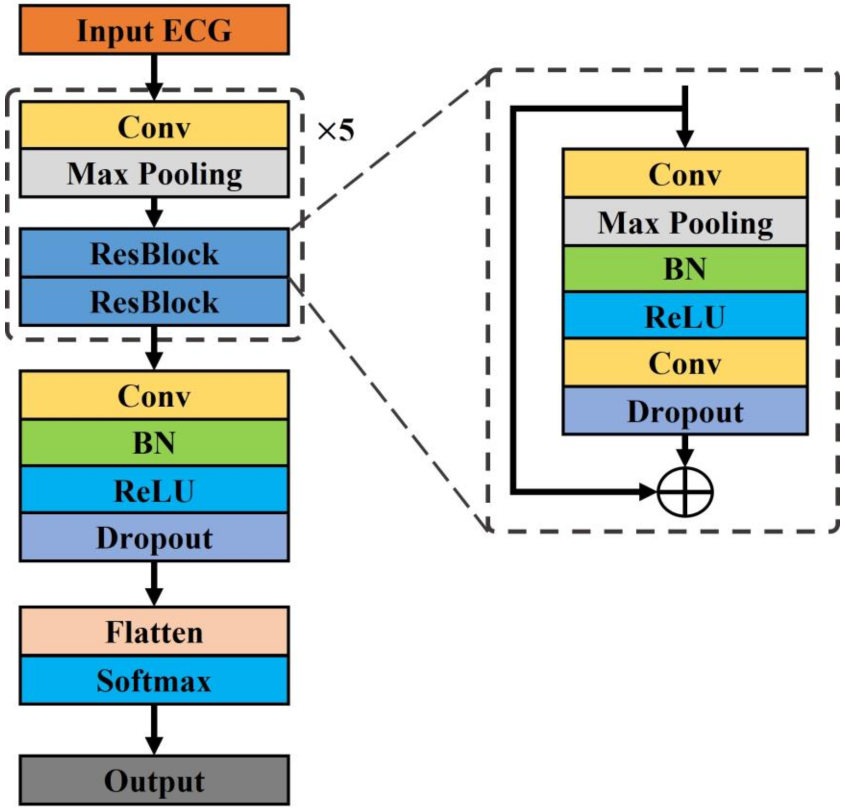
- ECG in our hospital are initially read by the GE Marquette ECG system.

- To enhance the accuracy of the labeling, independent group of clinicians confirmed the classification by reviewing medical records and ECG data, including Holter test.

- The recurrence was defined as the occurrence of atrial tachyarrhythmia including AF, atrial flutter, or atrial tachycardia longer than 30 seconds within 1 year after the procedure, excluding a blanking period of 3 months.

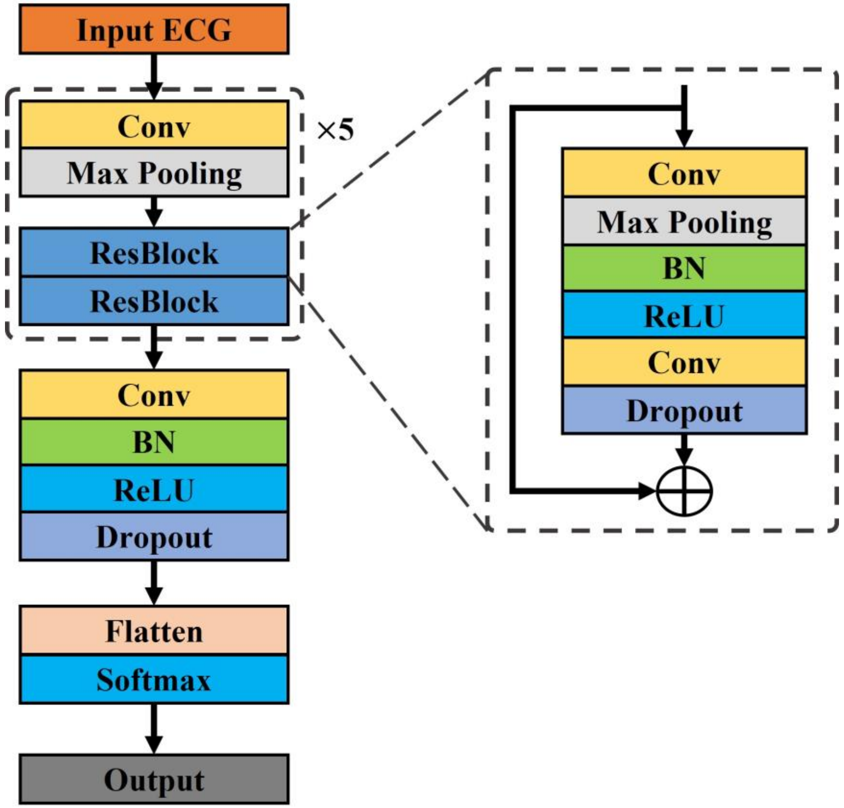
Deep learning model_Architecture

- Resnet architecture and convolution neural network (CNN) and Phyton 3.7 on Keras library with tensorflow
- The model consisted of 5 blocks with convolution and max pooling layers, followed by residual blocks.
- Each residual block included batch normalization for data normalization, “Leaky ReLU” activation for capturing complex features, and convolution layers.
- The number of filters and kernel size varied across blocks to extract diverse ECG features.
- The model's output was generated through a fully-connected layer with softmax activation, providing the probability of recurrent atrial fibrillation.



Deep learning model_Hyperparameter

- Activation function that multiplies the input by weights and transforms it into a non-linear value to facilitate non-linear learning during the training of ECG data in the model.



Activation function	Loss function	Batch size	Learning rate	Epoch
Leaky ReLU	Cross-Entropy	16	0.0005	120

Outcomes

- Primary outcome: ability of the AI-enhanced ECG to predict 1-year recurrence of AF after catheter ablation.

- The performance was mathematically assessed by the area under the curve (**AUC**) of the receiver operating characteristic (ROC) curve, as well as the sensitivity, specificity, accuracy, and F1 score of the model.

$$Accuracy = \frac{TP + TN}{TP + FN + FP + TN}$$

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$F1\ score = \frac{2 \times (Precision \times Recall)}{Precision + Recall}$$

RESULTS

Flow diagram

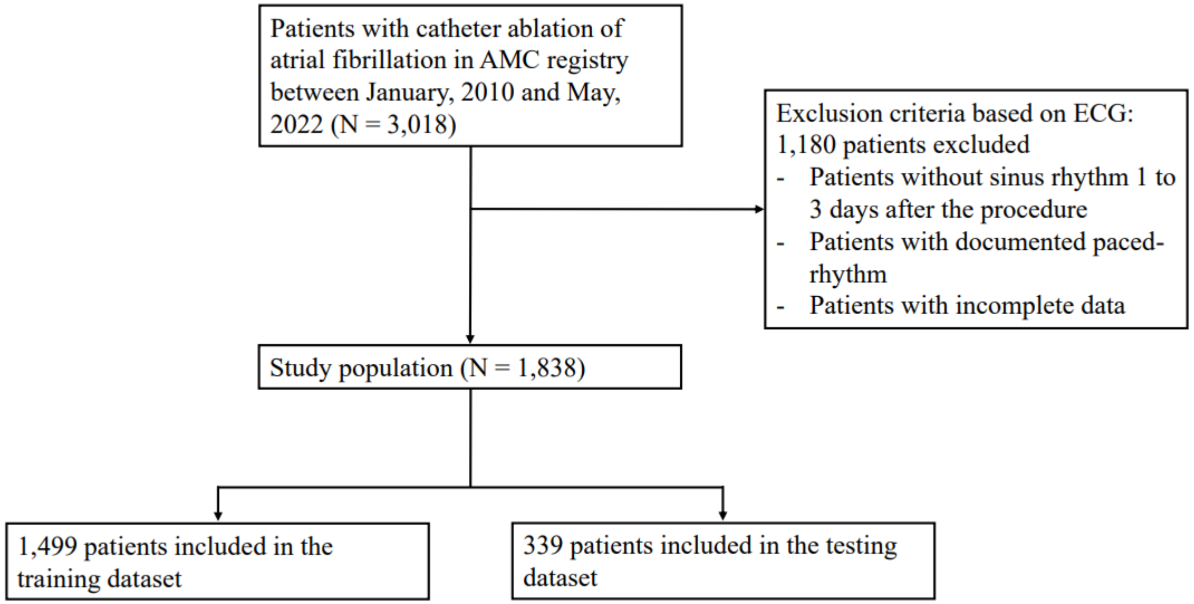
- Total 1,838 patients with normal sinus rhythm ECGs for analysis.

- 1,499 patients in the training dataset, 339 patients in the testing dataset.

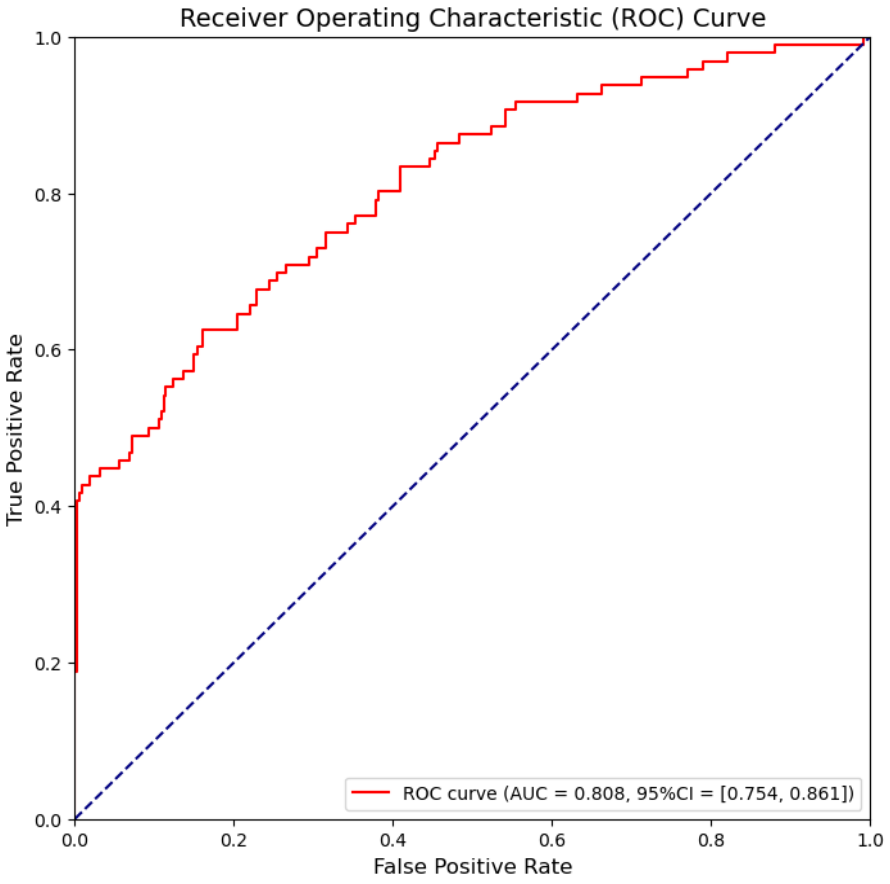
→In the training set, all ECGs (total 3,583 ECGs) during 1 to 3 days after the procedure

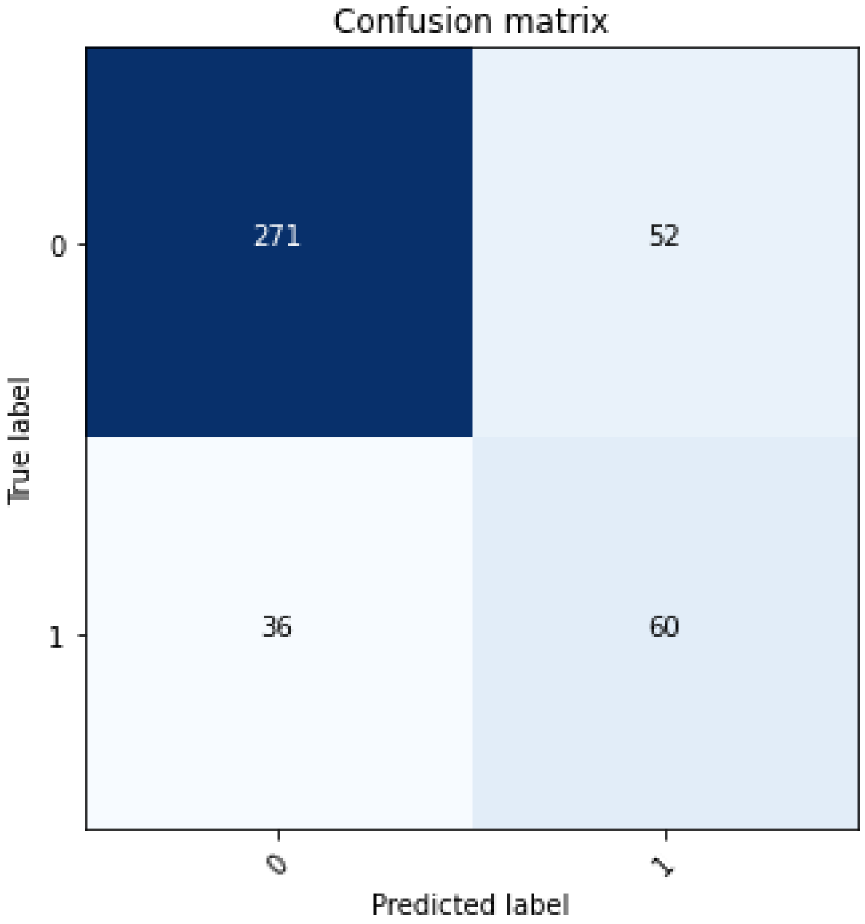
→In the testing set, first ECG after the procedure

- Among them, 431 patients (**23.4%**) was observed AF recurrence.



Model performance





Main analysis	AUC	Sensitivity	Specificity	F1 score	Accuracy
	0.808(0.754-0.861)	0.625(0.422-0.638)	0.839(0.812-0.861)	0.577(0.462-0.639)	0.79(0.787-0.85)

Limitations

1. A key limitation in AI study is **explainability**. So-called black box.
    - Identifying the features of the recurrence of AF could be of importance because they might offer novel findings that could provide new therapeutic targets or allow for more certainty for clinicians who are otherwise trying to understand what drives the network's interpretation.

2. Despite of rigorous review of ECGs, there are still possibility of false negative labelling.
    - Patients were considered negative for recurrence if they did not have any atrial tachyarrhythmia documented by transient finding of ECG, but it is likely that some patients in this negative group had undetected AF and were thus labelled incorrectly.

CONCLUSION

The predictive value of recurrence of AF after catheter ablation using AI on sinus rhythm echocardiogram showed higher. AI may assist to identify the effect of the procedure using immediate post sinus rhythm echocardiogram.

Thank you for attention!