



Machine Learning e IA in Cardiologia



Gaetano Maria De Ferrari

Division of Cardiology

Department of Medical Science

Città della Salute e della Scienza, University of Turin



Disclosures



None

Artificial Intelligence is revolutionizing our Lives, Medicine and Cardiology

Whether we like it or not

With us... or most likely without us

Artificial intelligence and its subclasses

ARTIFICIAL INTELLIGENCE

Any technique which enables computers to mimic human behavior



MACHINE LEARNING

AI techniques that give computers the ability to learn without being explicitly programmed to do so



DEEP LEARNING

A subset of ML which make the computation of multi-layer neural networks feasible





Supervised learning

Labelled data

Direct feedback

Aim: **prediction**

Unsupervised learning

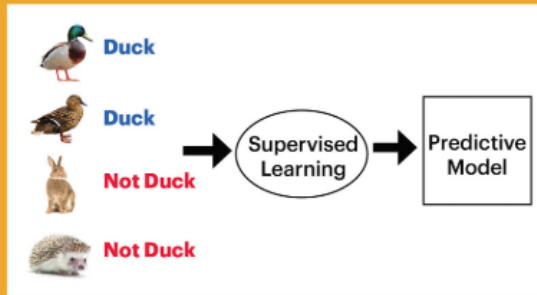
Unlabelled data

No feedback

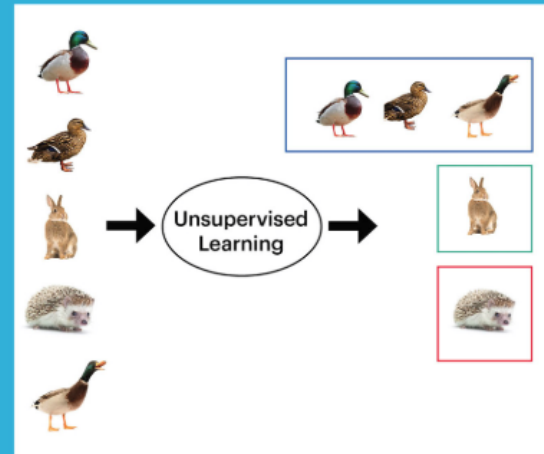
Aim: **find hidden structure** in data



Supervised Learning (Classification Algorithm)



Unsupervised Learning (Clustering Algorithm)



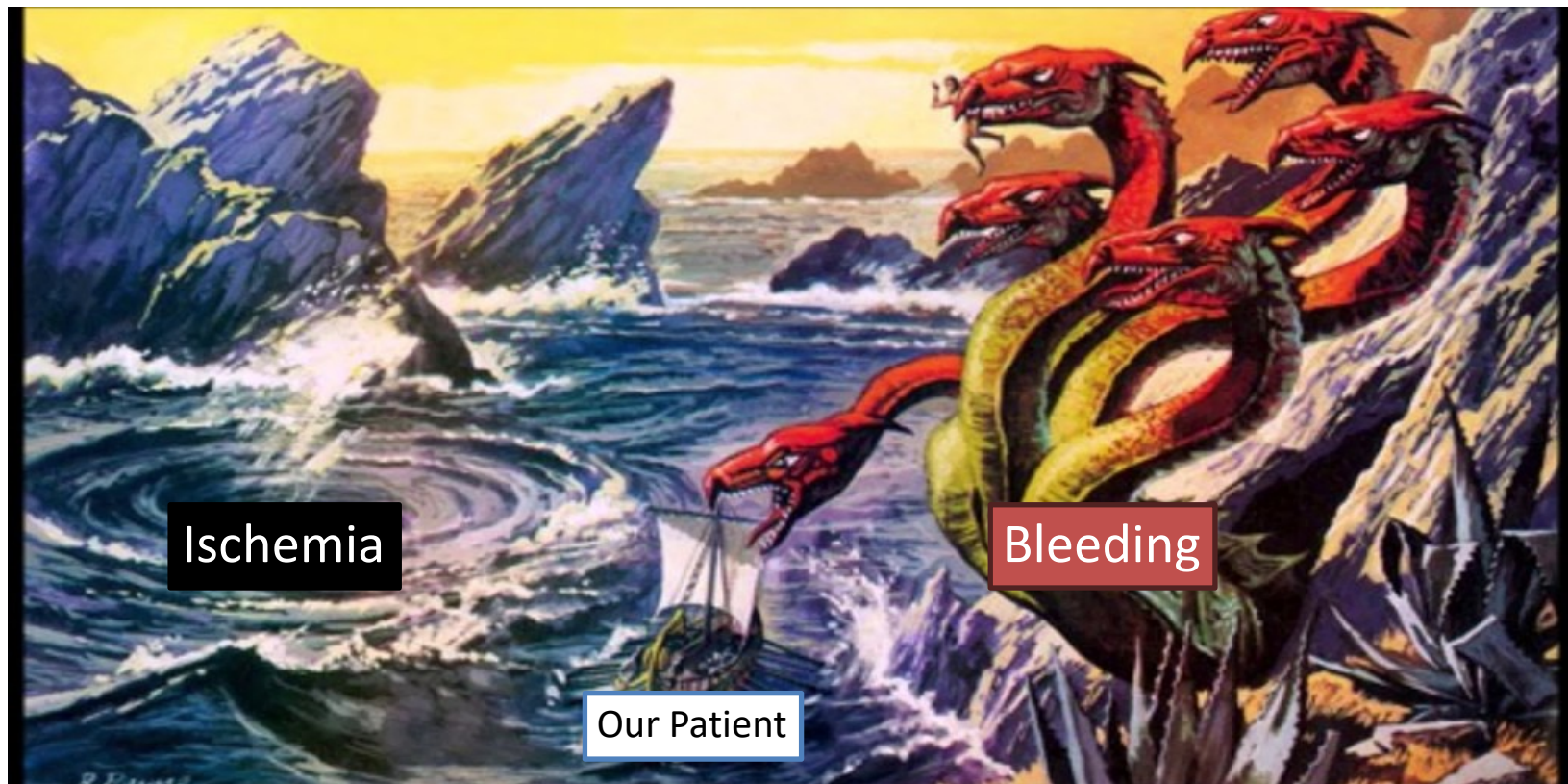
The Challenge of Identifying high Risk post-MI

Patients with high thrombotic risk benefit from aggressive treatment

Patients with high bleeding risk benefit from less aggressive DAPT



Between Scylla and Charybdis



Ischemia

Bleeding

Our Patient

Risk Scores Performance

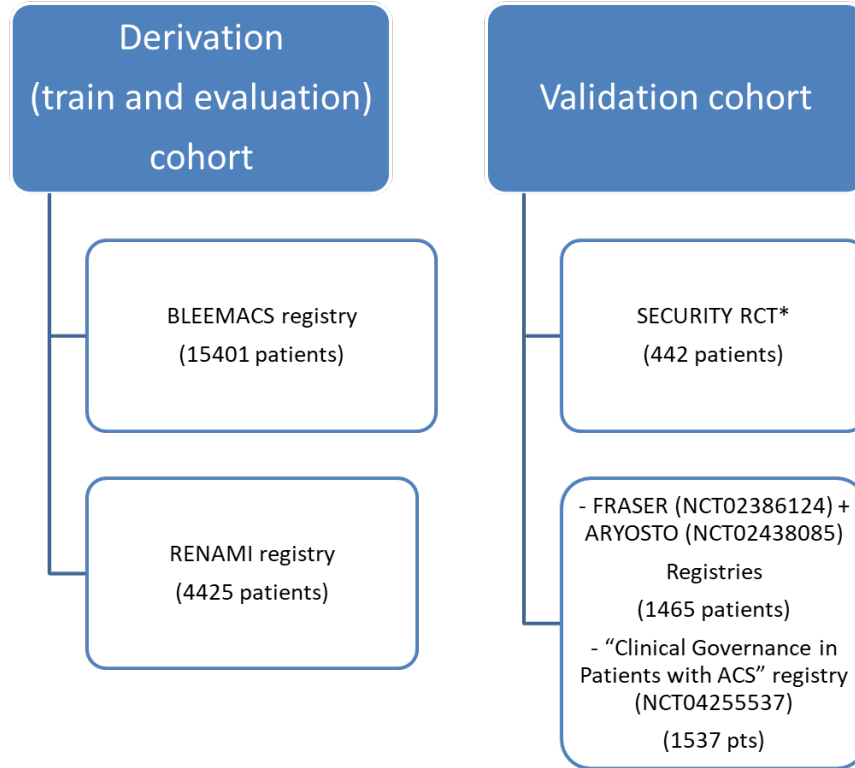
	TIMI major or minor bleeding		TIMI major bleeding	
	c-Index (95% CI)	p value*	c-Index (95% CI)	p value*
Derivation cohort				
PRECISE-DAPT	0.73 (0.61-0.85)	..	0.71 (0.57-0.85)	..
PRECISE-DAPT alternative	0.71 (0.57-0.84)	..	0.69 (0.53-0.85)	..
Validation cohort 1 (PLATO)				
PRECISE-DAPT	0.70 (0.65-0.74)	0.06	0.68 (0.63-0.74)	0.01
PRECISE-DAPT alternative	0.70 (0.66-0.74)	0.02	0.68 (0.63-0.74)	0.008
PARIS	0.66 (0.61-0.70)	Ref	0.62 (0.56-0.68)	Ref
Validation cohort 2 (BernPCI)				
PRECISE-DAPT	0.66 (0.61-0.71)	0.09	0.65 (0.58-0.71)	0.17
PRECISE-DAPT alternative	0.63 (0.58-0.68)	0.82	0.62 (0.55-0.68)	0.57
PARIS	0.63 (0.58-0.67)	Ref	0.62 (0.56-0.69)	Ref

Modest performance
and low
generalizability of
available risk scores
for ischemic and
bleeding events
following an ACS

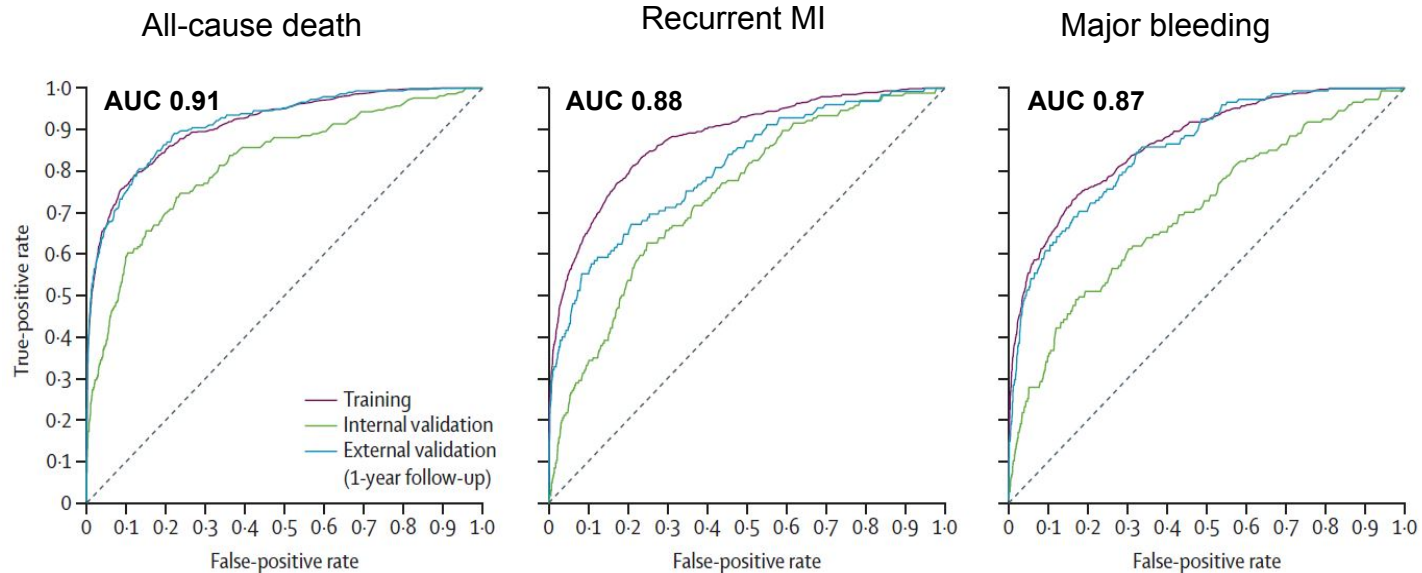
Machine learning-based prediction of adverse events following an acute coronary syndrome (PRAISE): a modelling study of pooled datasets

Fabrizio D'Ascenzo, Ovidio De Filippo, Guglielmo Gallone, Gianluca Mittone, Marco Agostino Deriu, Mario Iannaccone, Albert Ariza-Solé, Christoph Liebetrau, Sergio Manzano-Fernández, Giorgio Quadri, Tim Kinnaird, Gianluca Campo, Jose Paulo Simao Henriques, James M Hughes, Alberto Dominguez-Rodriguez, Marco Aldinucci, Umberto Morbiducci, Giuseppe Patti, Sergio Raposeiras-Roubin, Emad Abu-Assi, Gaetano Maria De Ferrari, on behalf of the PRAISE study group

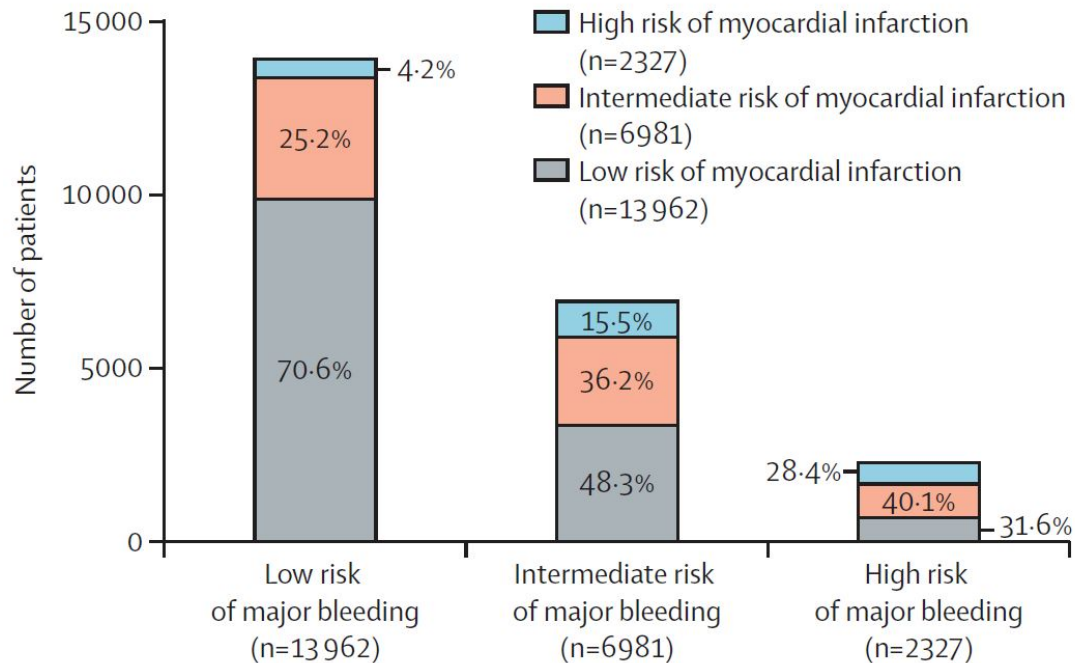
Patients population



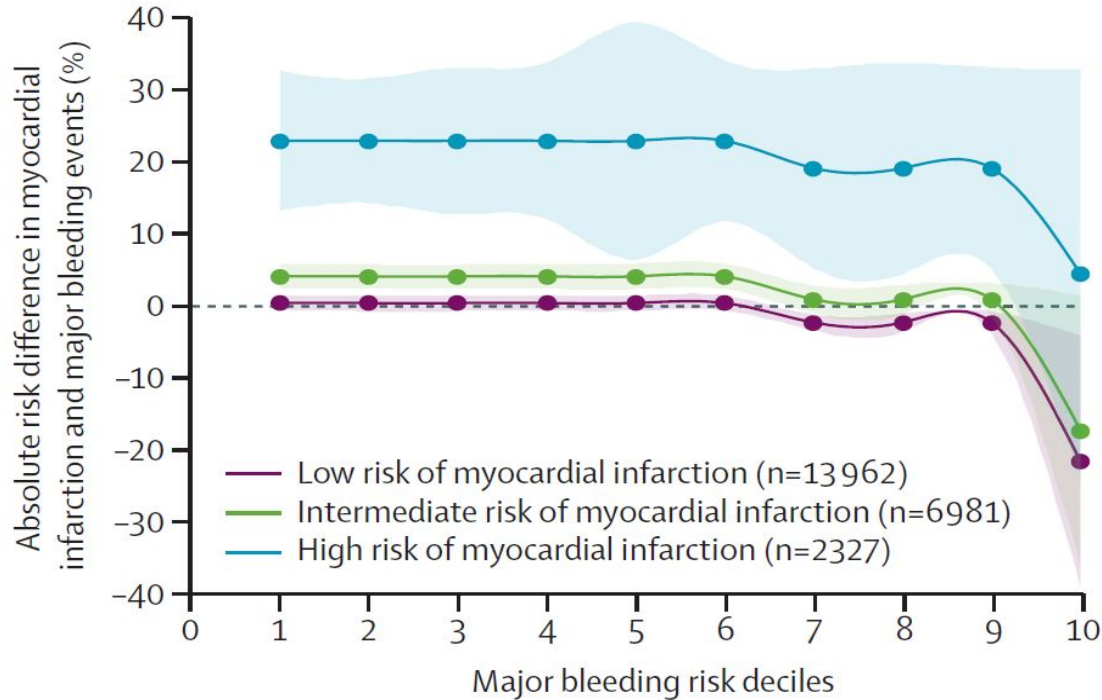
AUCs for death, MI, and major bleeding for the training, internal validation, and external validation datasets at 1-year follow-up



Cross-classification of myocardial infarction and major bleeding risk classes



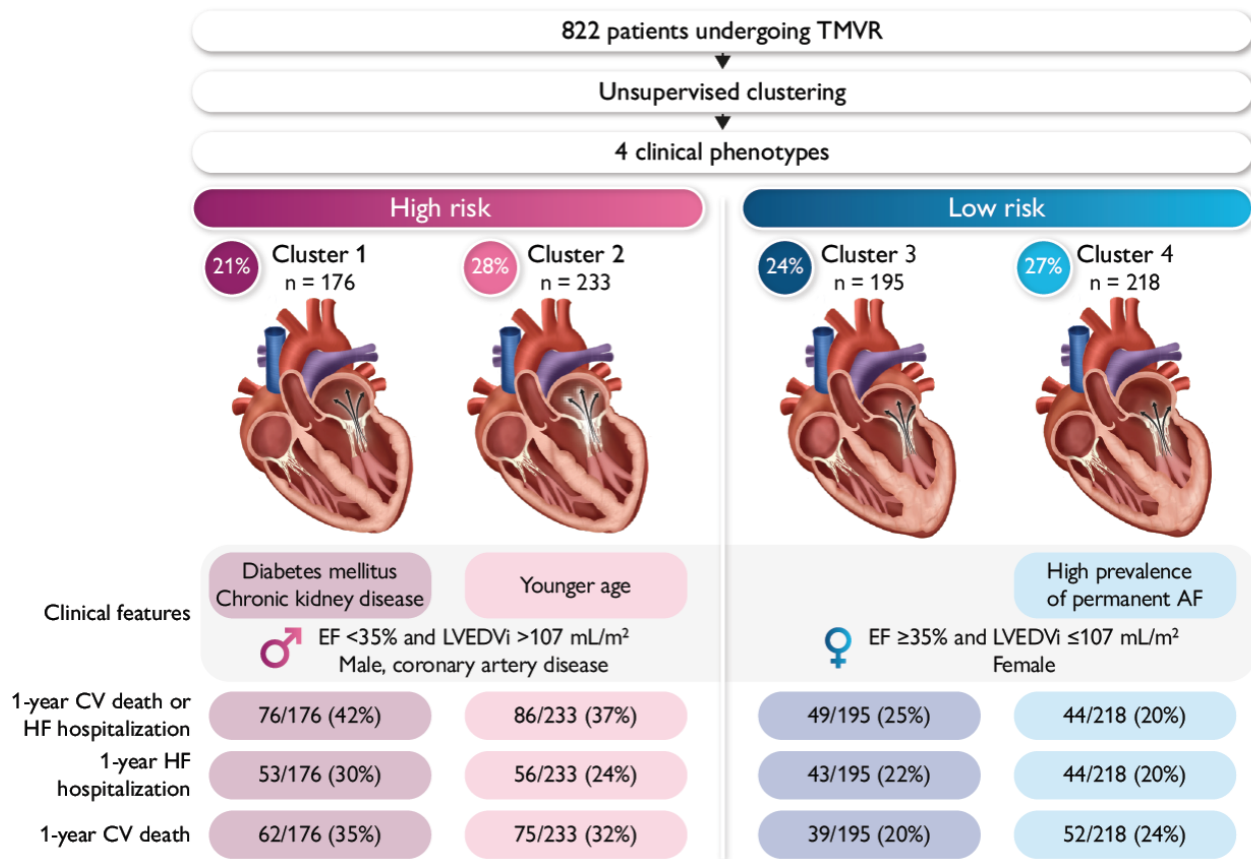
The hypothetical trade-off between the two types of risk



PRAISE Score
<https://praise.hpc4ai.it>









ESC

European Society
of Cardiology

Europace (2022) 00, 1–9

<https://doi.org/10.1093/europace/euac145>

CLINICAL RESEARCH

AFA-Recur: an ESC EORP AFA-LT registry machine-learning web calculator predicting atrial fibrillation recurrence after ablation

Andrea Saglietto ¹, **Fiorenzo Gaita** ², **Carina Blomstrom-Lundqvist** ³,
Elena Arbelo ^{4,5,6}, **Nikolaos Dagues** ⁷, **Josep Brugada** ⁸,
Aldo Pietro Maggioni ^{9,10}, **Luigi Tavazzi** ¹¹, **Josef Kautzner** ¹²,
Gaetano Maria De Ferrari ^{1*}, and **Matteo Anselmino** ¹, on behalf of the
AFA LT registry investigators group[†]

Derivation of multiple ML models



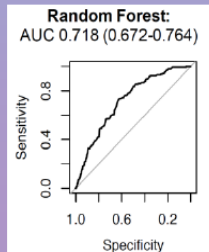
ESC-EORP AFA-LT Registry

- 3128 pts included
- 80% training, 20% test
- 27 candidate variables

Selection of best ML model



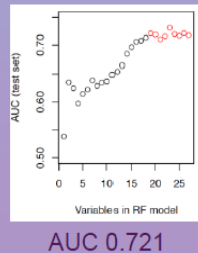
Random forest model



Selection of optimal variables



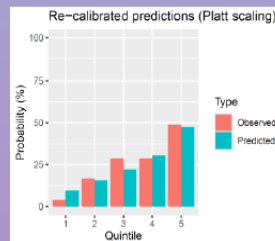
19-variable random forest model



Calibration



Platt scaling recalibration



Web calculator



Patient-specific predictions

	1-year recurrence (%)
Low risk	4-19%
Intermediate risk	19-38%
High risk	38-76%



Atrial Fibrillation Ablation Recurrence Score (AFA-Recur)

Left ventricular end diastolic volume [ml] 	Glomerular filtration rate (CKD-EPI) [ml/min/1.73m ²] 	Body mass index (BMI) [kg/m ²]
Age [years] 	Left atrium diameter [mm] 	Left ventricular ejection fraction [%]
CHA(2)DS(2)-VASc score 	Dyslipidemia No	History of atrial flutter No
Type of procedure First procedure	Type of atrial fibrillation Paroxysmal AF	Structural Heart Disease No
Hypertension No	Baseline Sinus Rhythm Yes	Gender Female
Abnormal ECG No	Heart Failure No	Coronary Artery Disease No
Smoker No		

<http://afarec.hpc4ai.unito.it/>



ESC

Europace (2026) 28, euag053

<https://doi.org/10.1093/europace/euag053>

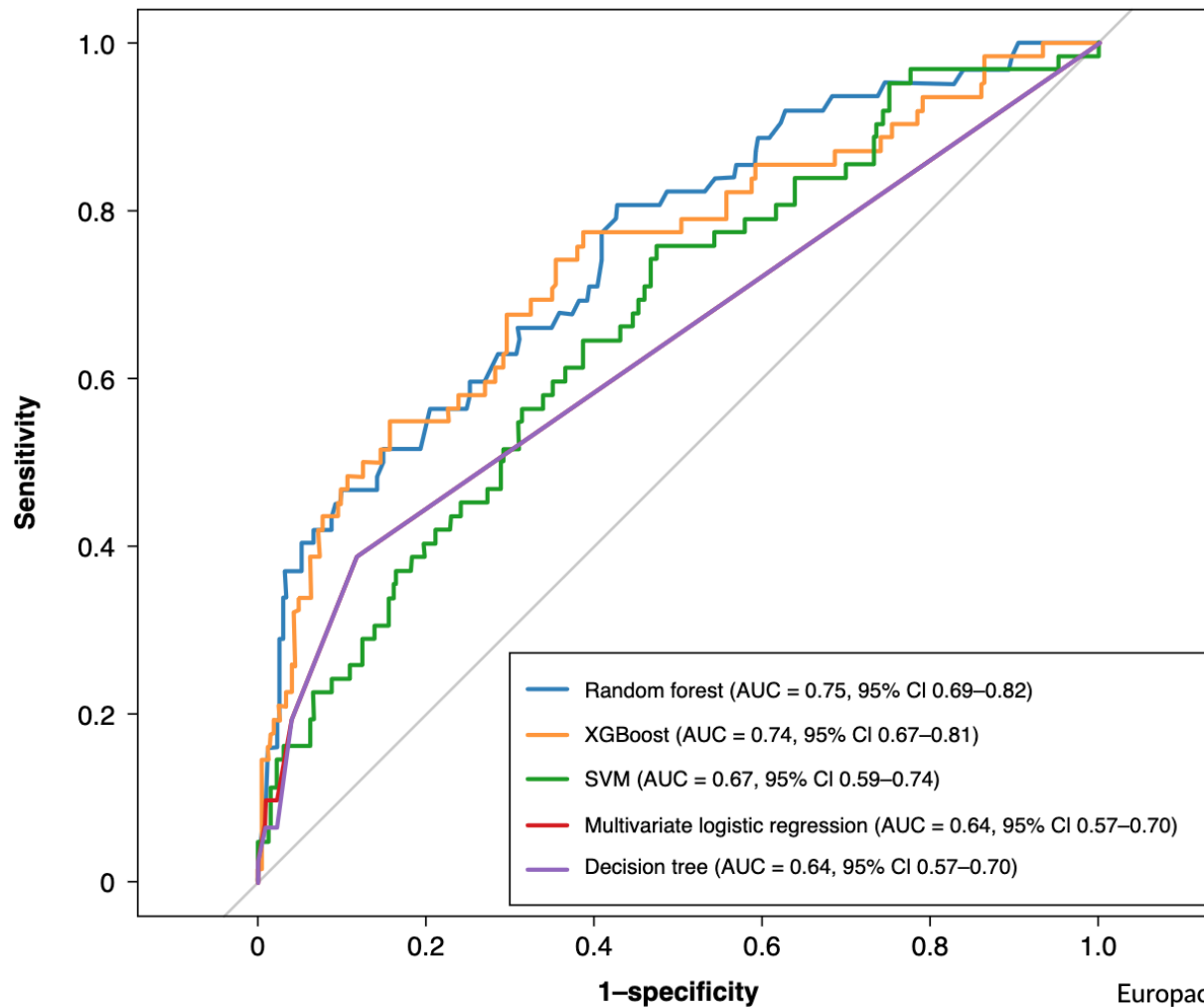
CLINICAL RESEARCH

<https://doi.org/10.1093/europace/euag053>

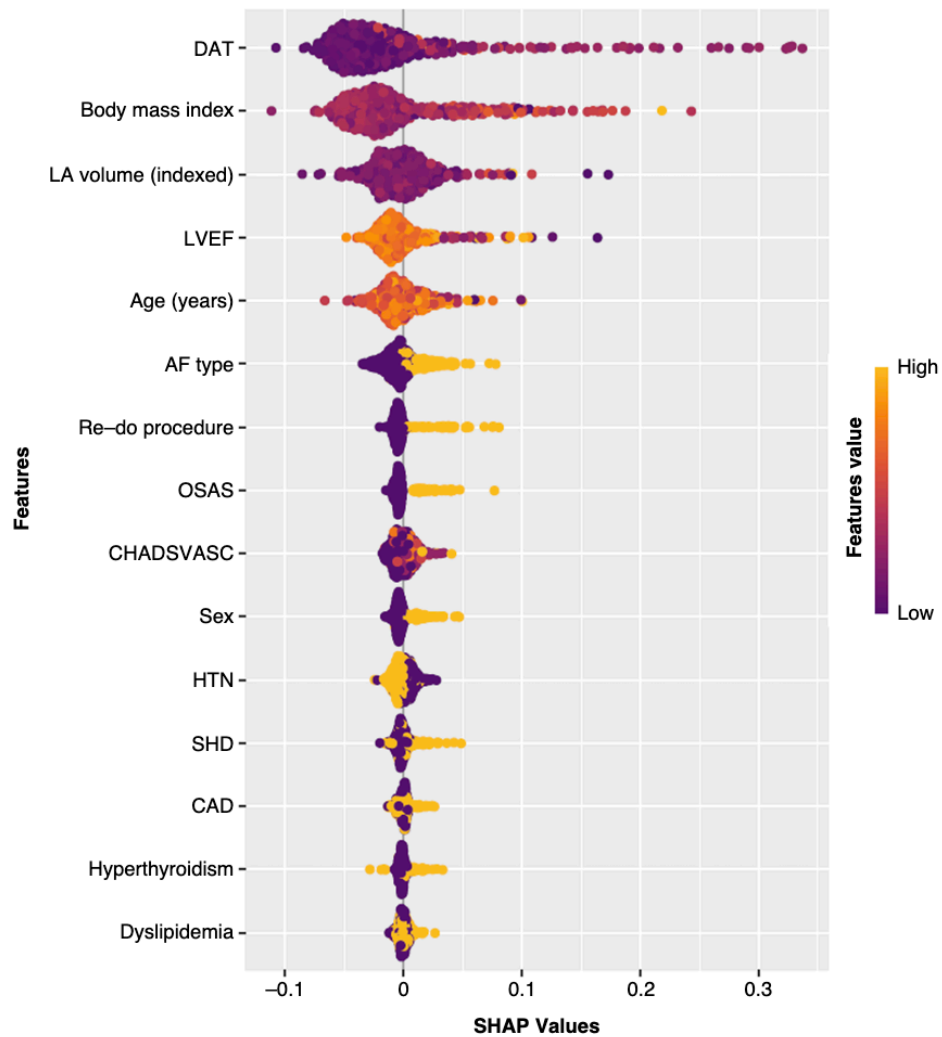
Machine learning prediction of outcome following pulsed-field atrial fibrillation ablation: patient selection and risk factors

Matteo Anselmino ^{1,2*}, Stefano Bianchi ³, Raffele De Lucia ⁴, Claudio Tondo ^{5,6},
Saverio Iacopino ⁷, Francesco Solimene ^{8,9}, Antonio Rossillo¹⁰, Matteo Bertini ¹¹,
Sakis Themistoclakis ¹², Ilaria Meynet ¹³, Maurizio Russo ¹⁴,
Antonio Dello Russo ^{9,15}, Gianluca Zingarini¹⁶, Stefano Bandino ¹⁷,
Mario Volpicelli ¹⁸, Pietro Rossi ³, Lorenzo Bianchini ⁵, Vincenzo Schillaci ⁸,
Antonio De Simone ¹⁹, Marco Scaglione ²⁰, Giovanni Rovaris²¹,
Gaetano Maria De Ferrari ^{1,2}, Maurizio Malacrida ²², Andrea Saglietto ^{1,2†},
and Giulio Zucchelli ^{4†}

ROC curve comparison



Global SHAP analysis



AI and the Renaissance of ECG



European Journal of Internal Medicine

Available online 20 May 2025

In Press, Corrected Proof [What's this?](#)



Review Article

Artificial intelligence and the electrocardiogram: A modern renaissance

Stefano Palermi ^a, Marco Vecchiato ^b, Fu Siong Ng ^{c d e}, Zachi Attia ^f, Youngjin Cho ^{g h i},
Matteo Anselmino ^j, Gaetano Maria De Ferrari ^j, Andrea Saglietto ^j on behalf of the
International AI-ECG Working Group[#]

Arunashis Sau ^{k l}, I-Min Chiu ^{n o}, Juan M. Farina ^p, Reza Arsanjani ^p, Giuseppe Biondi Zoccai ^{q r},
Leonarda Galiuto ^s, Luca Nissardi ^m, Veronica Dusi ^m

The School of Athens by Raffaello 1510

The Challenge of Identifying AF

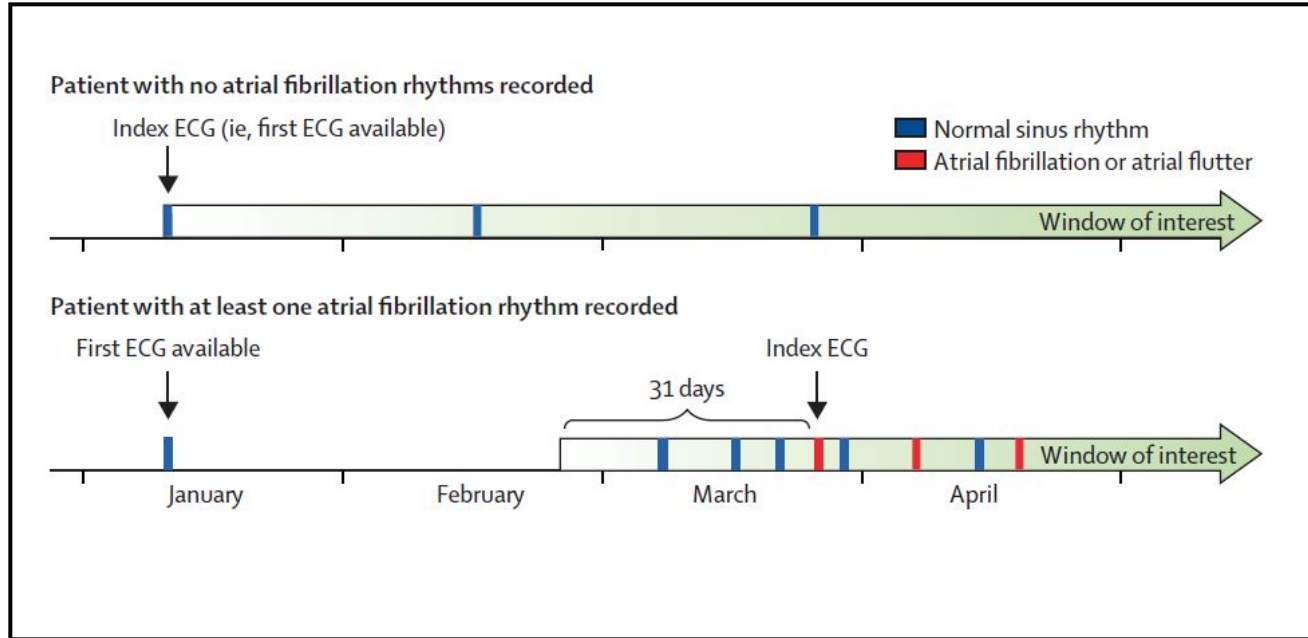
Stroke Prevention in Atrial Fibrillation



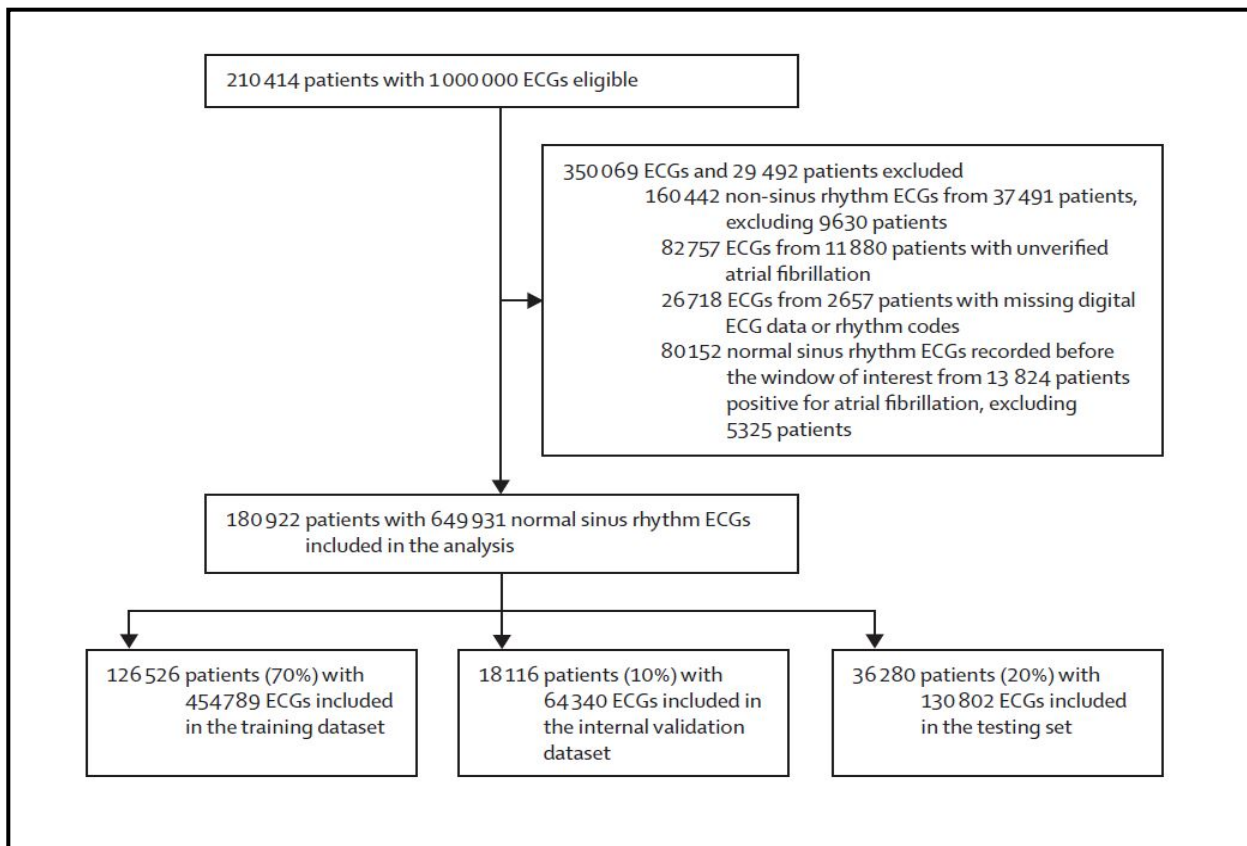
An artificial intelligence-enabled ECG algorithm for the identification of patients with atrial fibrillation during sinus rhythm: a retrospective analysis of outcome prediction

Zachil 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*

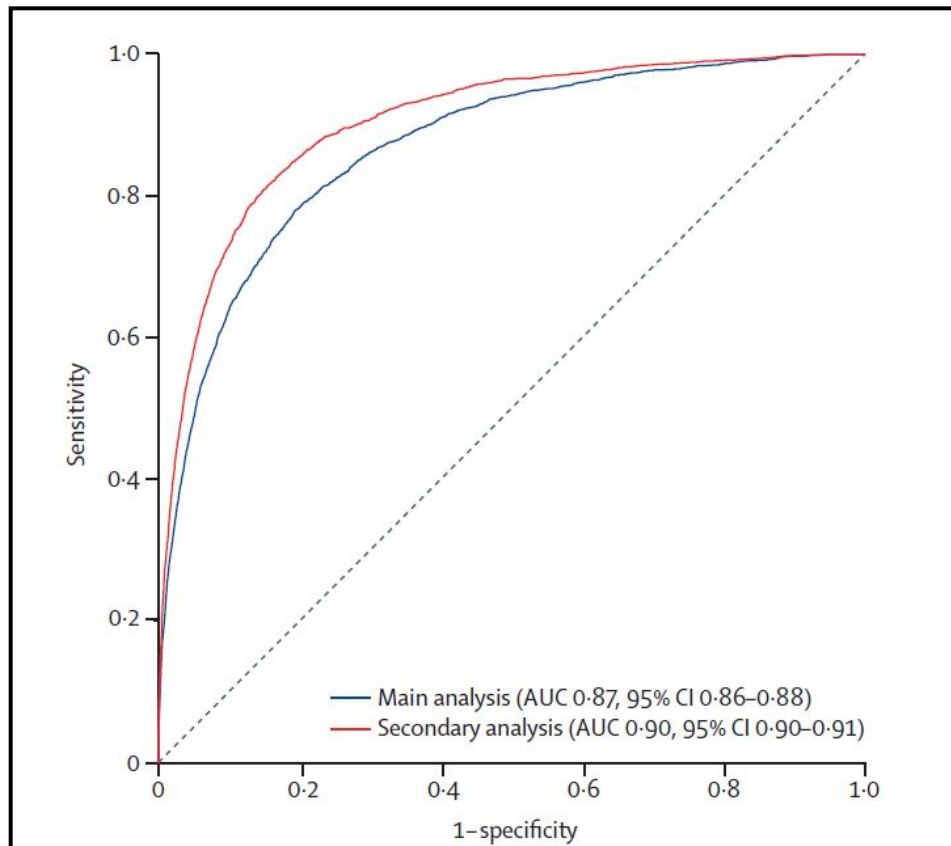
ECG selection and windows of interest for patients with multiple ECGs



Patients flow diagram



ROC curves for the testing dataset



Why does a patient develop AF?

Classical electrophysiological approach:

In addition to autonomic influence

Atrial fibrosis

→ slowed conduction

→ altered P-wave morphology

What should the investigators study ?

- P-wave morphology
- P-wave duration
- P-wave dispersion
- P-wave terminal force in V1
- Interatrial block
- Signs of atrial cardiomyopathy

The Philosophical Contrast

- For fifty years we have been trying to understand which component of the P wave predicts atrial fibrillation.
- Attia's neural network bypassed the question entirely and simply learned the answer.
- That is the essence of the (Cartesian) revolution of AI.

The Philosophical Contrast

Cartesian Medicine

- Identify atrial fibrosis
- Study P-wave abnormalities
- Explain mechanism
- Prediction follows explanation

AI Medicine

- Analyze raw ECG
- Study 5000+ hidden features
- Learn statistical patterns
- Prediction precedes explanation

A PROVOCATIVE QUESTION

CAN WE TRUST
WHAT WE DO NOT
UNDERSTAND?



OBSERVATION



EXPLANATION



MECHANISTIC
UNDERSTANDING

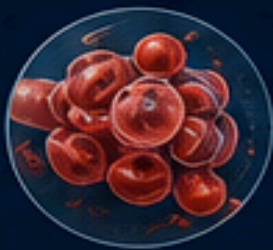
EXAMPLES



Understanding coronary atherosclerosis led to **statins**.



Understanding neurohormonal activation led to **heart failure therapies**.



Understanding thrombosis led to **antithrombotic strategies**.



KEY MESSAGE

PREDICTION
FOLLOWS
EXPLANATION.

This has been the dominant paradigm of medicine for the last 400 years.

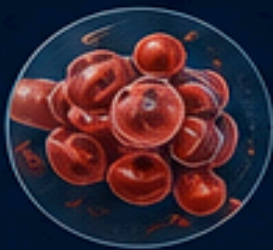
EXAMPLES



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**PREDICTION
FOLLOWS
EXPLANATION.**

This has been the dominant paradigm of medicine for the last 400 years.

A PROVOCATIVE QUESTION

CAN WE TRUST WHAT WE DO NOT UNDERSTAND?

FOR CENTURIES,
MEDICINE ANSWERED:

NO.



?



OBSERVATION



EXPLANATION



MECHANISTIC
UNDERSTANDING

Should we Trust Oracles ?



Artificial intelligence-enabled electrocardiogram for mortality and cardiovascular risk estimation: a model development and validation study

Arunashis Sau, Libor Pastika, Ewa Sieliwiczek, Konstantinos Patlatzoglou, Antônio H Ribeiro, Kathryn A McGurk, Boroumand Zeidaabadi, Henry Zhang, Krzysztof Macierzanka, Danilo Mandic, Ester Sabino, Luana Giatti, Sandhi M Barreto, Lidyane do Valle Camelo, Ioanna Tzoulaki, Declan P O'Regan, Nicholas S Peters, James S Ware, Antonio Luiz P Ribeiro, Daniel B Kramer, Jonathan W Waks, Fu Siong Ng

Summary

Background Artificial intelligence (AI)-enabled electrocardiography (ECG) can be used to predict risk of future disease and mortality but has not yet been adopted into clinical practice. Existing model predictions do not have actionability at an individual patient level, explainability, or biological plausibility. We sought to address these limitations of previous AI-ECG approaches by developing the AI-ECG risk estimator (AIRE) platform.

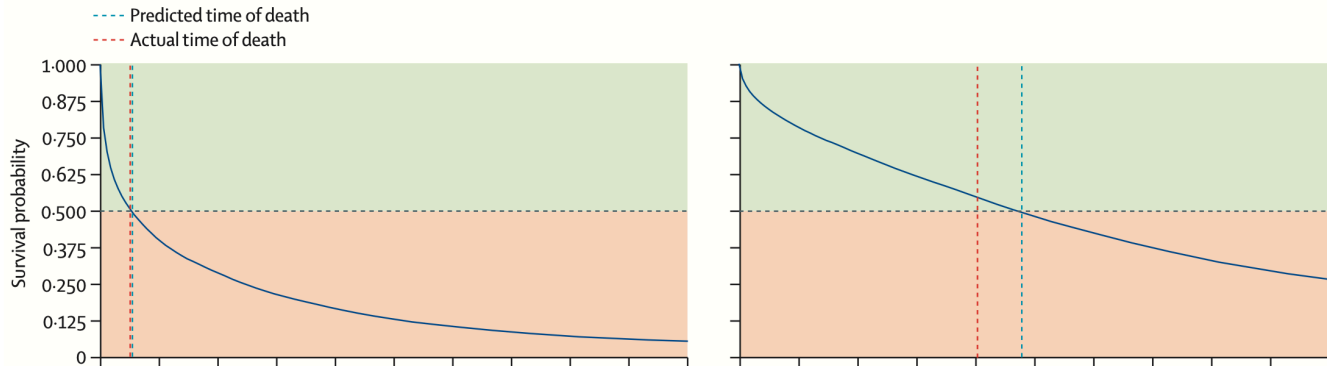
Methods The AIRE platform was developed in a secondary care dataset (Beth Israel Deaconess Medical Center [BIDMC]) of 1163401 ECGs from 189539 patients with deep learning and a discrete-time survival model to create a patient-specific survival curve with a single ECG. Therefore, AIRE predicts not only risk of mortality, but also time-to-mortality. AIRE was validated in five diverse, transnational cohorts from the USA, Brazil, and the UK (UK Biobank [UKB]), including volunteers, primary care patients, and secondary care patients.

Findings AIRE accurately predicts risk of all-cause mortality (BIDMC C-index 0.775, 95% CI 0.773–0.776; C-indices on external validation datasets 0.638–0.773), future ventricular arrhythmia (BIDMC C-index 0.760, 95% CI 0.756–0.763; UKB C-index 0.719, 95% CI 0.635–0.803), future atherosclerotic cardiovascular disease (0.696, 0.694–0.698; 0.643, 0.624–0.662), and future heart failure (0.787, 0.785–0.789; 0.768, 0.733–0.802). Through phenome-wide and genome-wide association studies, we identified candidate biological pathways for the prediction of increased risk, including changes in cardiac structure and function, and genes associated with cardiac structure, biological ageing, and metabolic syndrome.

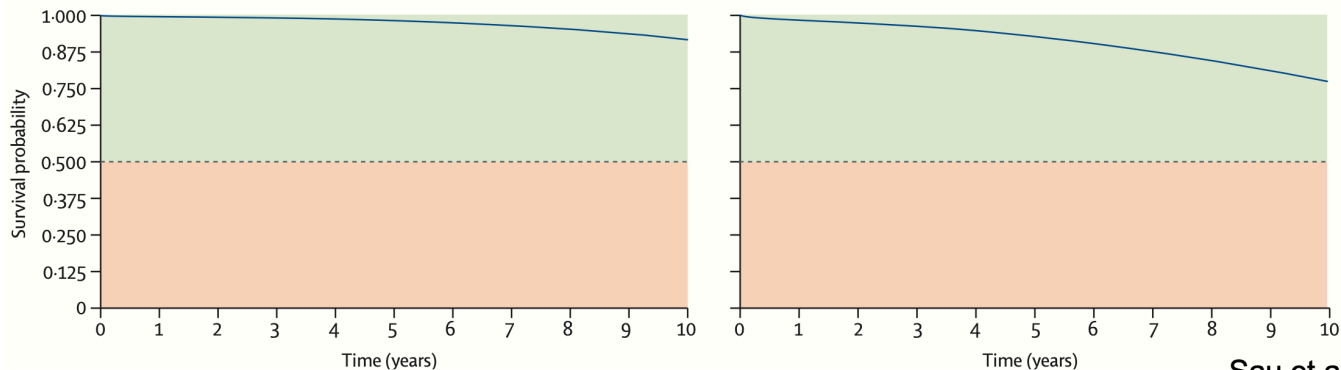
Interpretation AIRE is an actionable, explainable, and biologically plausible AI-ECG risk estimation platform that has the potential for use worldwide across a wide range of clinical contexts for short-term and long-term risk estimation.

AIRE Patient Specific Survival Prediction

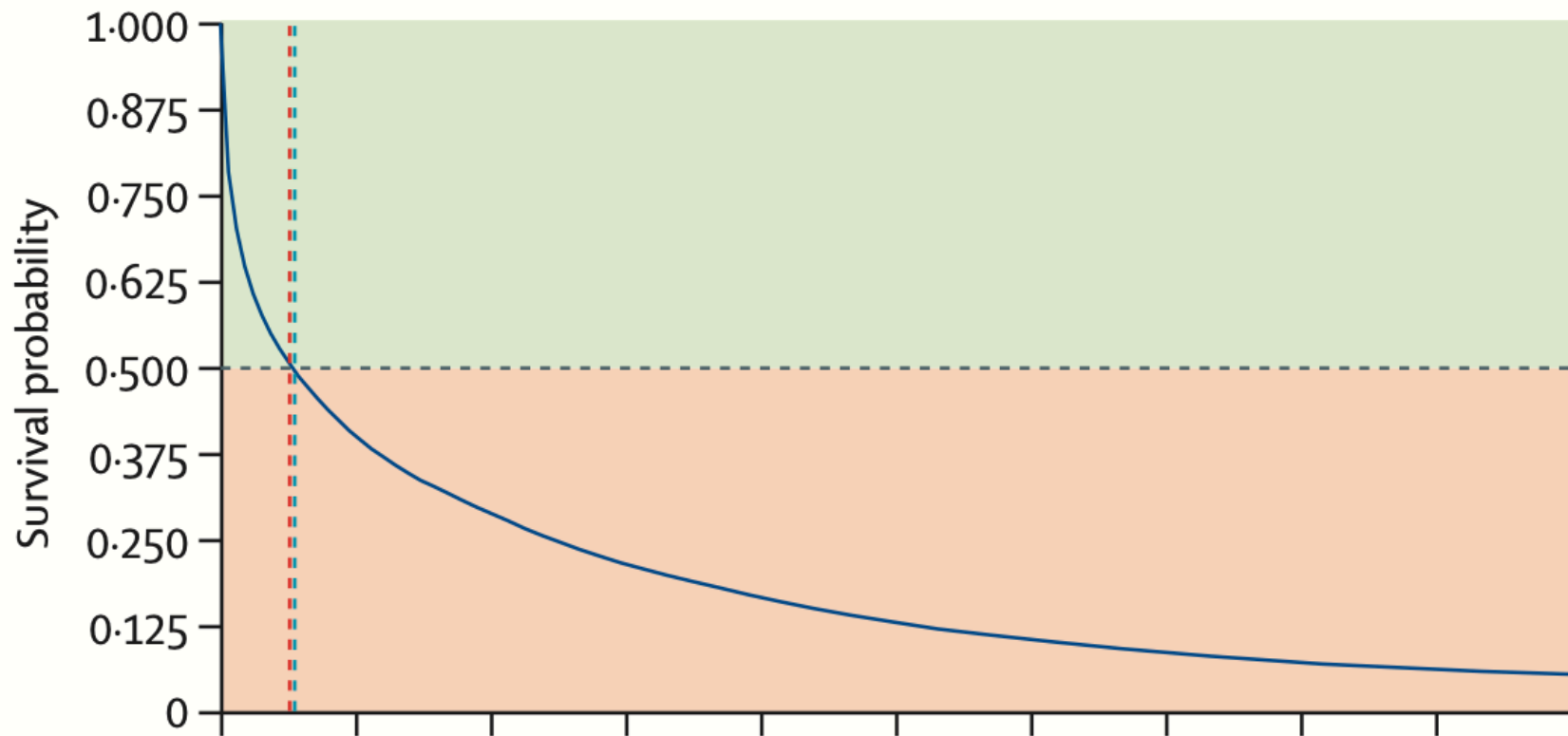
A AIRE patient-specific survival curves



B



AIRE Patient Specific Survival Prediction



A PROVOCATIVE QUESTION

CAN WE TRUST WHAT WE DO NOT UNDERSTAND?

FOR CENTURIES,
MEDICINE ANSWERED:

NO.



OBSERVATION



EXPLANATION



MECHANISTIC
UNDERSTANDING



?



TODAY, ARTIFICIAL
INTELLIGENCE CHALLENGES
THIS ASSUMPTION.

INCREASINGLY, THE ANSWER MAY BE:

YES.

A New Medical Epistemology

17th century

Understanding → Prediction

21st century

Prediction → Understanding

AI may generate hypotheses before mechanisms are discovered.

Take-home Messages

AI will not replace cardiologists

But

- The role of cardiologists will shift from information holder to interpreter, integrator and ethical decision-maker
- Cardiologists who master AI will replace cardiologists who do not

We desperately need AI-literate Doctors !!



Segreteria Master COREP
Tel. 011 6399 206/223/353
Email: areamedica@corep.it



gaetanomaria.deferrari@unito.it