Holter ECG: Delegation et Intelligence artificielle

INSTITUT CARDIOVASCULAIRE PARIS SUD

www.ICPS.fr

Drs Mina Aït Saïd, Francois Bouvier, Charlène Coquard,
<u>Laurent Fiorina</u>, Jérôme Horvilleur, Jérôme Lacotte,,
Vladimir Manenti, Fiorella Salerno & Salem Younsi

Disclosure

- Co-développeur de Cardiologs

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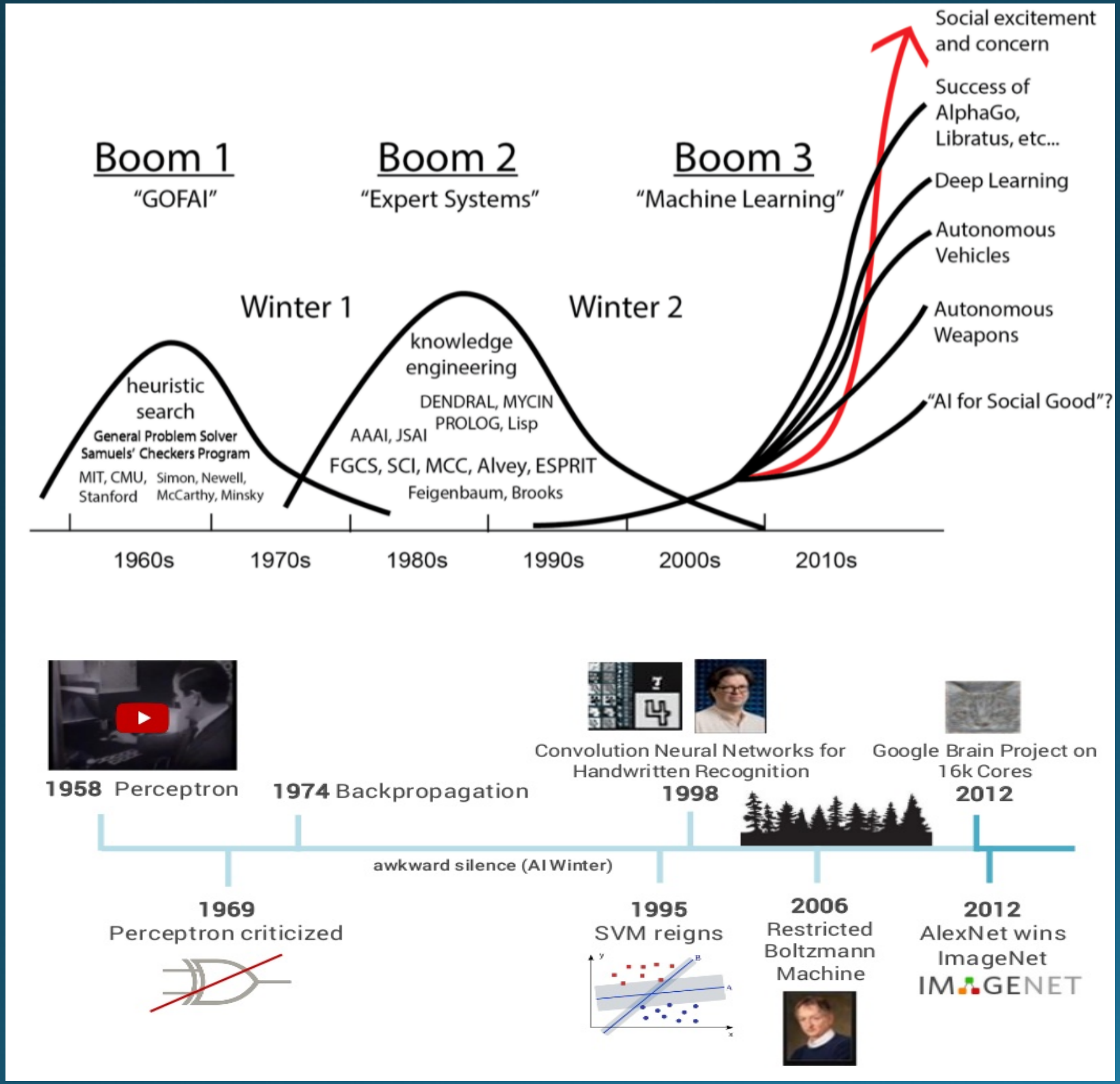
L’intelligence artificielle, une histoire à rebond



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Garvey C. Broken promises & empty threats : the evolution of AI in the USA, 1956-1996. Technology’s Stories. 2018 ; Vol 6, n°1 DOI: 10.15763/jou.ts.2018.03.16.02
Conseil de l’Europe. Histoire de l’intelligence artificielle. https://www.coe.int/fr/web/artificial-intelligence/history-of-ai. Consulté le 3 mars 2022. https://www.slideshare.net/LuMa921/deep-learning-a-visual-introduction.

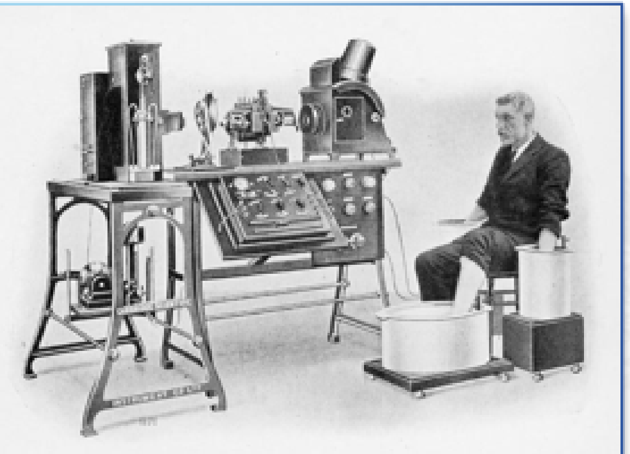
1842

Carlo MATTEUCI
Potentiels électriques

1895

Willem EINTHOVEN
Galvanomètre à cordes,
Dénomination des ondes P, Q, R, S, T

Nobel 1924



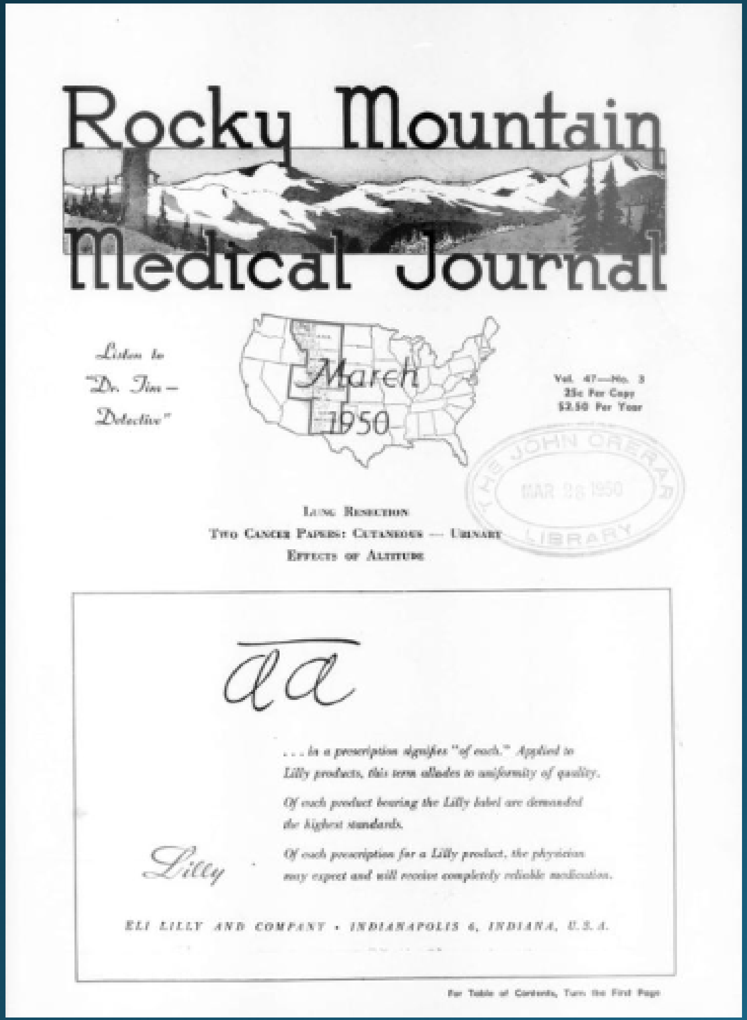
PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

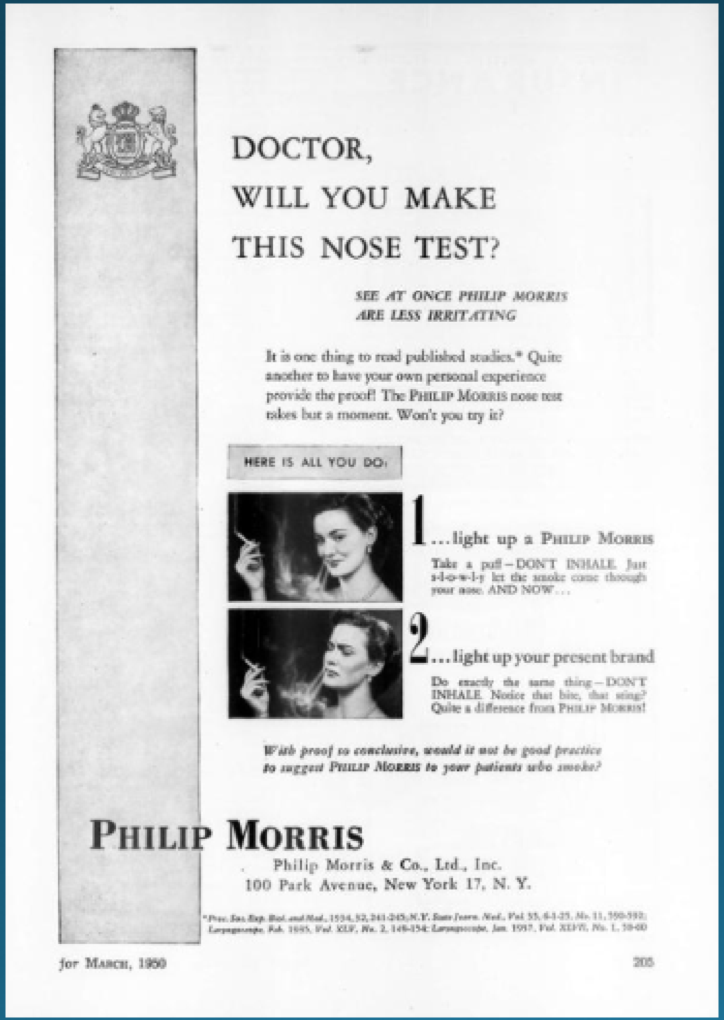
1942

Goldberger
ECG 12D

Materre Alexandre, Histoire de l'électrocardiogramme : de la découverte de l'électrophysiologie à l'électrocardiographie moderne, thèse d'exercice, Limoges, Université de Limoges, 2016. Disponible sur http://aurore.unilim.fr/ori-oai-search/notice/view/unilim-ori-107383. Consulté le 3 mars 2022.

The democratic disruption of arrhythmia diagnostic





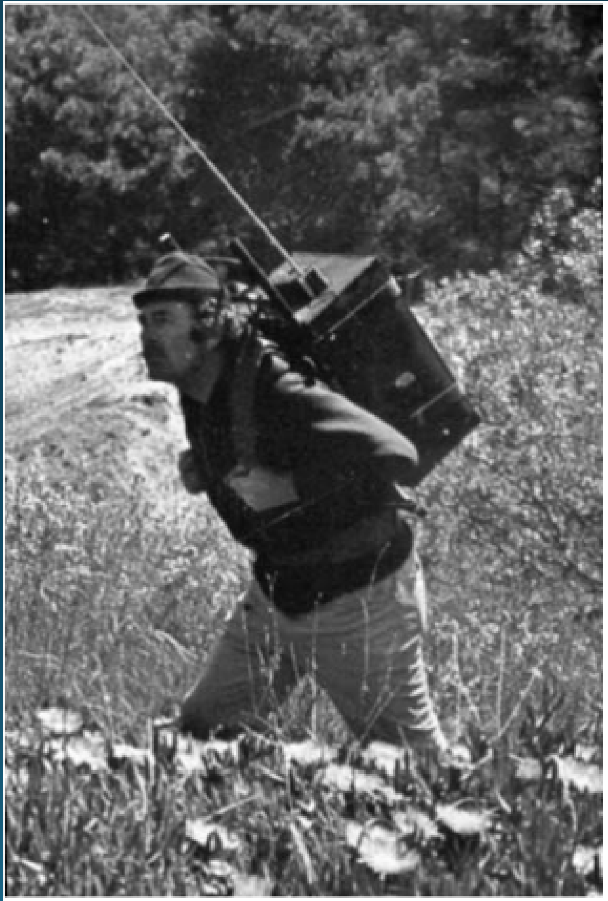


Figure 1. (A) Radiotransmitter in the form of an 85-pound backpack whose signal was carried a distance of one block.

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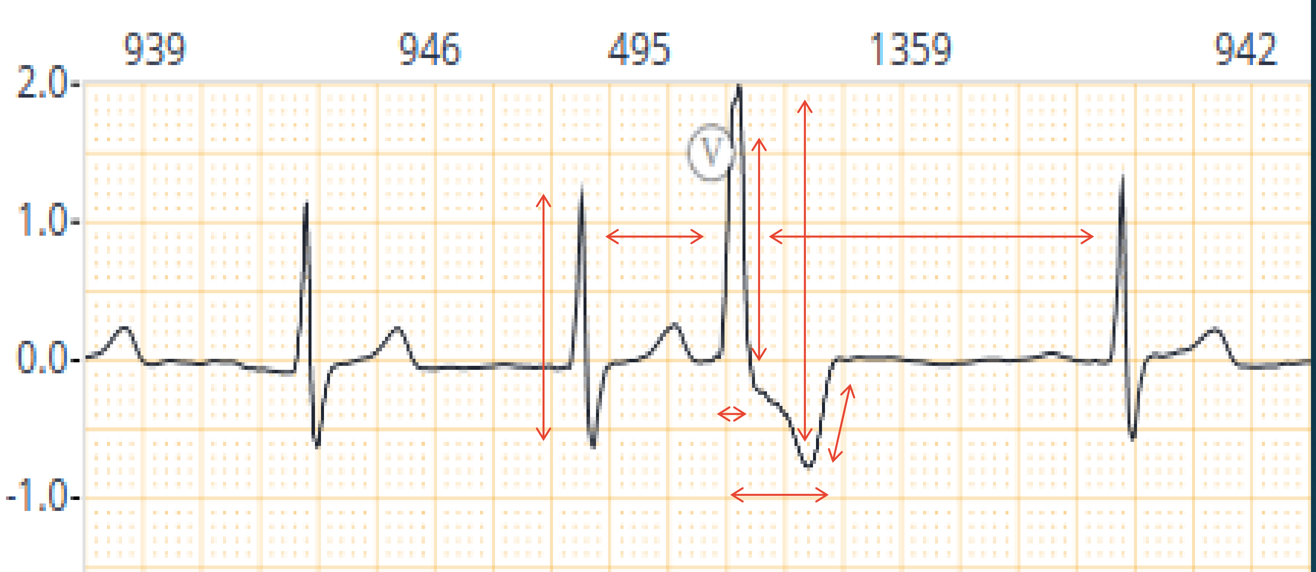
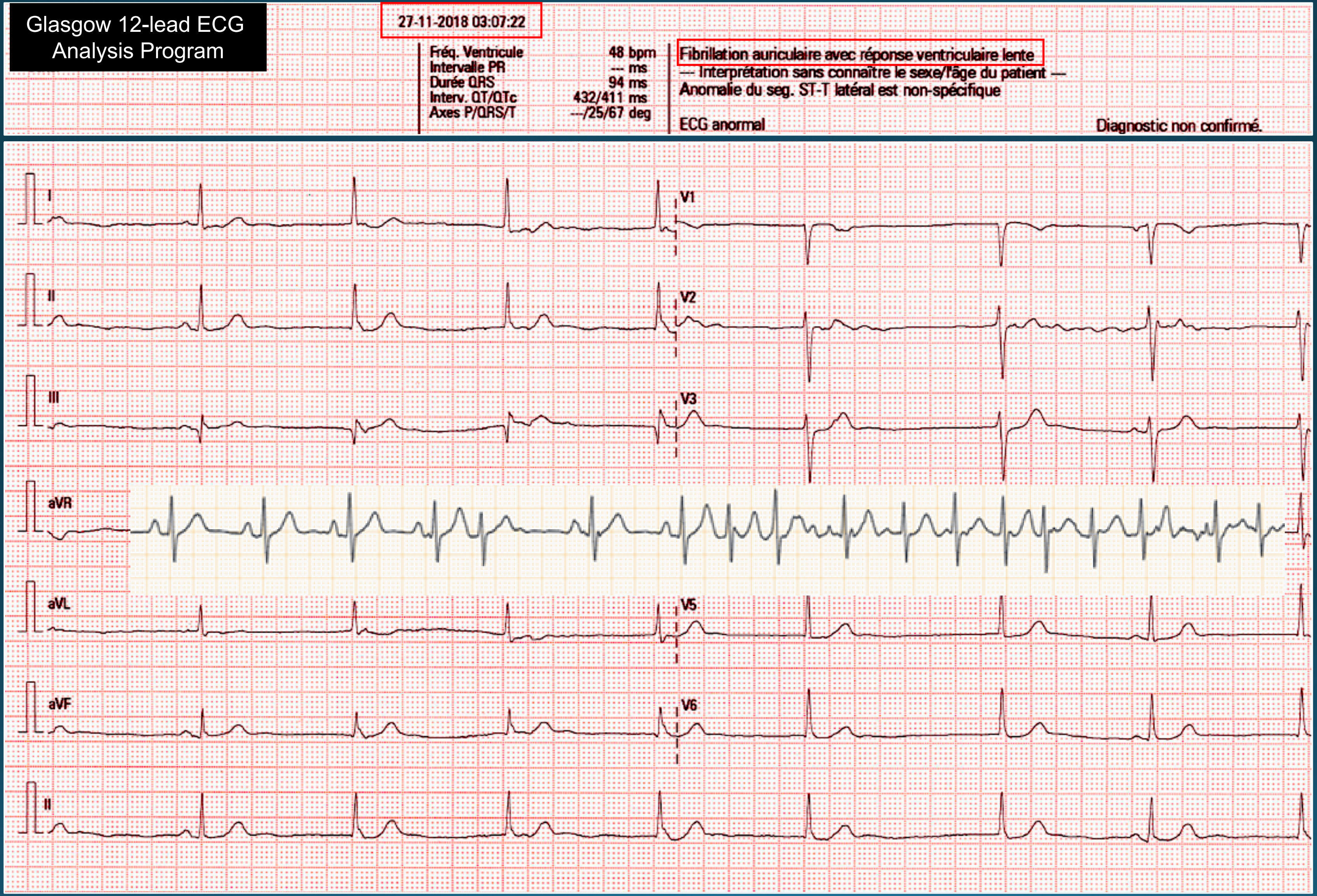
Deep Learning

- **Détection des ECG automatique**
  - Apprentissage sur des milliers de paramètres
  - Besoin de beaucoup d'exemples

(Cardiologs base de données de 200 millions d'ECG et 40 000 ans de signal ECG Holter)





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kDPP0v4D

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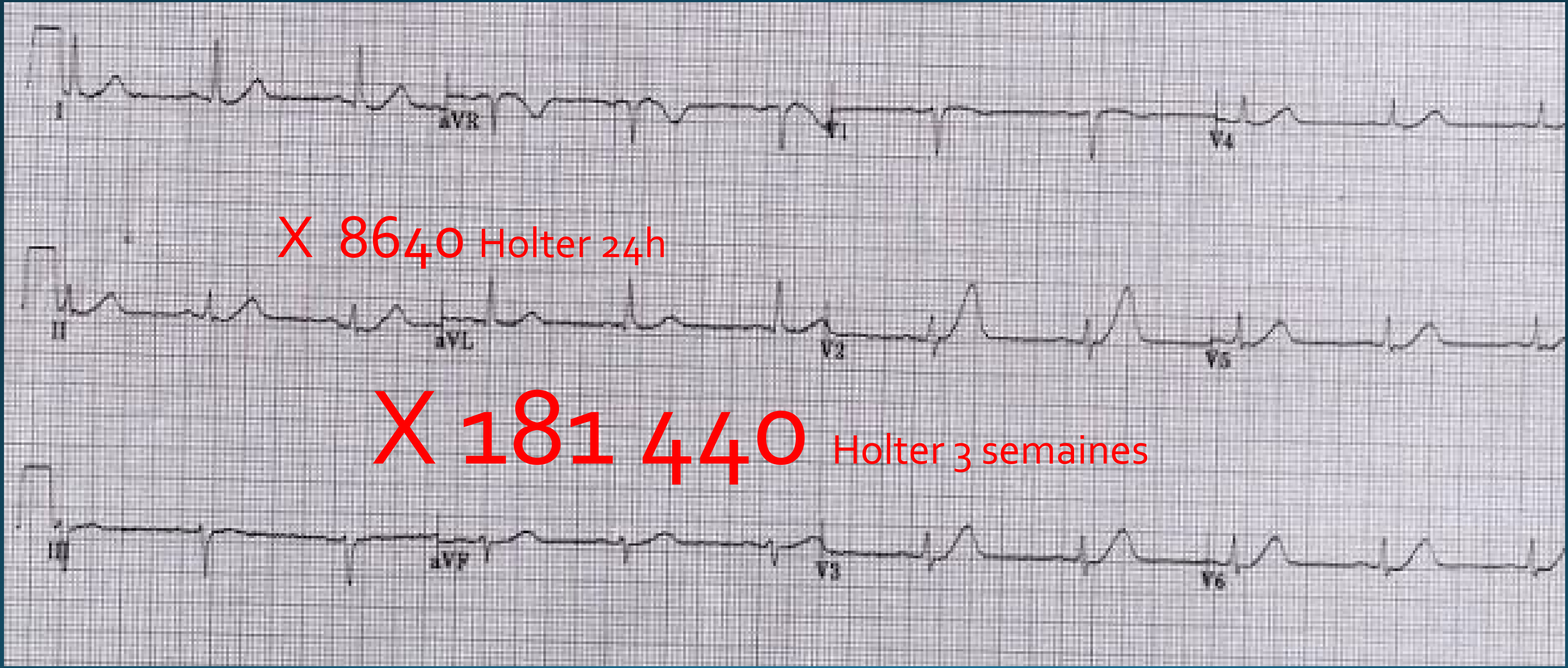
Que peut résoudre l'IA?



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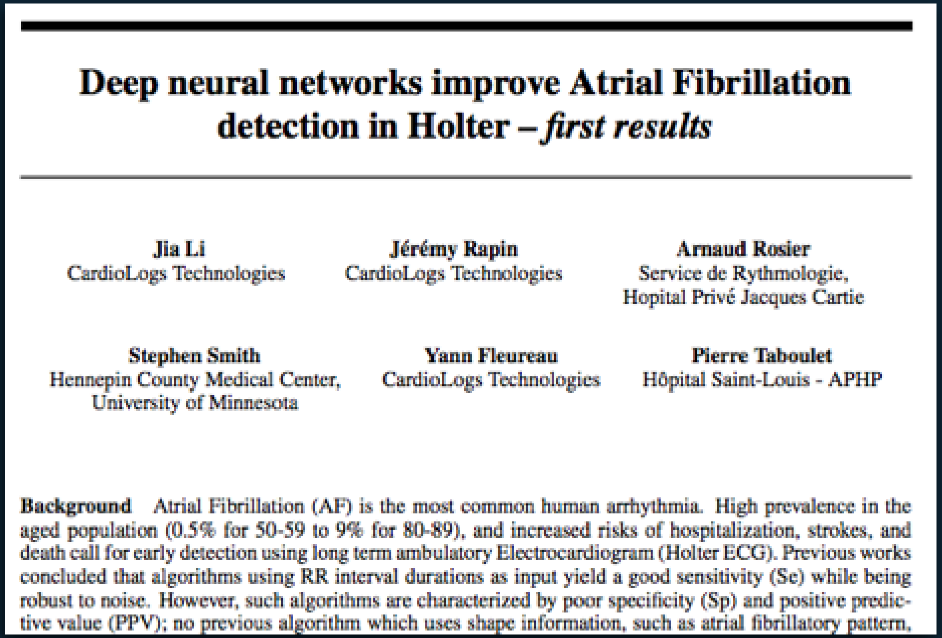
Importance de la quantité de données et amélioration de l’algorithme



Deep neural networks improve Atrial Fibrillation detection in Holter – *first results*

Jia Li CardioLogs Technologies

Jérémy Rapin CardioLogs Technologies

Arnaud Rosier Service de Rythmologie, Hopital Privé Jacques Cartie

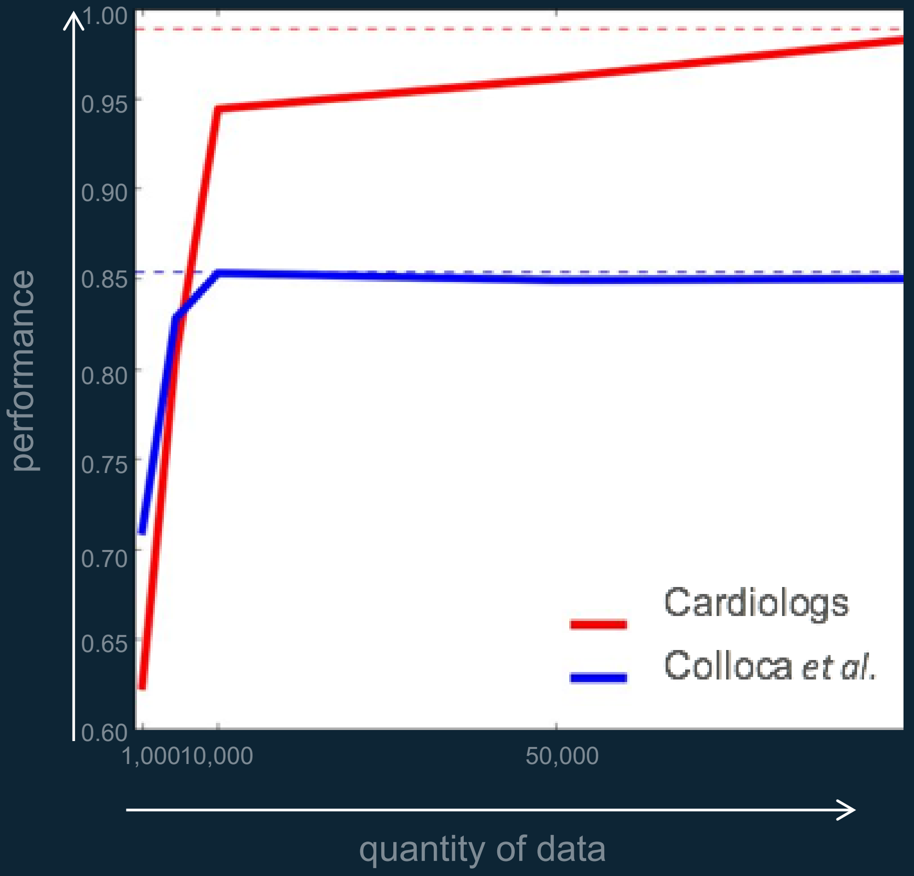
Stephen Smith Hennepin County Medical Center, University of Minnesota

Yann Fleureau CardioLogs Technologies

Pierre Taboulet Hôpital Saint-Louis - APHP

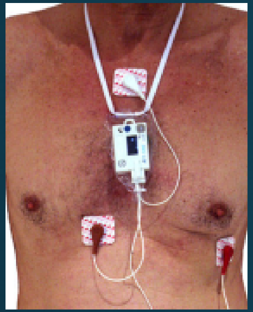
Background Atrial Fibrillation (AF) is the most common human arrhythmia. High prevalence in the aged population (0.5% for 50-59 to 9% for 80-89), and increased risks of hospitalization, strokes, and death call for early detection using long term ambulatory Electrocardiogram (Holter ECG). Previous works concluded that algorithms using RR interval durations as input yield a good sensitivity (Se) while being robust to noise. However, such algorithms are characterized by poor specificity (Sp) and positive predictive value (PPV); no previous algorithm which uses shape information, such as atrial fibrillatory pattern,

Accuracy Score

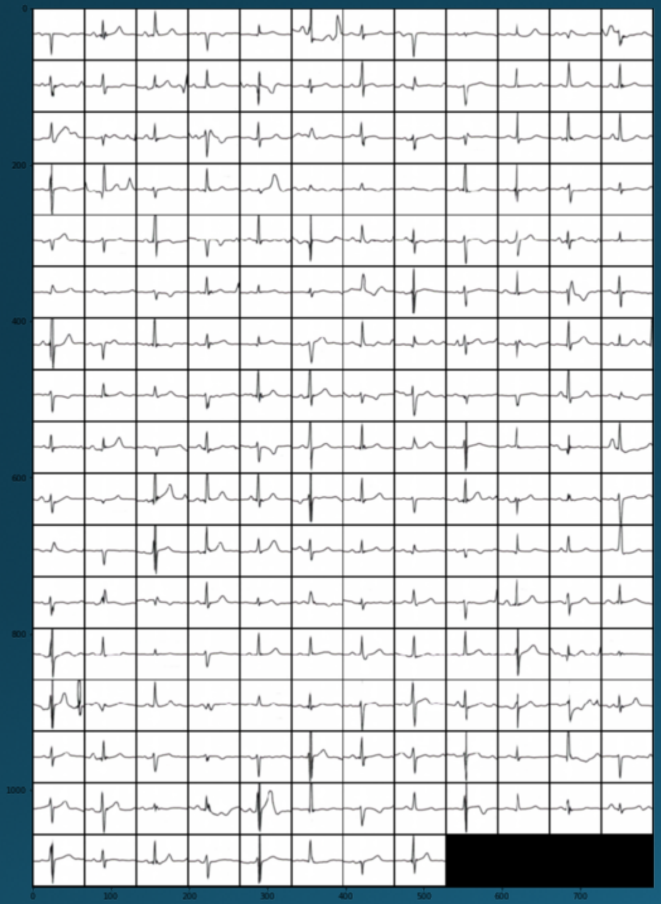


	SE*	PPV**
State-of-the-art	96.3	58.7
Cardiologs AI	97.1	93.4

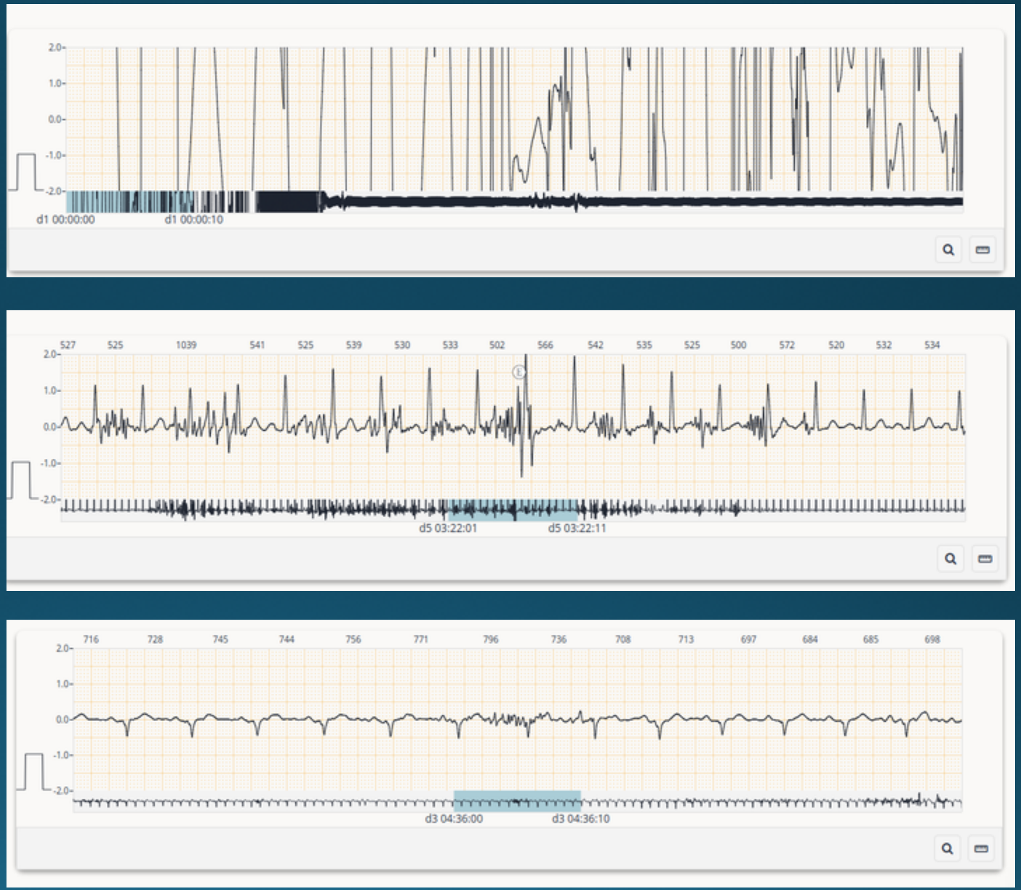
*Sensitivity: Proportion of positive cases truly identified **Positive Predictive Value: Proportion of true positive cases in cases detected.



Complexité liée au Holter ECG



Inter-intra-patient variability



Noise and artefacts

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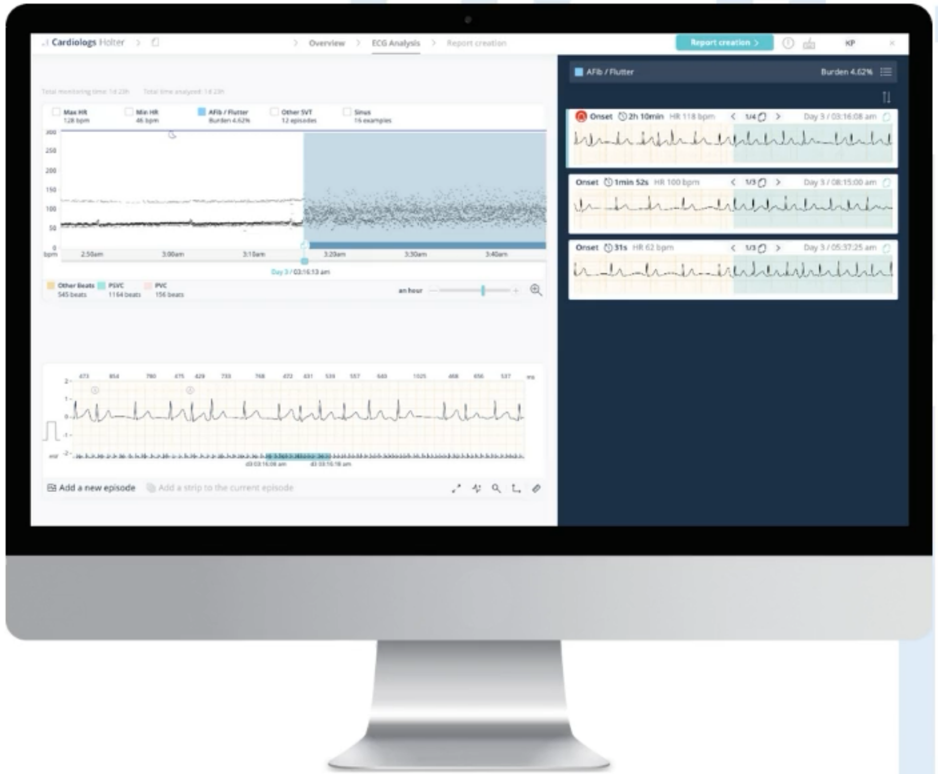
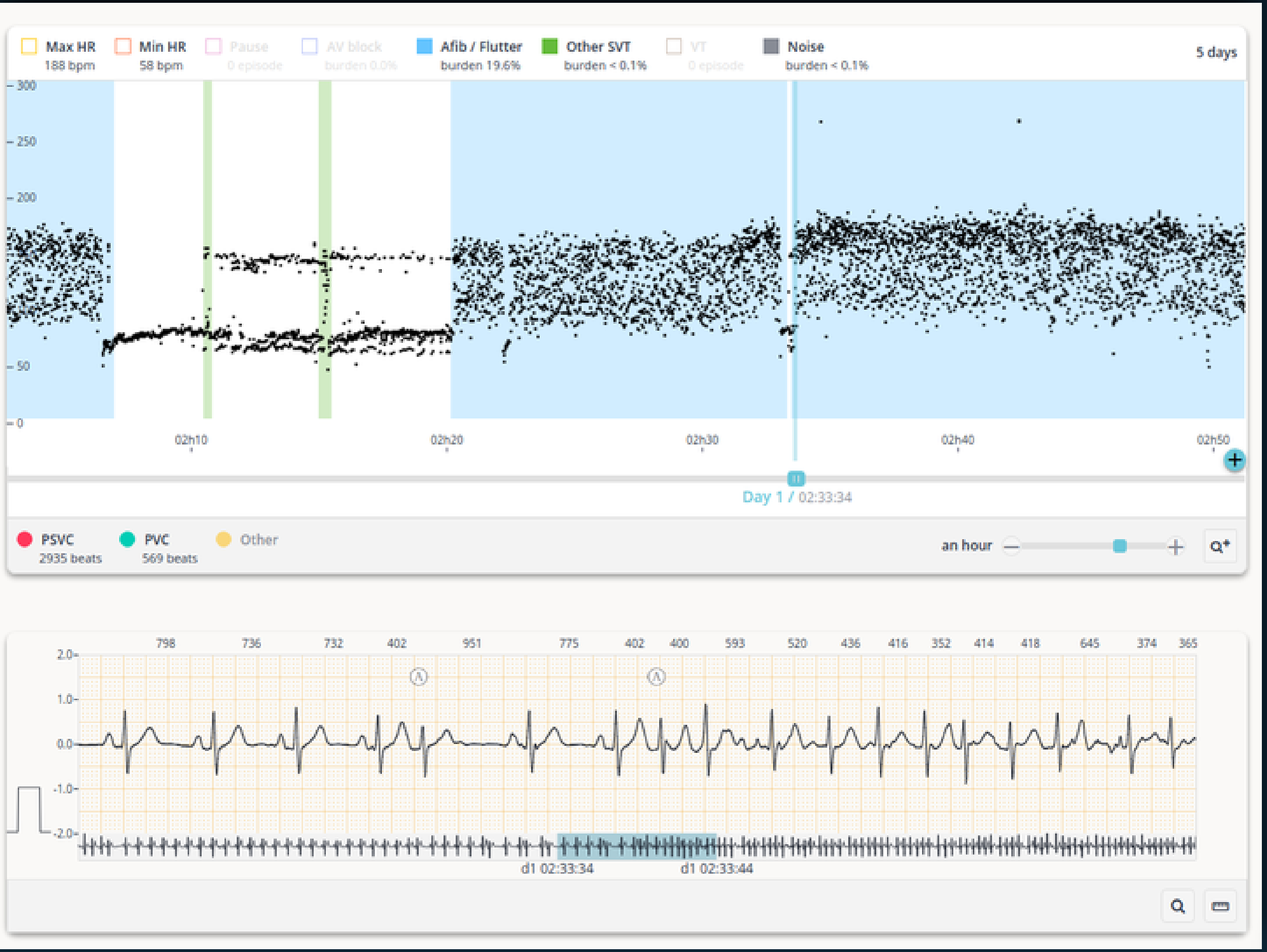
Cardiologs®
Holter

SOLUTION CARDIOLOGS HOLTER

Votre partenaire d'aide au
diagnostic cardiaque



Atrial Fibrillation



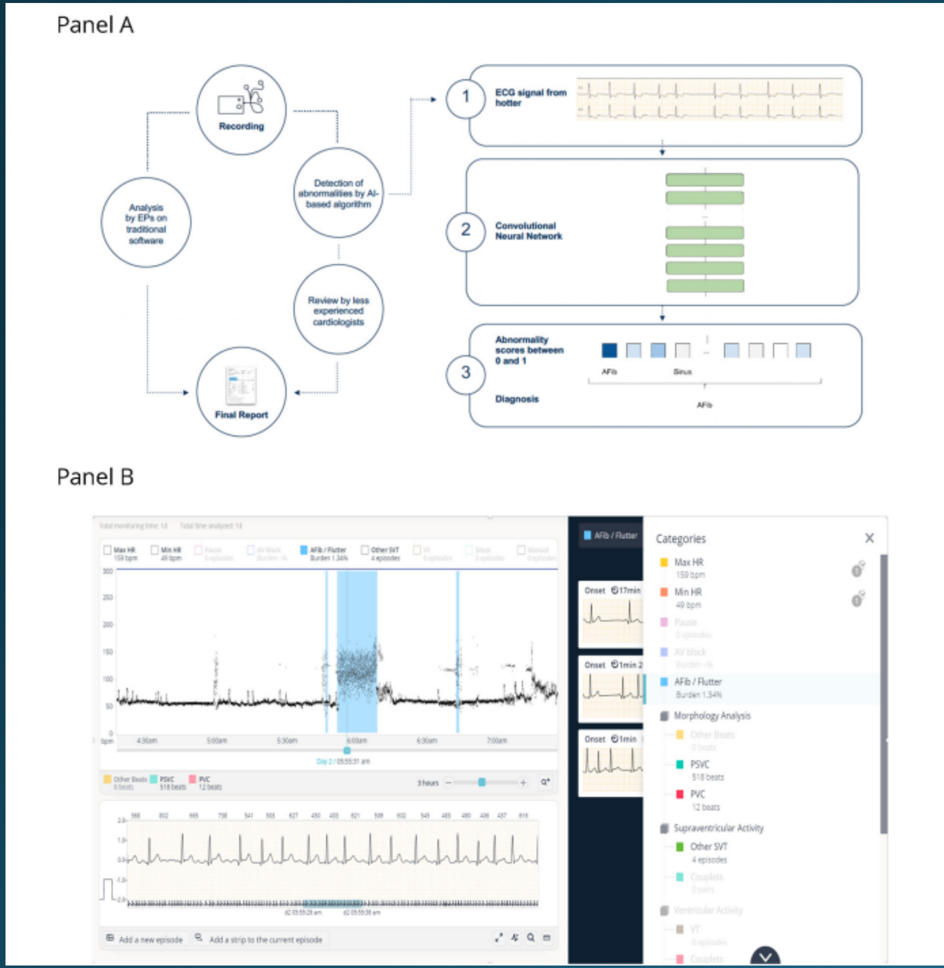
IA en pratique courante: n=1000 Holters sur 3 centres

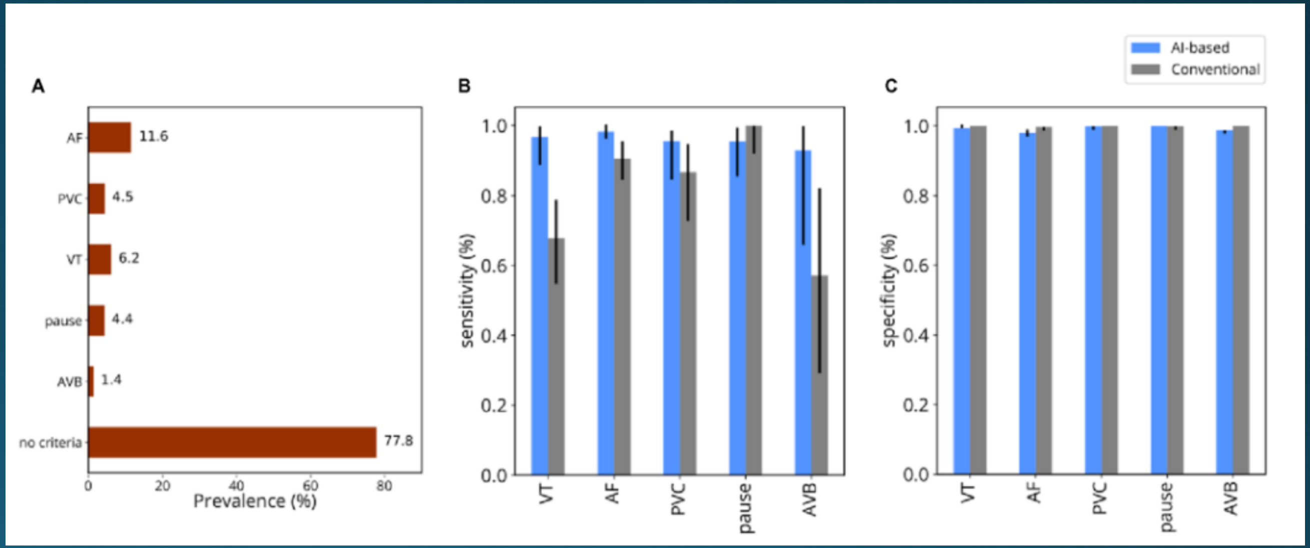
Journal of the American Heart Association
Volume 11, Issue 18, 20 September 2022
https://doi.org/10.1161/JAHA.122.026196

BRIEF COMMUNICATION

Evaluation of an Ambulatory ECG Analysis Platform Using Deep Neural Networks in Routine Clinical Practice

Laurent Fiorina, MD; Carole Maupain, MD; Christophe Gardella, PhD; Vladimir Manenti, MD; Fiorella Salerno, MD; Pierre Socie, MD; Jia Li, MSc; Christine Henry, MSc; Audrey Plesse, MSc; Kumar Narayanan, MD, FHRS; Aurélie Bourmaud, MD; Eloi Marijon, MD, PhD





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Fiorina L, Maupain C, Gardella C, Manenti V, Salerno F, Socie P, et al. Evaluation of an Ambulatory ECG Analysis Platform Using Deep Neural Networks in Routine Clinical Practice. Journal of the American Heart Association. 20 sept 2022;11(18):e026196.

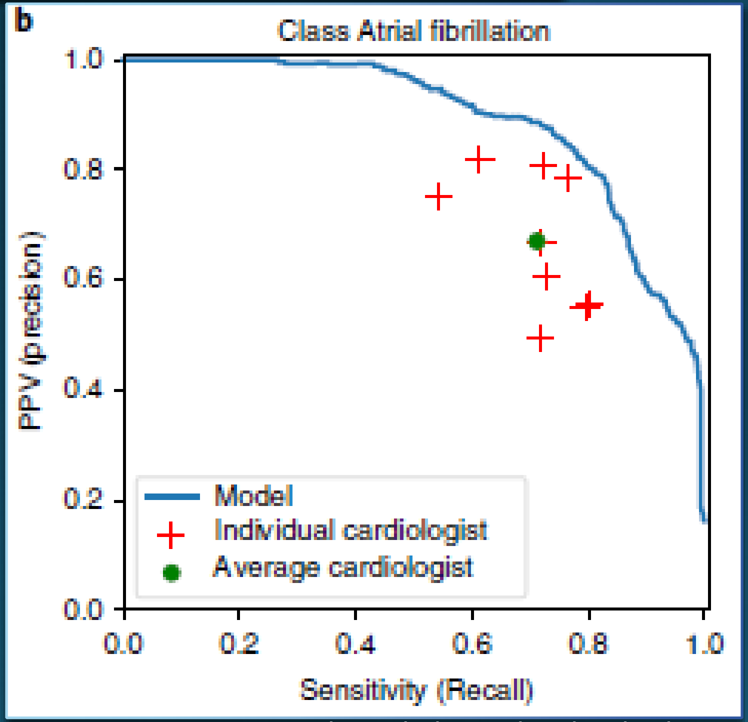
2019 :
1ère étude dans Nature

nature medicine FOCUS | LETTERS
https://doi.org/10.1038/s41591-018-0268-3

Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network

Awni Y. Hannun[1,6*], Pranav Rajpurkar[1,6], Masoumeh Haghpanahi[2,6], Geoffrey H. Tison[3,6], Codie Bourn[2], Mintu P. Turakhia[4,5] and Andrew Y. Ng[1]

FA et ECG 1 dérivation : Patch IRythm n = 328 ; base d'entraîneme du Deep Learning 91 232 enregistrements



Sensibilité de l'algorithme Deep Learning et des cardiologues comparativement à un consensus d'experts

	Specificity	Average cardiologist sensitivity	DNN algorithm sensitivity
Atrial fibrillation and flutter	0.941	0.710	0.861
AVB	0.981	0.731	0.858
Bigeminy	0.996	0.829	0.921
EAR	0.993	0.380	0.445
IVR	0.991	0.611	0.867
Junctional rhythm	0.984	0.634	0.729
Noise	0.983	0.749	0.803
Sinus rhythm	0.859	0.901	0.950
SVT	0.983	0.408	0.487
Ventricular tachycardia	0.996	0.652	0.702
Wenckebach	0.986	0.541	0.651

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Hannun A *et al.* Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network. Nat Med 2019 ; 25(1) : 65-69.

L'IA comme détecteur de trésor

- FEVG
- CMH
- Valvulopathies
- Canalopathies
- Dyskaliémie
- Glucose
- …

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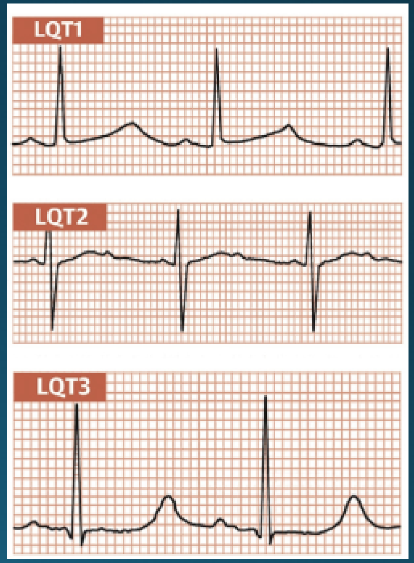
Canalopathies

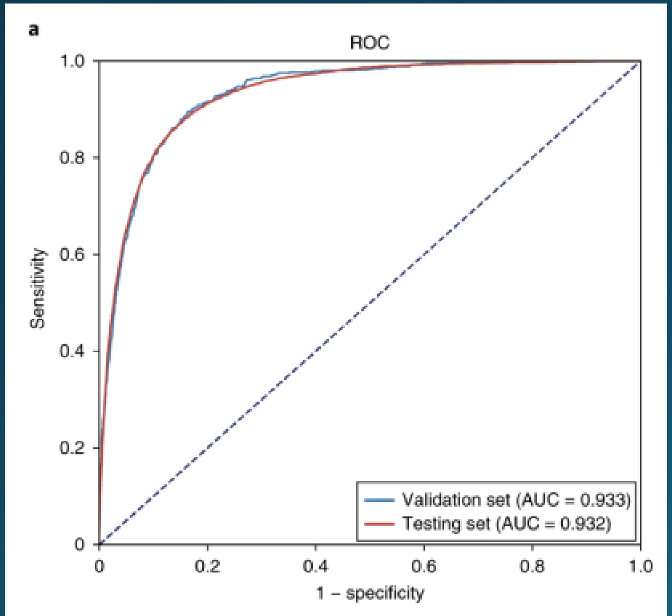
- LQTs N=2059 avec test genetique; prev= 47%: AUC=0,9
- Si QT normal AUC =0,86
- Différenciation des sous-types de LQT 1 / 2 / 3



Bos JM, Attia ZI, Albert DE, Noseworthy PA, Friedman PA, Ackerman MJ. Use of artificial intelligence and deep neural networks in evaluation of patients with electrocardiographically concealed long QT syndrome from the surface 12-lead electrocardiogram. JAMA Cardiol 2021;6:532–538.

FEVG<35% sur ECG 12D

- N=52000 rétrospective, prev=7,8% : AUC=0,93
- N=3874 prospective , prev=7% : AUC=0,91



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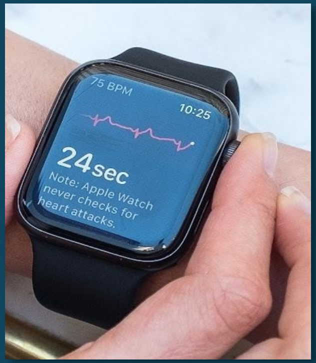
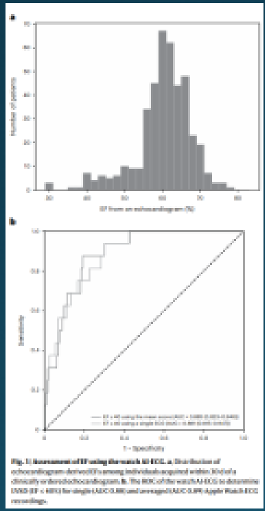
Attia ZI, Kapa S, Lopez-Jimenez F, McKie PM, Ladewig DJ, Satam G, Pellikka PA, Enriquez-Sarano M, Noseworthy PA, Munger TM, Asirvatham SJ, Scott CG, Carter RE, Friedman PA. Screening for cardiac contractile dysfunction using an artificial intelligence-enabled electrocardiogram. Nat Med 2019;25:70–74

Bientôt sur Smartwatch! Ou Sthetoscope!

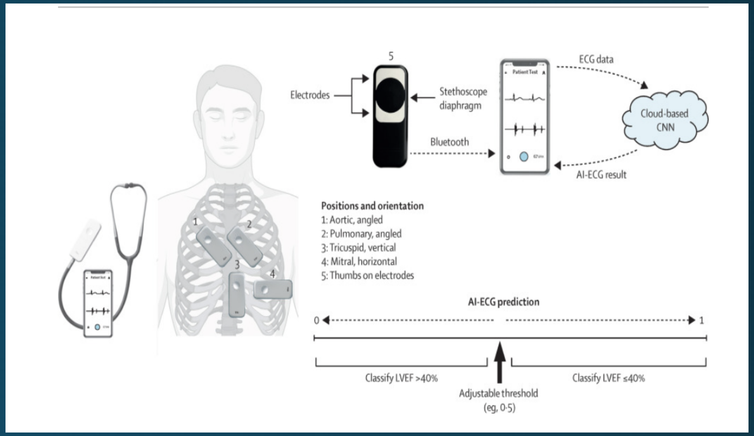
- N=421 «À domicile»
  FEVG<40%
  AUC=0,88





Attia ZI, Harmon DM, Dugan J, Manka L, Lopez-Jimenez F, Lerman A, et al. Prospective evaluation of smartwatch-enabled detection of left ventricular dysfunction. Nat Med. déc 2022;28(12):2497-503.

- N=1050
  FEVG<40%
  AUC=0,91



Bachtiger P, Petri CF, Scott FE, Park SR, Kelshiker MA, Sahemey HK, et al. Point-of-care screening for heart failure with reduced ejection fraction using artificial intelligence during ECG-enabled stethoscope examination in London, UK: a prospective, observational, multicentre study. The Lancet Digital Health. 1 févr 2022;4(2):e117-25.

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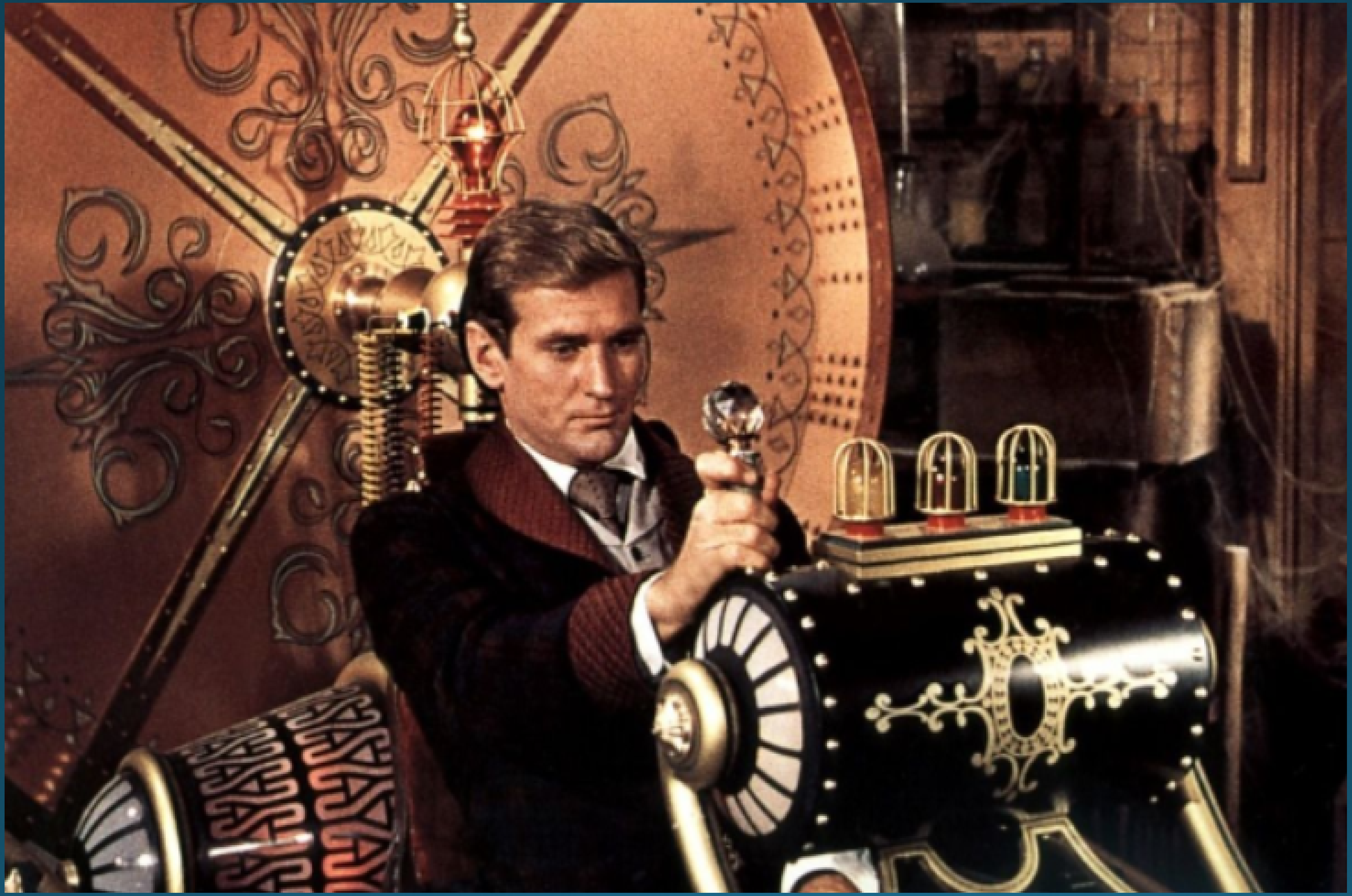

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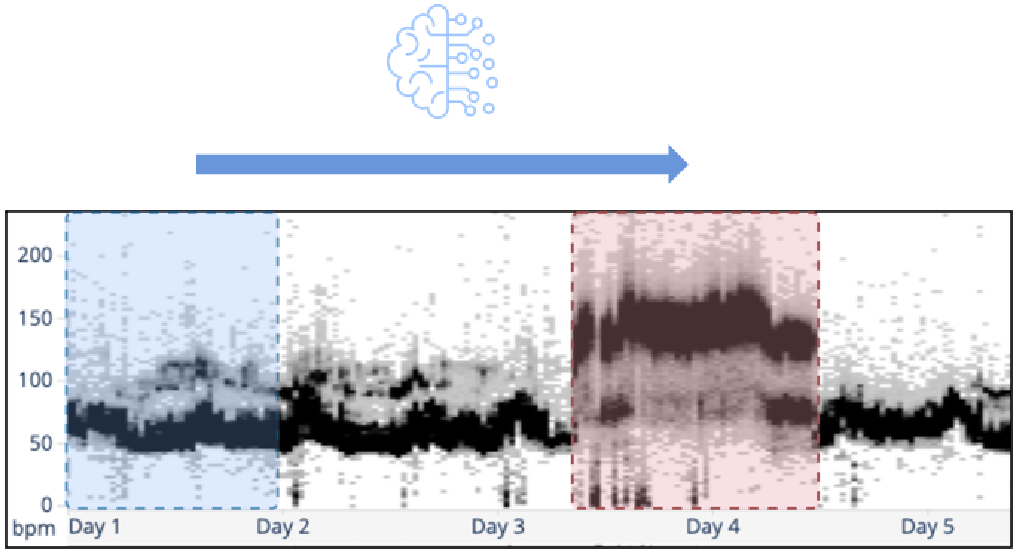
Prédiction sur 1 dérivationà court terme



ESC European Society of Cardiology
European Heart Journal - Digital Health (2022) **3**, 208–217
https://doi.org/10.1093/ehjdh/ztac014
ORIGINAL ARTICLE

Short-term prediction of atrial fibrillation from ambulatory monitoring ECG using a deep neural network

Jagmeet P. Singh [1,*], Julien Fontanarava[2], Grégoire de Massé[2], Tanner Carbonati[2], Jia Li[2], Christine Henry[2], and Laurent Fiorina[3]

[1]Massachusetts General Hospital, 55 Fruit Street, Boston, MA 02114, USA; [2]Cardiologs, 136 rue Saint Denis, 75002 Paris, France; and [3]Ramsay Santé, Institut Cardiovasculaire Paris Sud, Hôpital privé Jacques Cartier, 91300 Massy, France

Received 31 December 2021; revised 16 February 2022; online publish-ahead-of-print 6 April 2022

- 9993 Holters de 2 semaines sans FA dans les 1eres 24h
- 4% de FA
- **Prédiction FA dans les 2 semaines**
- **AUC 0,79**

Singh JP, Fontanarava J, de Massé G, Carbonati T, Li J, Henry C, Fiorina L. Short term prediction of Atrial Fibrillation from ambulatory monitoring ECG using a deep neura
network. European Heart Journal - Digital Health. 6 avr 2022;ztac014.

Explicabilité du DNN

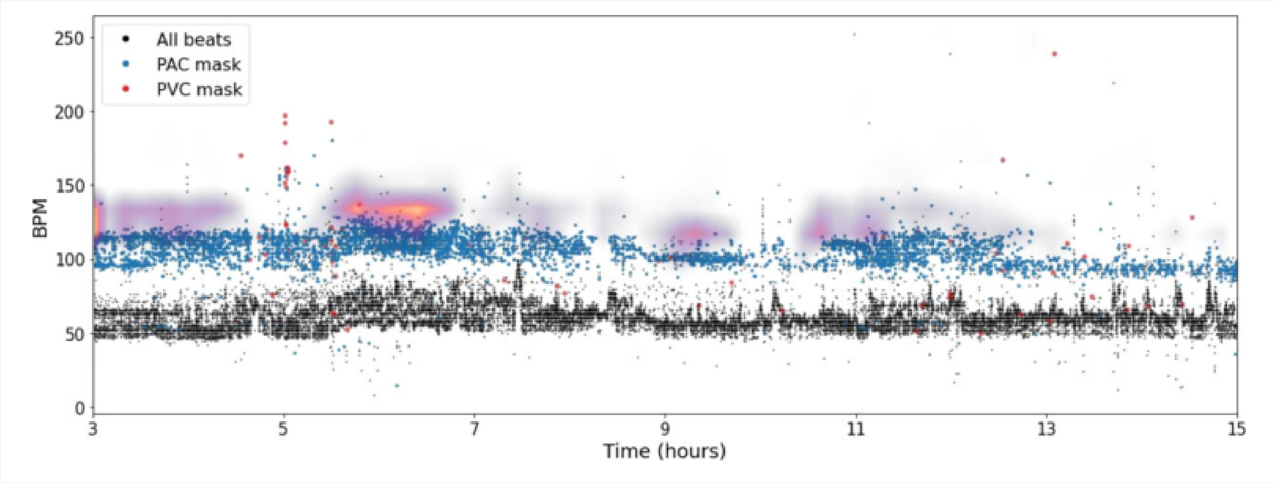
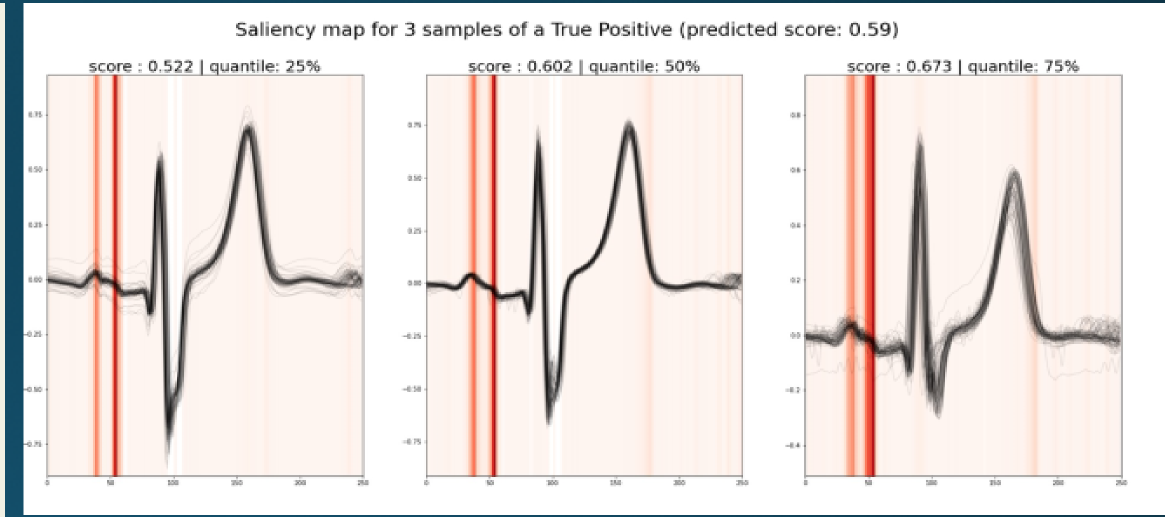


Figure 5 Heart rate-deep neural network interpretability. Saliency map overlaid on a heart-rate plot of the first 15 h of a true-positive Holter (a Holter with atrial fibrillation predicted from the first 24 h and atrial fibrillation documented within 2 weeks after). The highlighted areas indicate regions of the input that influence the prediction. The saliency map activations focus predominantly on regions with high density of pre-mature atrial contractions.



Carte de « Saillance »: ce qui atire l’œil du DNN et pèse dans son choix

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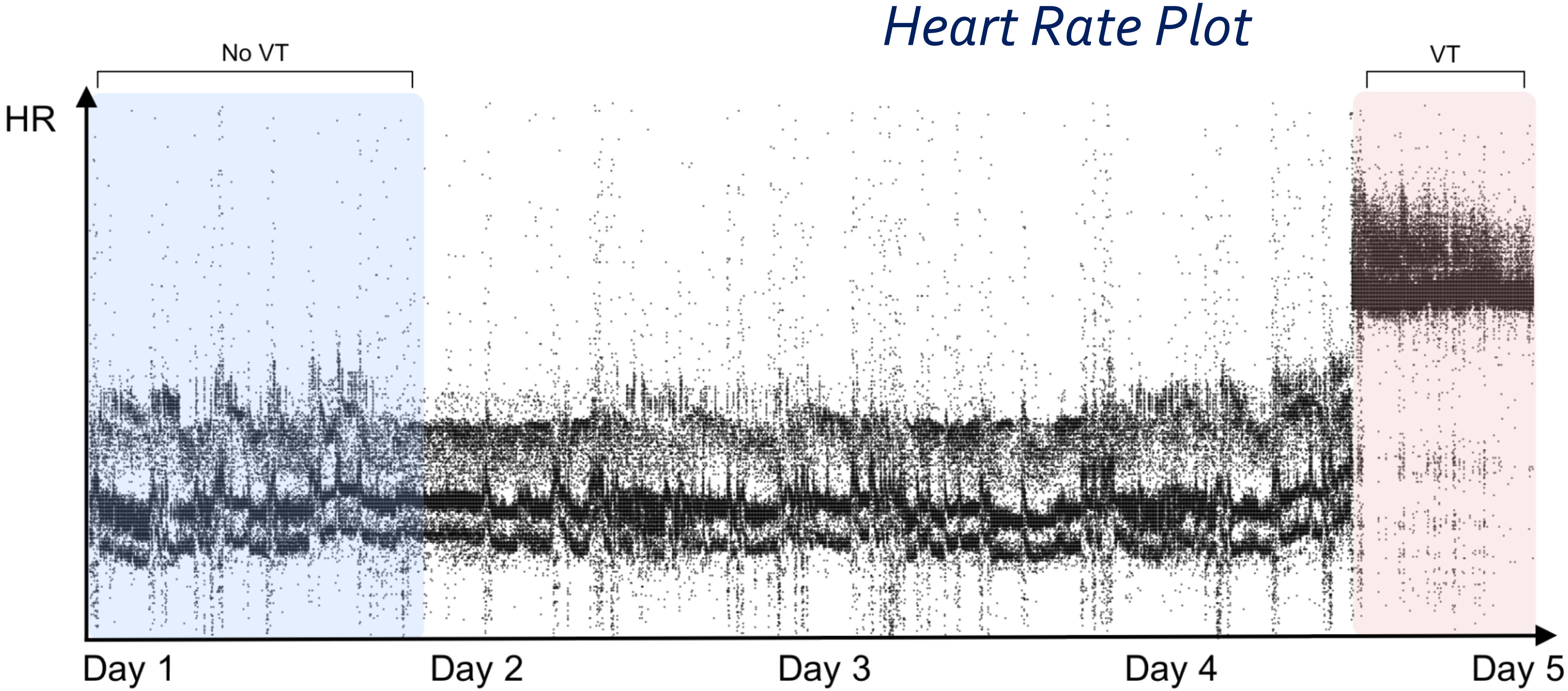
HEART RHYTHM
BRINGING THE WORLD OF EP TOGETHER
MAY 19 - 21, 2023 • NEW ORLEANS

Near-Term Prediction of Life-Threatening Ventricular Arrhythmias using Artificial Intelligence-Enabled Single Lead Ambulatory ECG

Laurent Fiorina, Tanner Carbonati, Kumar Narayanan, Jia Li, Christine Henry, Jagmeet P. Singh, Eloi Marijon

May 19, 2023

Methods



First 24 hours (w/o VT) used as input to a deep learning model

We then labeled each recording according to whether there is any VT documented in the following 13 days and used it as output for the algorithm

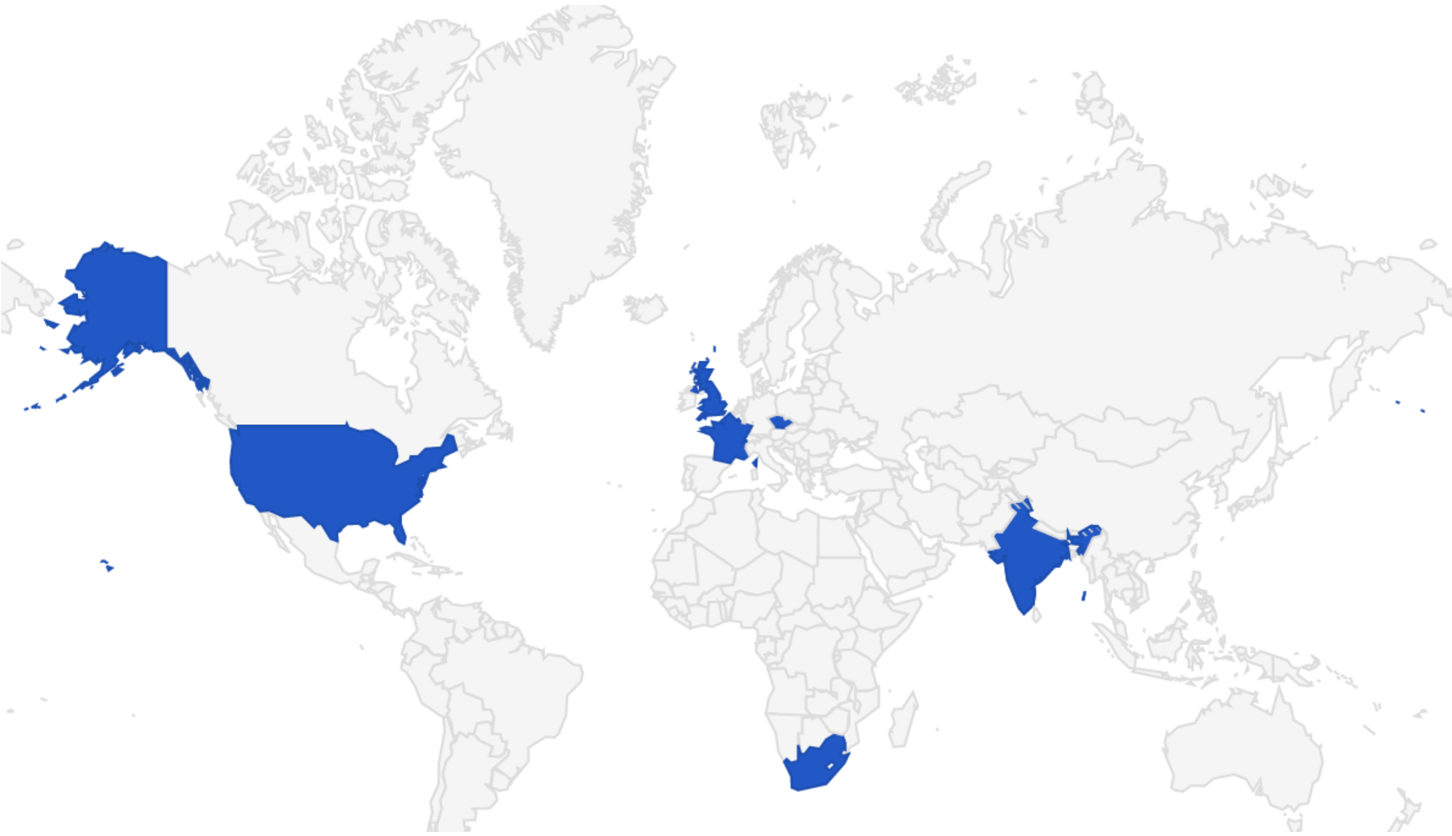
Study Population

- Independent Diagnostic Testing facilities (IDTFs) from USA, UK, France, Czech Republic, South Africa, & India

- 137,551 recordings were used for analysis

- 992 experienced sustained VA (985 VT & 7 VF)

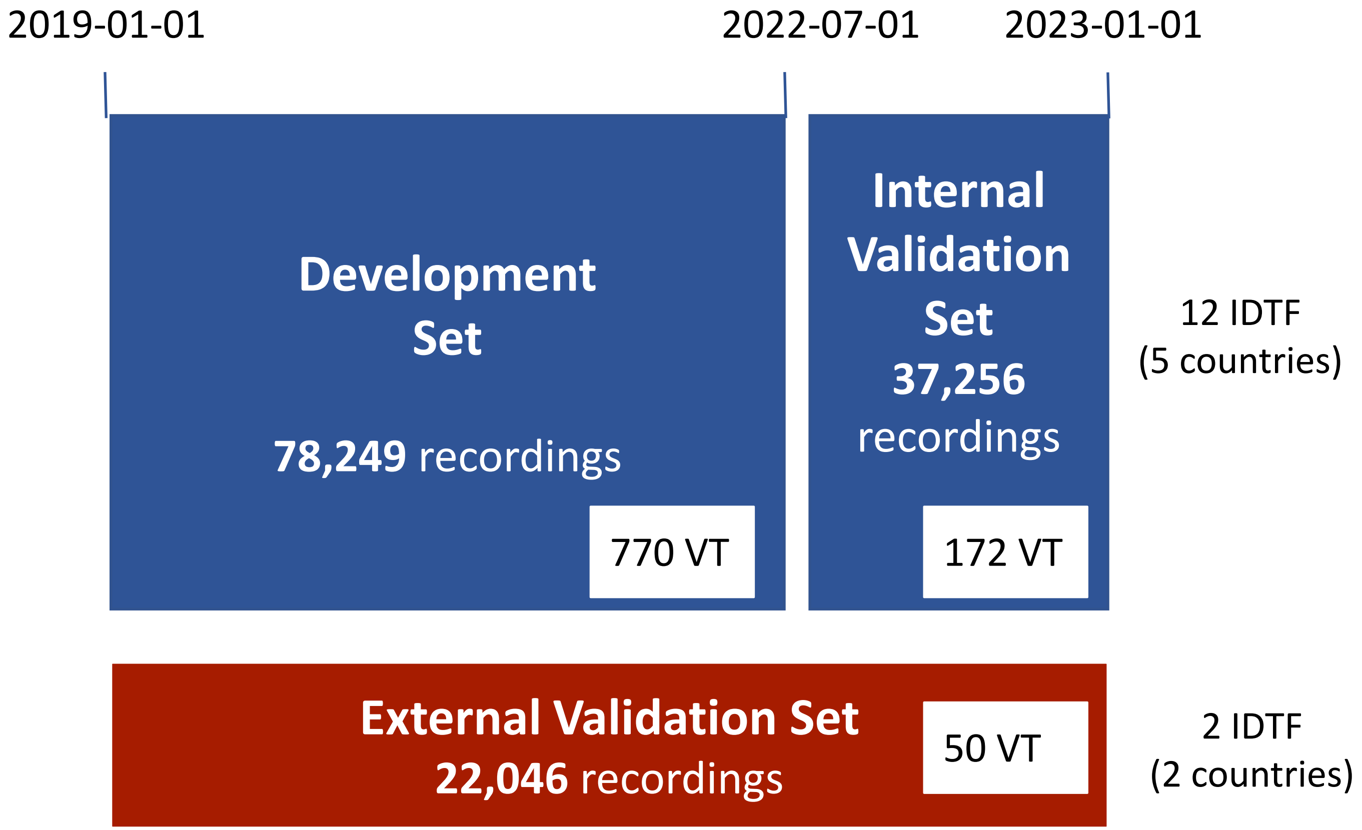
- 25% experienced a sustained episode with a rate ≥180 bpm



Datasets

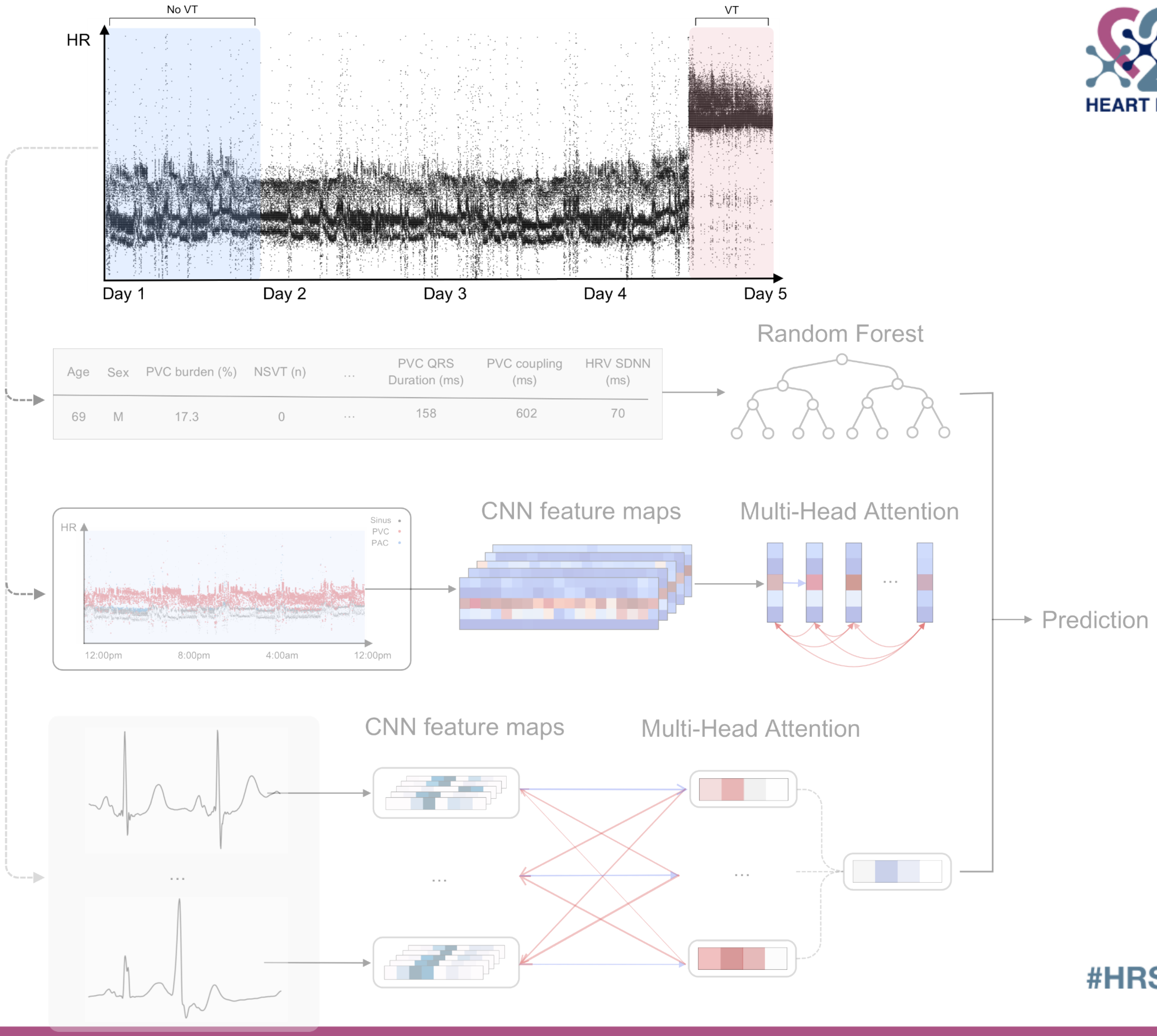
The main dataset was split into three sets

- Development set
  - Used to train the AI-model
- Internal validation set
  - Assess performance
- External validation set
  - Measure generalizability



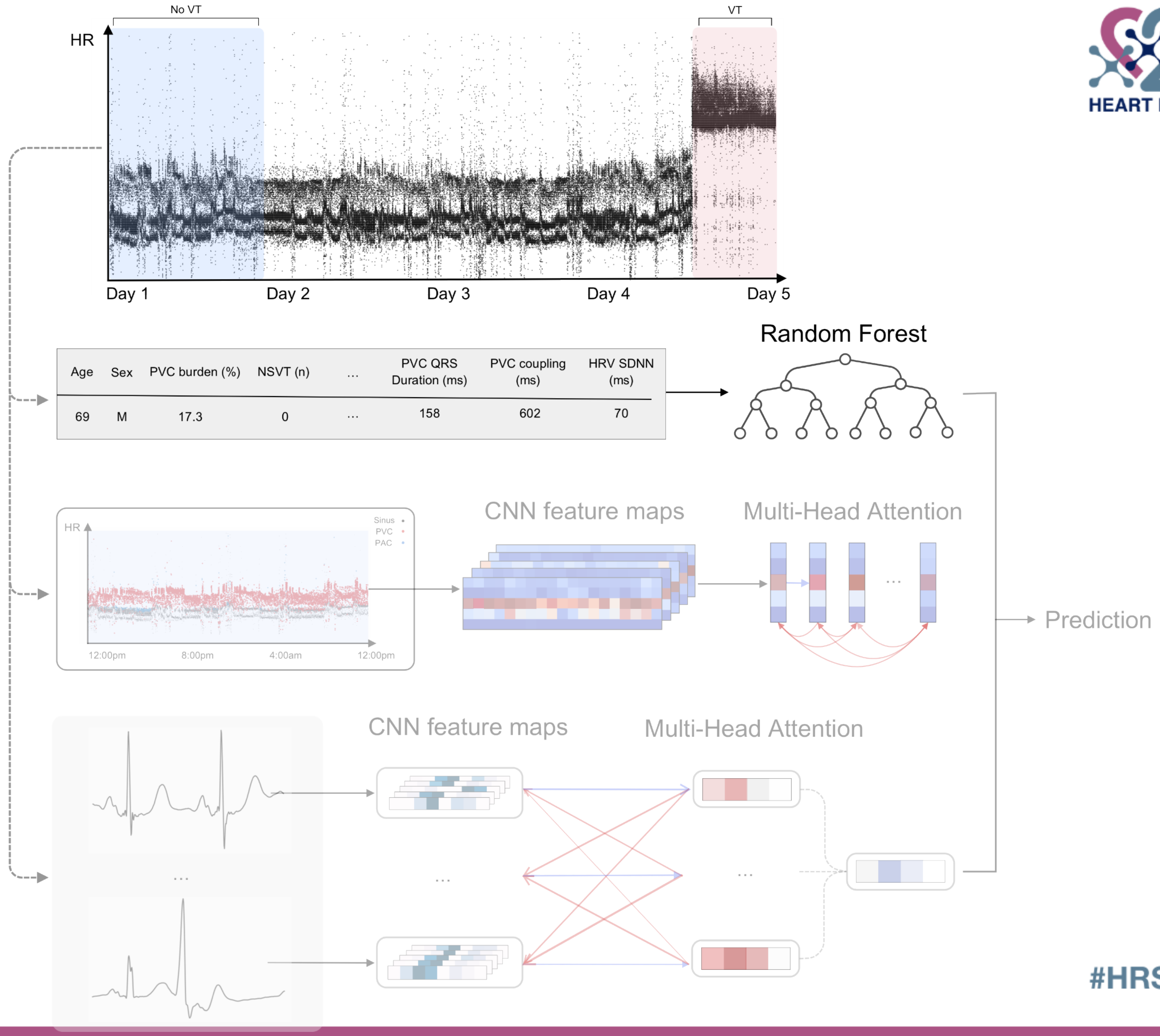
AI-based Model

We developed 3 distinct algorithms, each taking as input different modalities from the first 24-hour recording



AI-based Model

The 1st algorithm was a random forest classifier, which took as input the patients age, sex, and classical measurements computed from the ECG recording

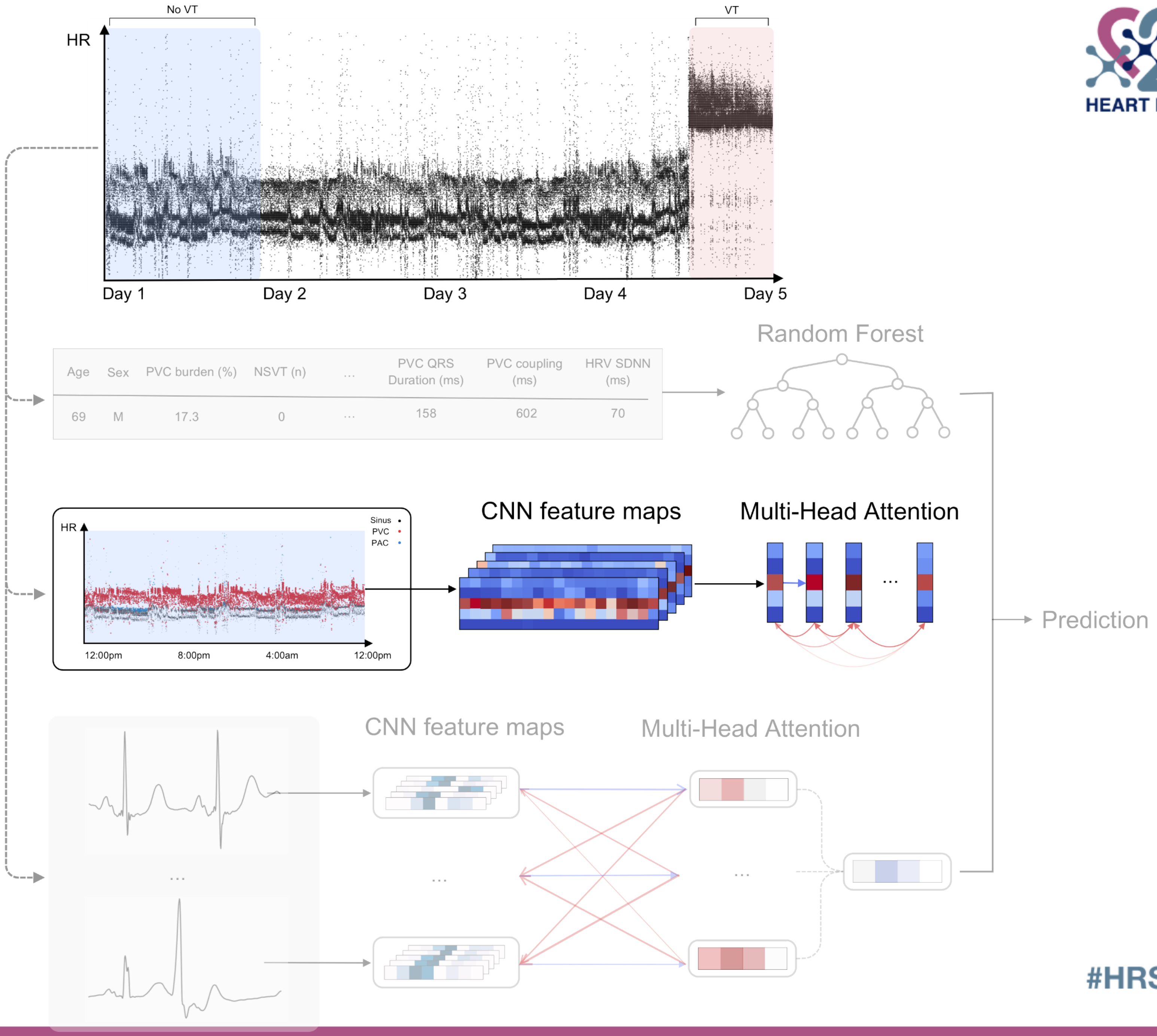


HEART RHYTHM

#HRS2023

AI-based Model

The 2nd algorithm was a deep neural network, which took as input a HR density plot to extract information related to the instantaneous HR *(autonomic nervous system)*

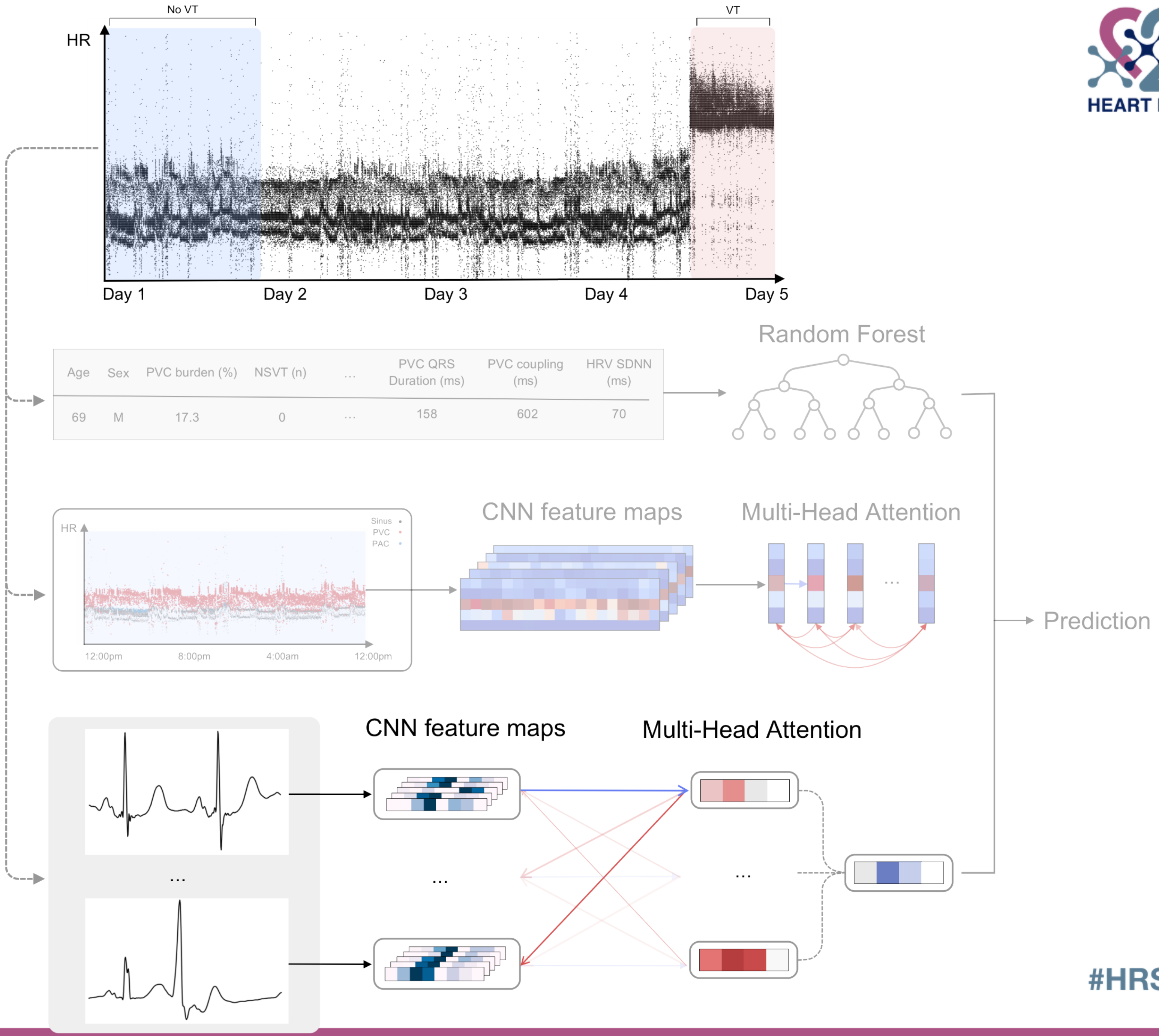


HEART RHYTHM

#HRS2023

AI-based Model

The 3rd algorithm was also a deep neural network using raw ECG waveform, to extract information related to the QRS and T-wave morphology *(arrhythmogenic substrate & trigger)*

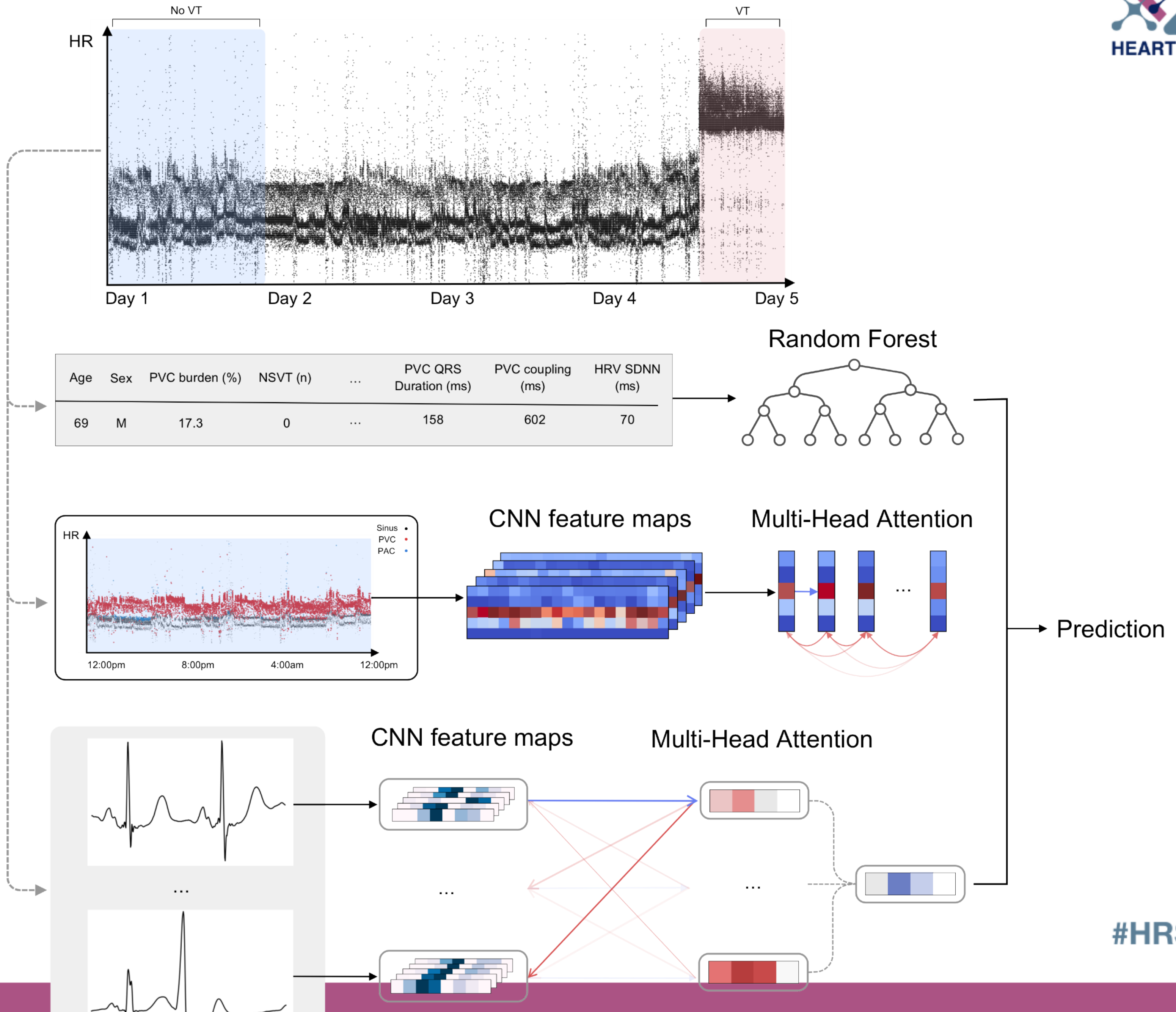


HEART RHYTHM

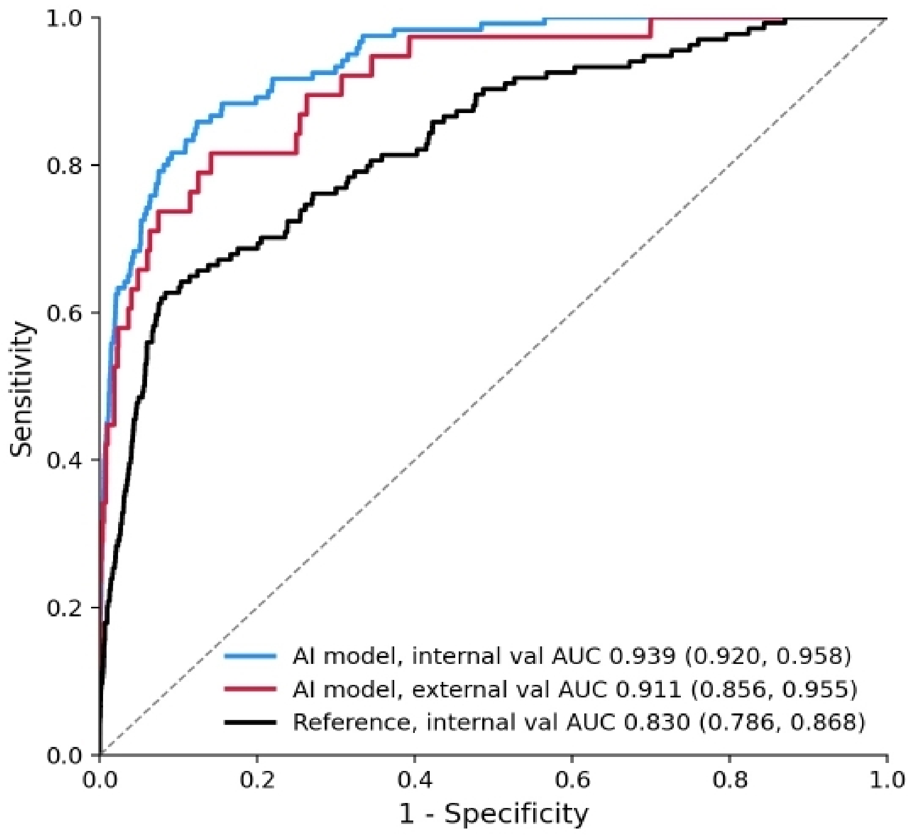
#HRS2023

AI-based Model

Overall, we averaged the 3 prediction models to produce a final risk score



Results – Area Under the ROC Curve



AI model, internal validation AUC **0.939**

AI model, external validation AUC **0.911**

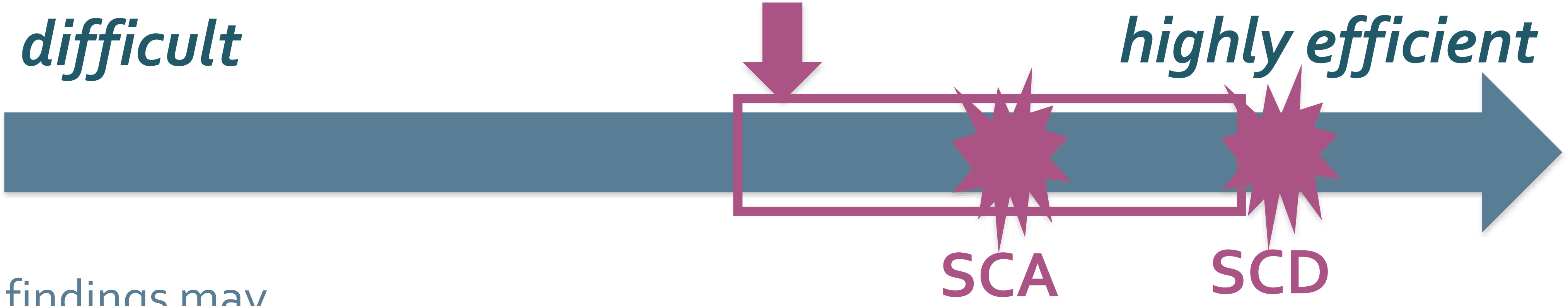
Reference, internal validation AUC **0.830**

Clinical Perspective

Prevention:
Ideal but difficult

Preemptive action

Resuscitation:
Not ideal but highly efficient



Our findings may have numerous applications across different clinical settings…

"Smart" Cardiac In-Hospital Monitoring

Artificial intelligence-enabled single-lead ambulatory ECG can unmask conduction tissue disease

Back to the future to identify syncope of cardiac cause

Laurent FIORINA, MD, Institut Cardiovasculaire Paris Sud, France

Laurent Fiorina, Tanner Carbonati, Baptiste Maille, Kumar Narayanan, Pauline Porquet, Christine Henry, Jagmeet P. Singh, Eloi Marijon, Jean-Claude Deharo

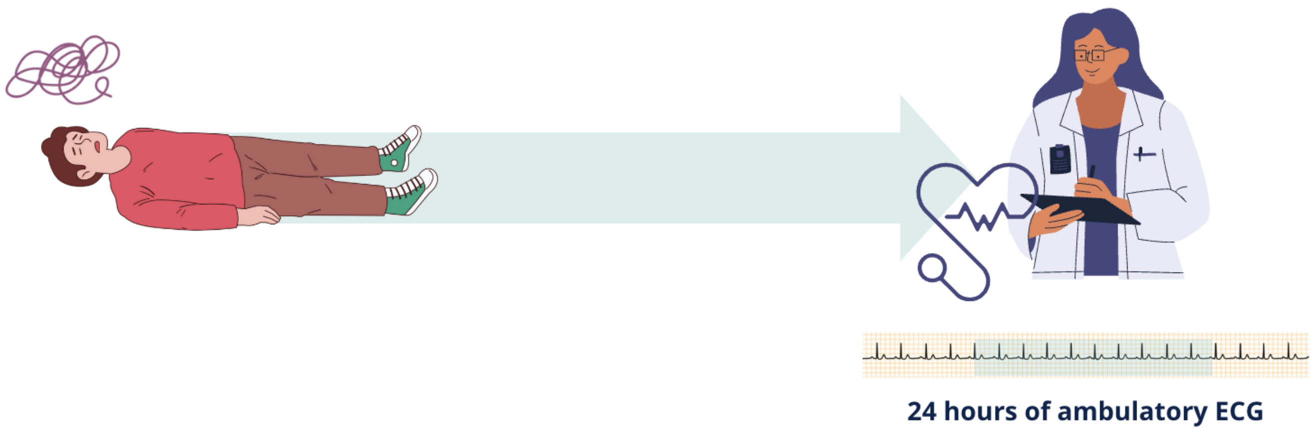
April 7, 2024

Study objective

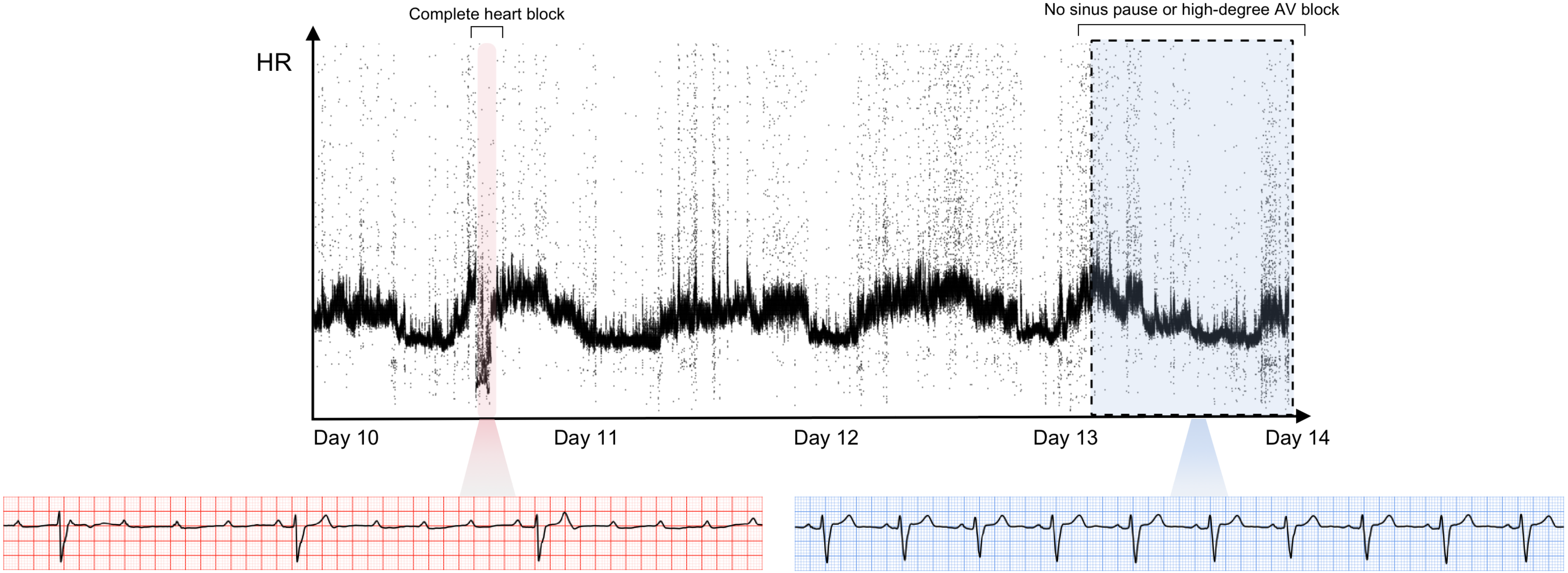
> “ **Evaluate the ability of an artificial intelligence (AI)-enabled single-lead ambulatory electrocardiogram (ECG) to identify patients who previously experienced asystole due to sinus pause or complete heart block.**

Hypothesis: A 24-hour single lead ECG contains electrical markers that are the footprint of conduction tissue disorders

Back to the Future: Artificial intelligence-enabled single-lead ambulatory ECG can unmask conduction tissue disease



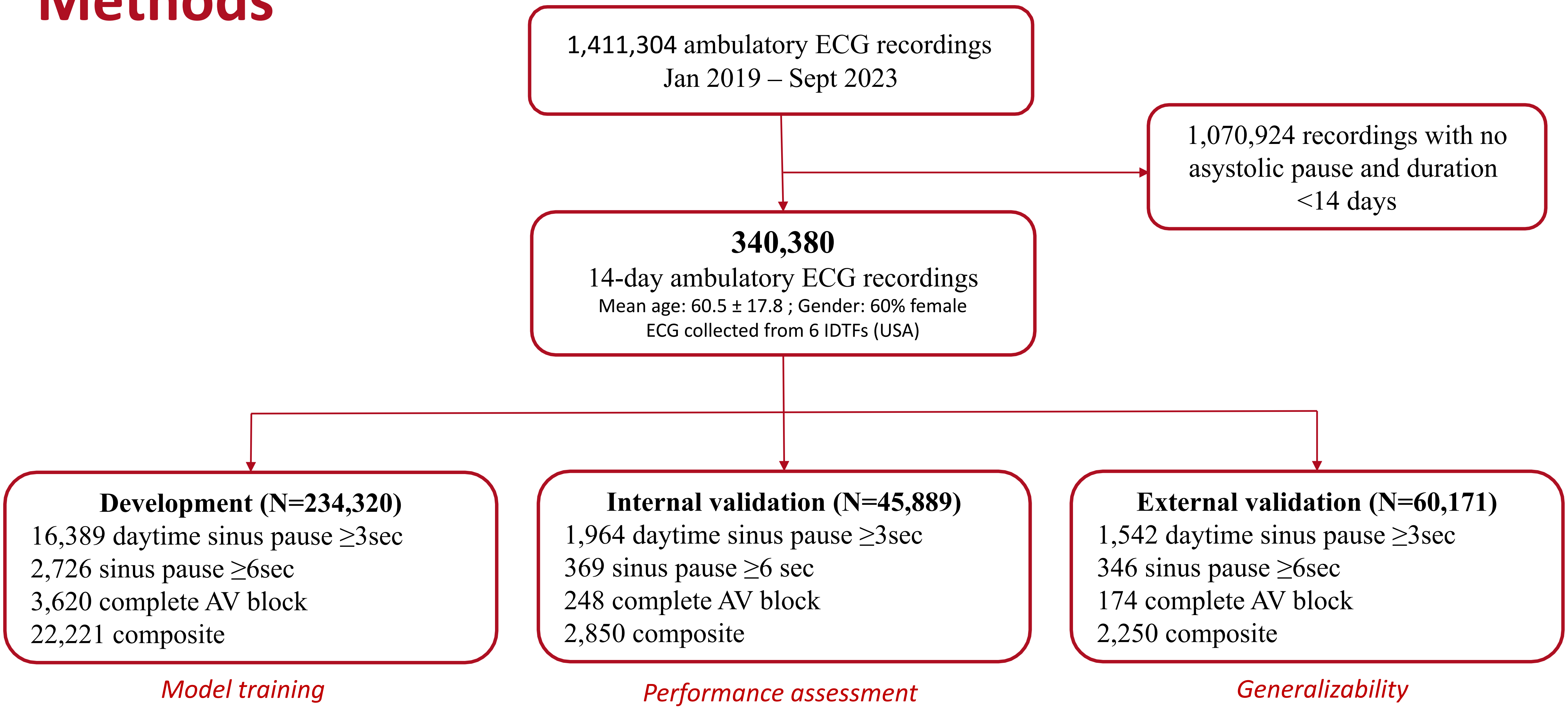
Methods



Each recording is annotated according to whether there is an asystolic pause documented during the first 13 days and used it as output for the algorithm

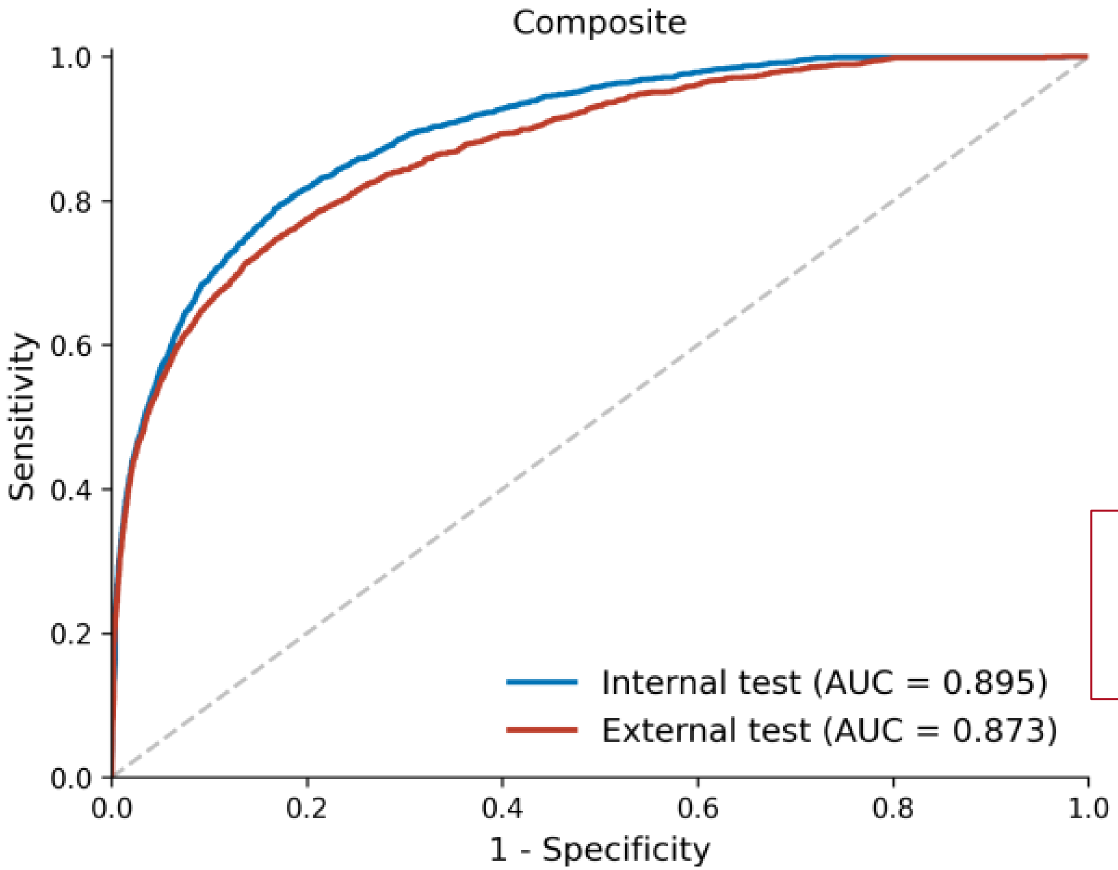
The last 24 hours (without an asystolic pause) is used as input to the algorithm

Methods



1,411,304 ambulatory ECG recordings
Jan 2019 – Sept 2023
1,070,924 recordings with no asystolic pause and duration <14 days
340,380
14-day ambulatory ECG recordings
Mean age: 60.5 ± 17.8 ; Gender: 60% female
ECG collected from 6 IDTFs (USA)
Development (N=234,320)
16,389 daytime sinus pause ≥3sec
2,726 sinus pause ≥6sec
3,620 complete AV block
22,221 composite
Internal validation (N=45,889)
1,964 daytime sinus pause ≥3sec
369 sinus pause ≥6 sec
248 complete AV block
2,850 composite
External validation (N=60,171)
1,542 daytime sinus pause ≥3sec
346 sinus pause ≥6sec
174 complete AV block
2,250 composite
Model training
Performance assessment
Generalizability

Results



	Sensitivity (95% CI)	Specificity (95% CI)
Daytime pause ≥3 s	77.1 (74.5-79.6)	85.5 (85.3-85.8)
Sinus pause ≥6 s	74.4 (68.2-79.9)	84.5 (84.3-84.8)
Complete AV block	81.1 (73.4-88.5)	72.8 (72.5-73.1)
Composite	80.4 (78.1-82.7)	80.0 (79.7-80.3)

Ref: Fujimura et al. NEJM 1989; EPS shows 15% sens. and 76% spe.

Forces :

- Gain de temps, jamais fatigué
- Perfectibilité
- Outils diagnostics plus précis (beyond human eyes)
- Pallier le manque de ressources
- Réduction de la variabilité intra & inter observateur

Faiblesses :

- Pas de full automatique pour l’instant
- Attention : quantité data > qualité annotations ! « Garbage in garbage out »
- Jamais du 100 % : l’I.A. se trompe!
- Menace pour notre job ?

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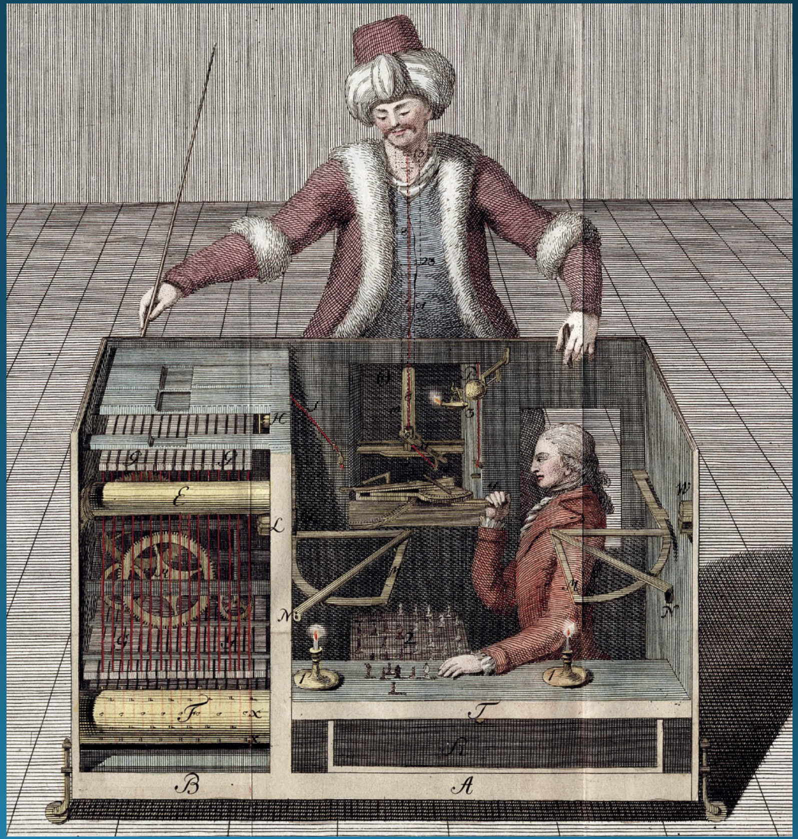
Externalisation/ Delegation

- A qui? Médecin/IDE/tech
- Cadre légal? Diplôme tech spécialisé
- A une société: confiance, process qualités

- Solution IA «full automatique» Avenir mais...



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