KU Leuven
Group Biomedical Sciences
Department Cardiovascular Sciences
Research Unit Hypertension and Cardiovascular Epidemiology

Artificial intelligence in cardiac imaging

Nicholas Cauwenberghs, Ph.D.

Academic career at KU Leuven, Belgium

BSc/MSc Biomedical Sciences (2009-2014)

└ **PhD in Cardiovascular Medicine** (2014-2019)

└ **Full-time postdoc researcher** (2019- ...)

"Europe's Most Innovative University since 2016"
(Reuters top 100)

Our research pillars

Healthy ➔ CV risk factors ➔ subclinical CV damage ➔ symptomatic CVD

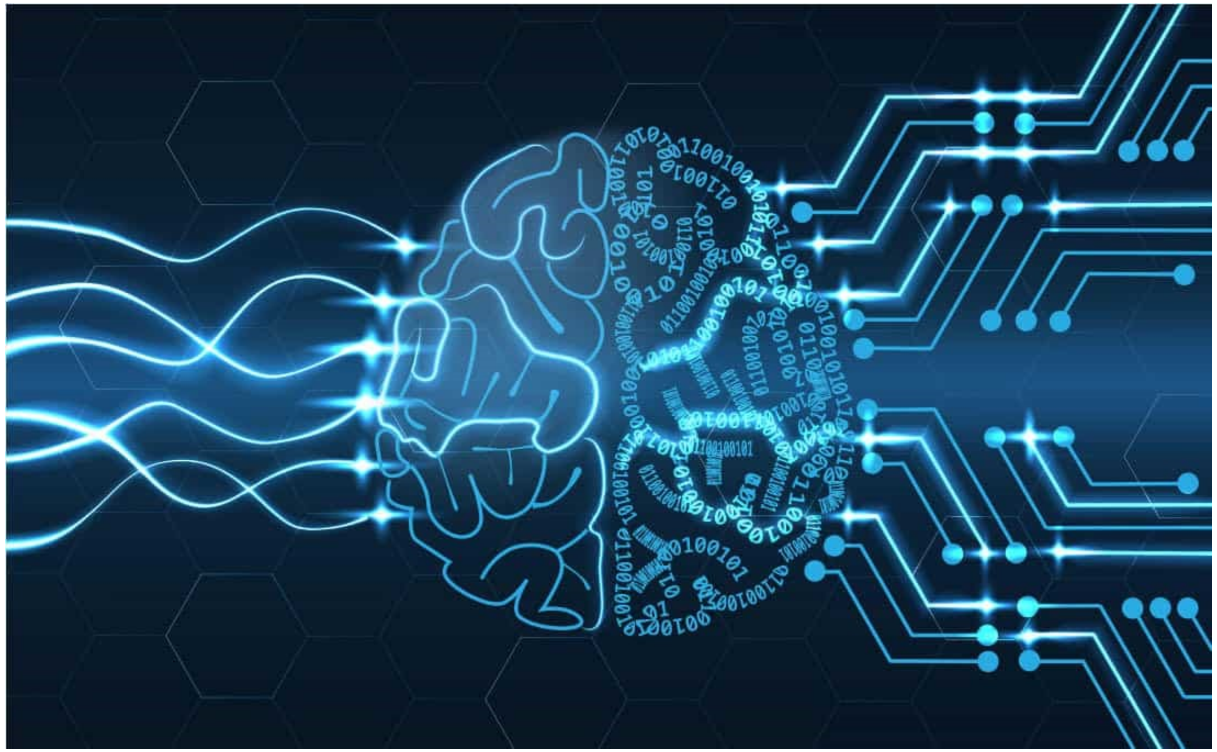
- Understand CVD pathogenesis
- Biomarkers for CV risk stratification and early disease detection
- Disease prophylaxis / therapy

AI in cardiac imaging

- **Introduction to AI**
- AI applications in cardiac imaging
- Challenges

Artificial intelligence (AI)

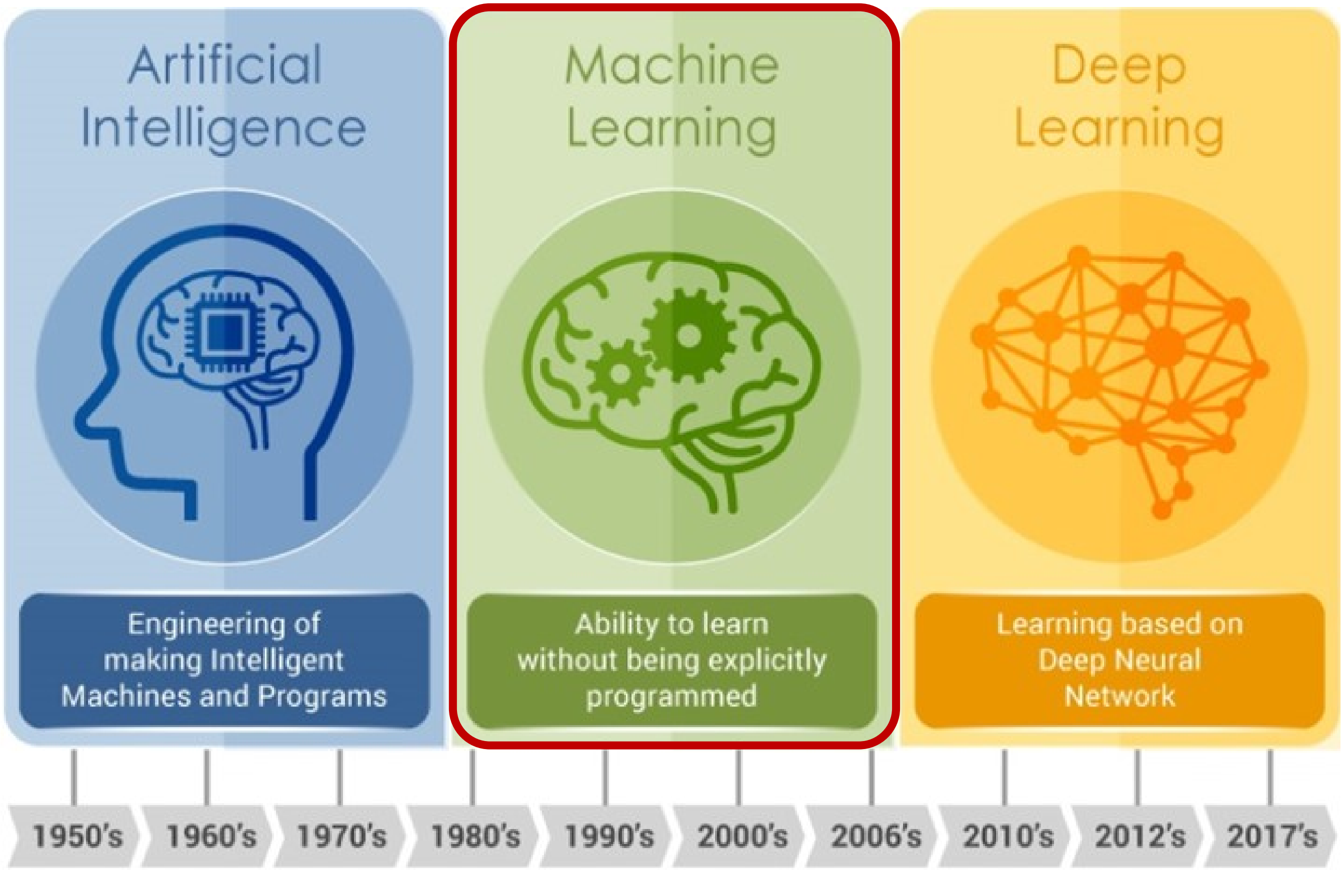
"The non-human ability to deal with cognitive complexity"[1]



[1] *Gottfredson L, SciAm. 1998*

Machine learning: the AI most used in medicine

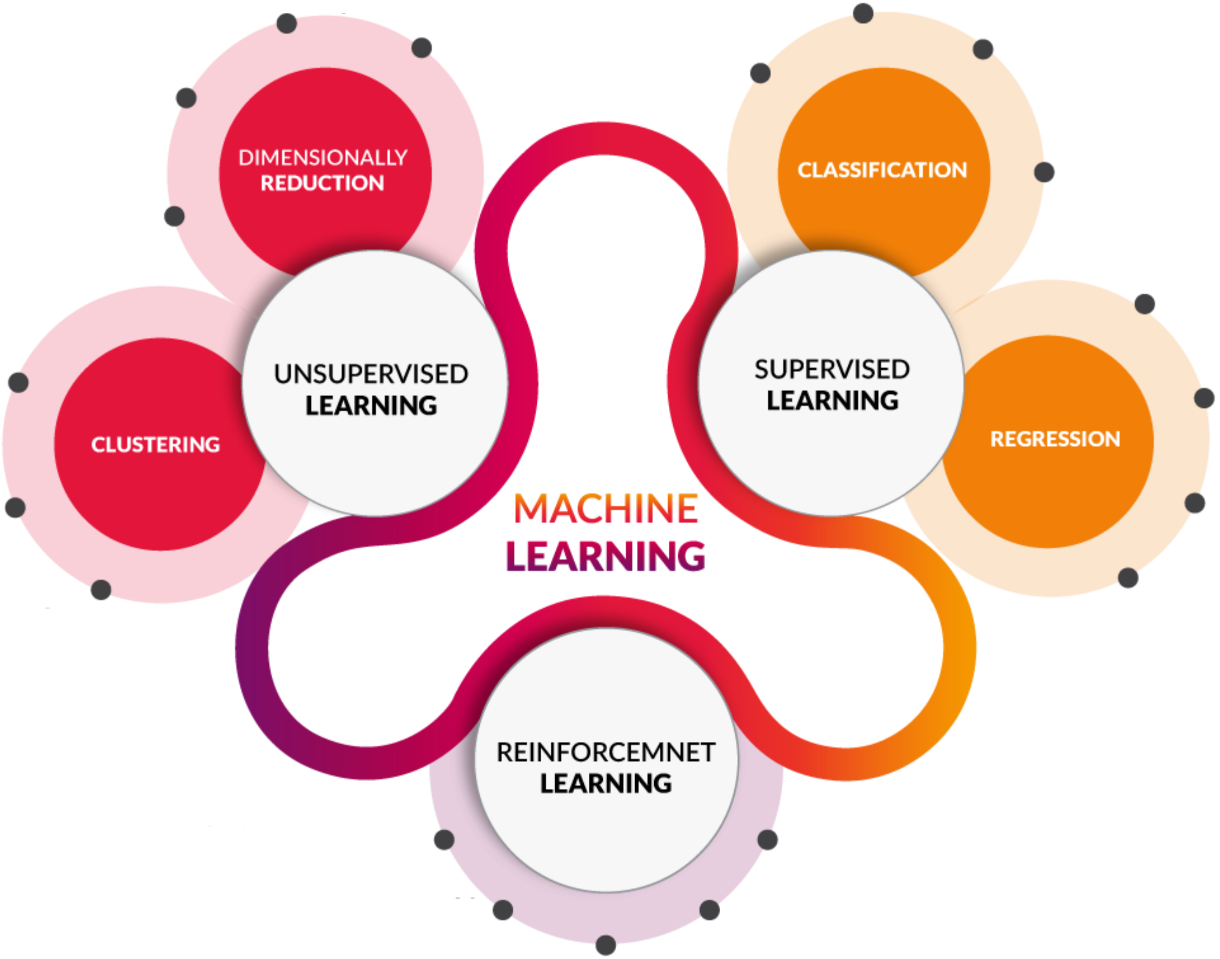
~~Rule-based systems~~



Learn by example

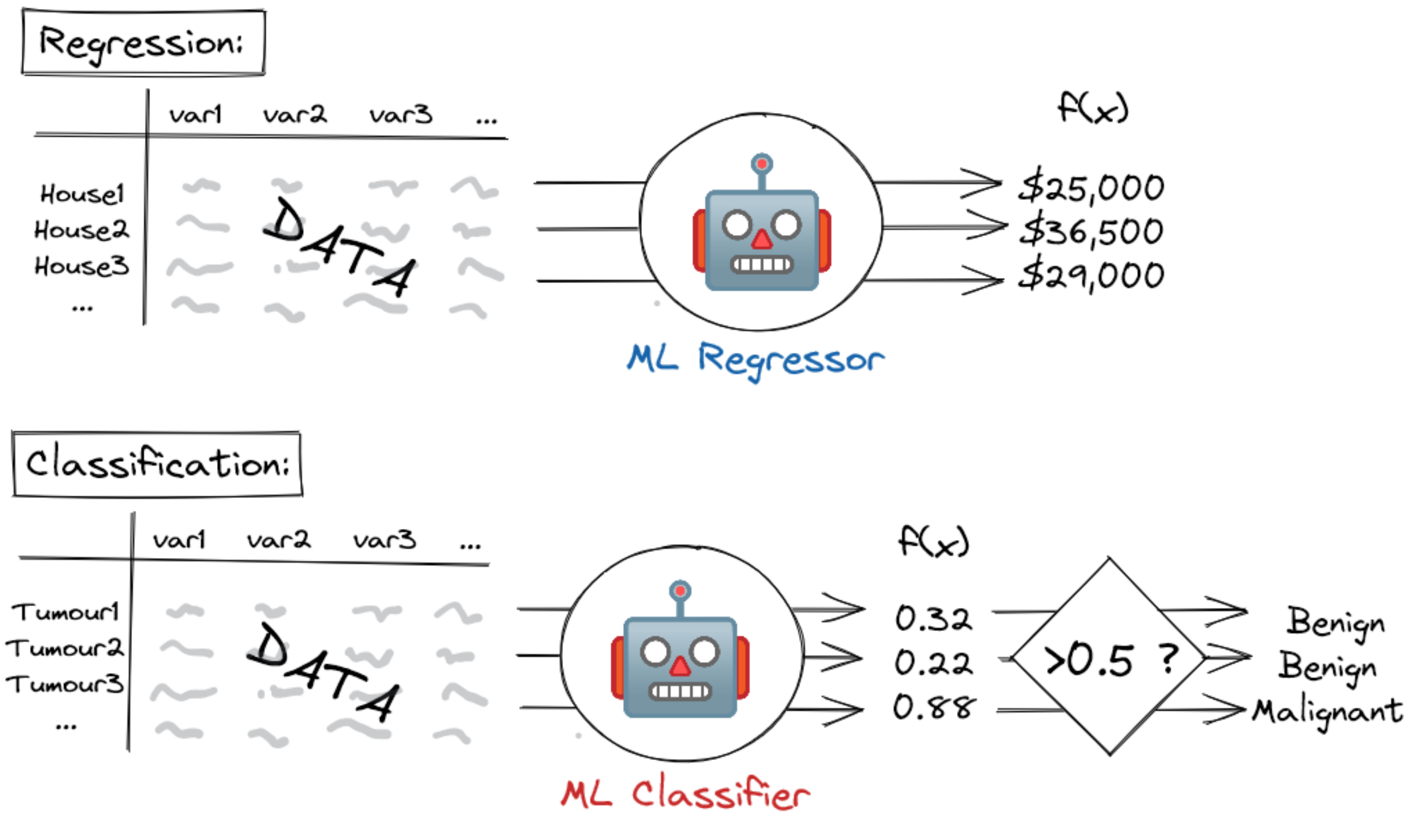
ML approaches

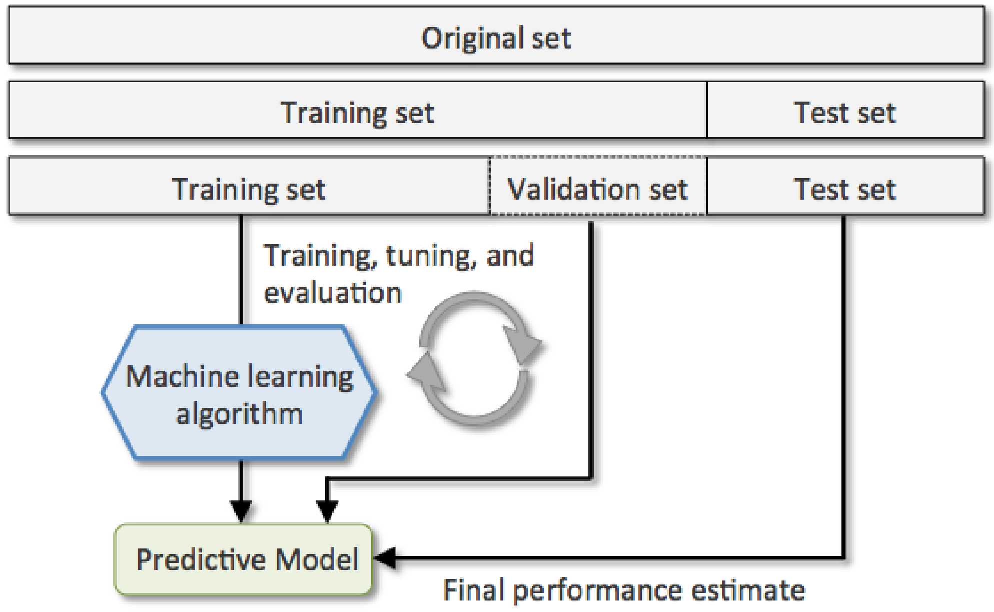
K-means clustering
K-nearest neighbours
Hierarchal clustering
Principle Component Analysis
…



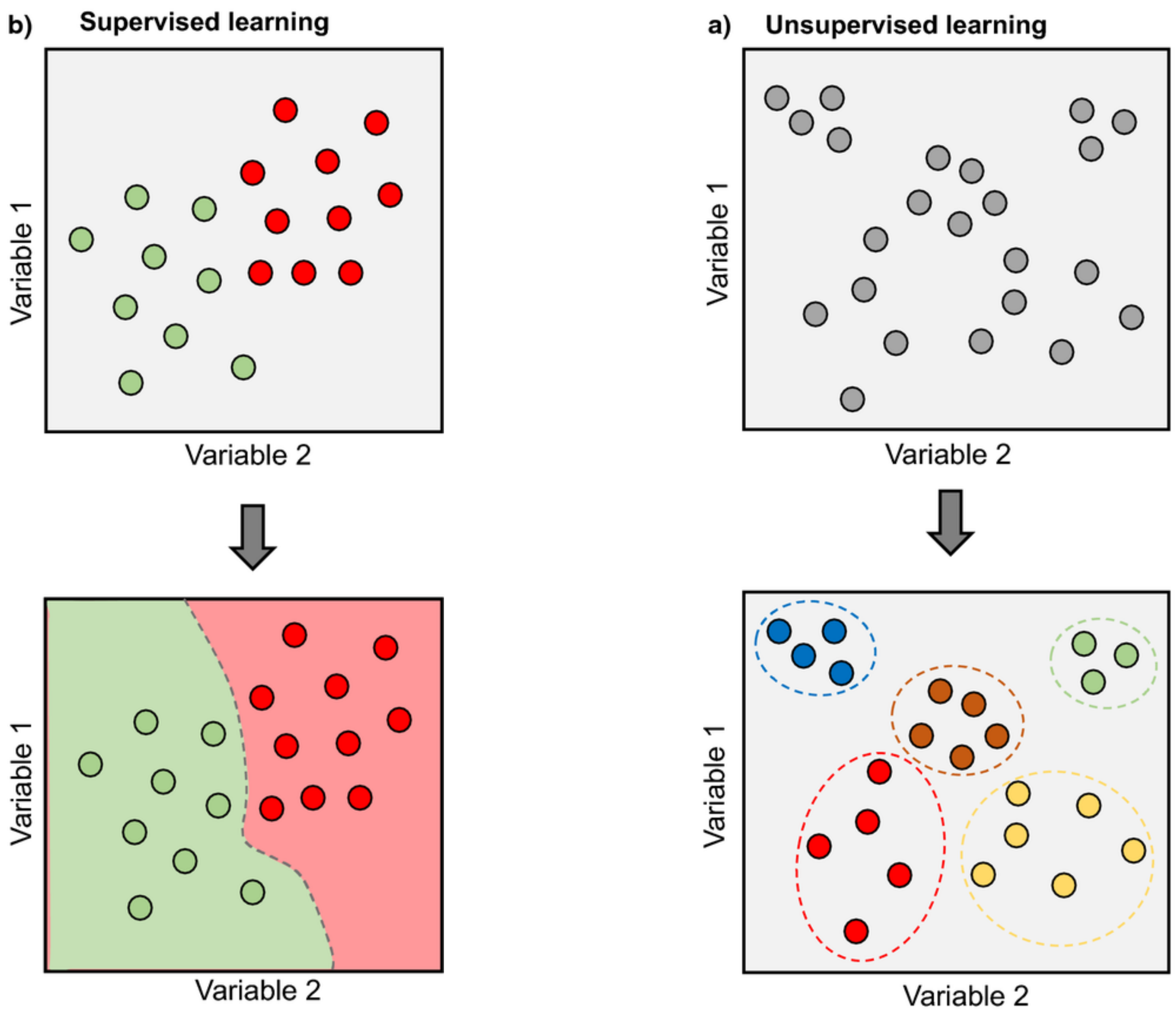
XgBoost
Random Forest
Support Vector Machines
Linear methods
…

Supervised ML: Regression or classification





Unsupervised ML: discover patterns / subsets



➔ Input data and # clusters ~ prior knowledge, supervised ML and metrics

➔ Validation by characterization

AI in cardiac imaging

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Why do we need AI in cardiology?

AI echocardiogram reports fully automated from a GE Vivid E95

By Us2.ai / 26 May, 2023 / Comments Off

- **Automation**
  e.g. echocardiographic imaging and post-processing
  ⇔ €€€, time-consuming, injuries!

- **Reduce clinical complexity:** Interpret ever complex data
  e.g. wearables, -omics, ..

- **Accurate risk / diagnosis / prognosis / management**
  e.g. cardiovascular disease predicted from routine clinical data[2]

[1] *For instance, see EchoGO, us2.ai and others*
[2] *Sabovčik F, EHJ Cardiovasc Imaging. 2020*

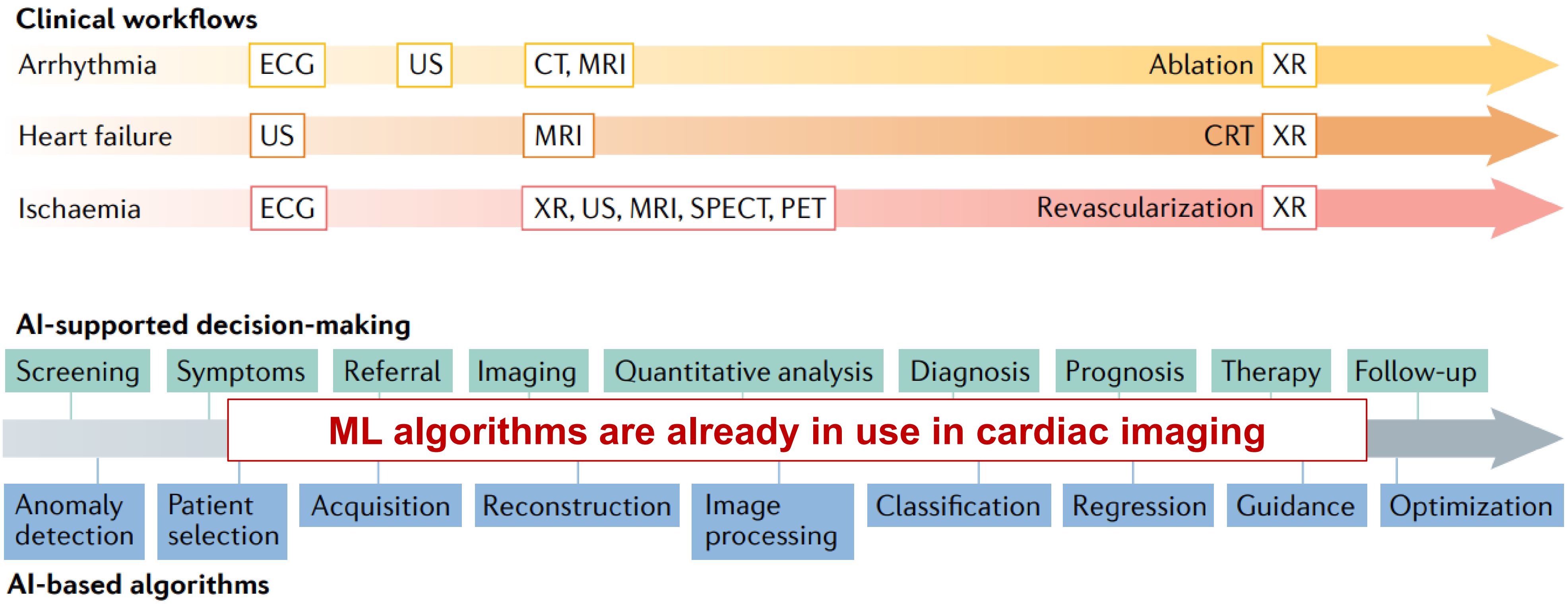
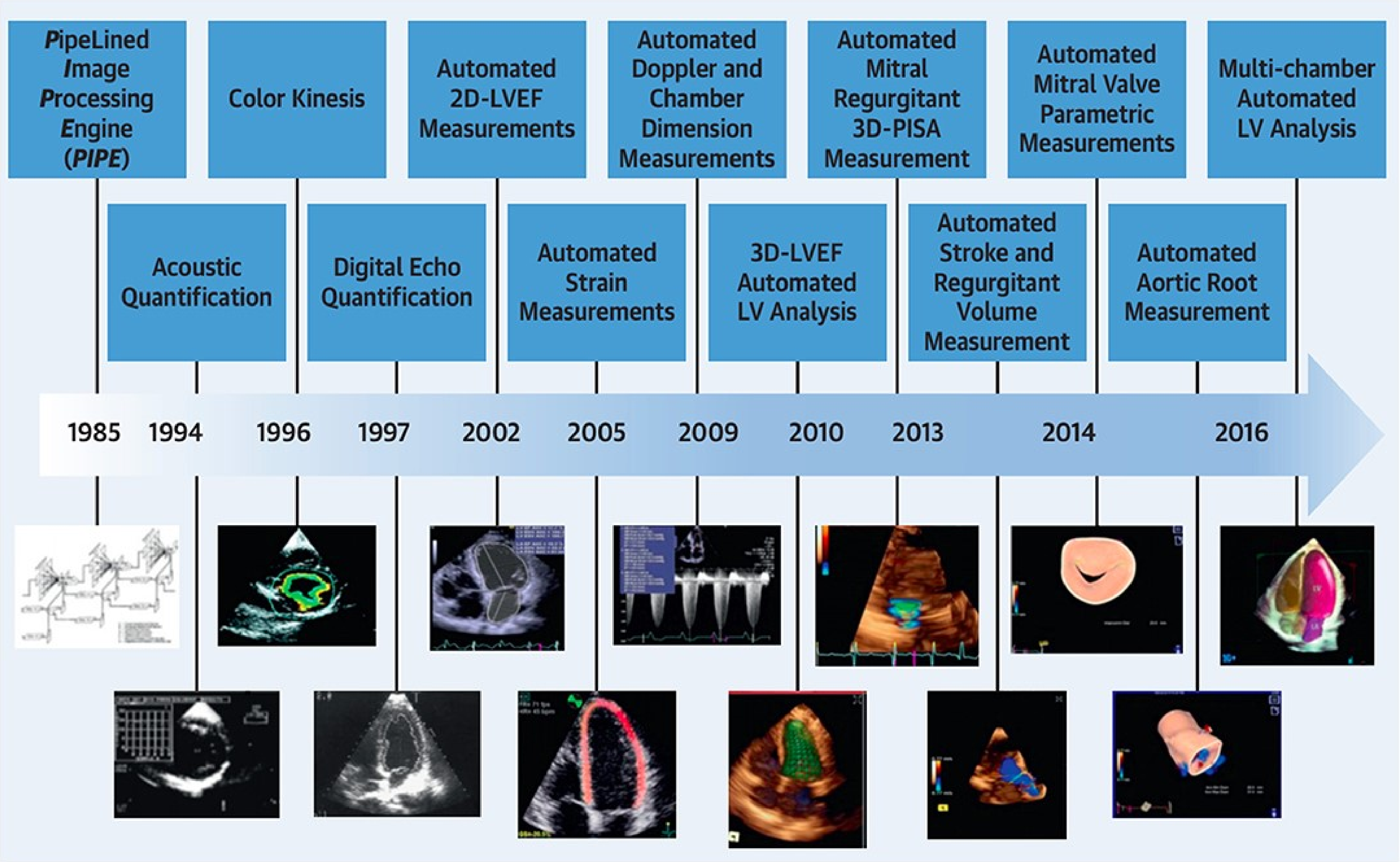


Fig. 1 | **Clinical workflow, AI-based algorithms and AI-supported decision-making.** A patient's pathway through the clinical workflow often includes the acquisition of a number of cardiovascular images with the use of various imaging modalities. Artificial intelligence (AI) can contribute to many of the required steps to acquire, reconstruct and process these images to achieve AI-supported decision-making. CRT, cardiac resynchronization therapy; ECG, electrocardiogram; SPECT, single-photon emission CT; US, ultrasonography, XR, radiography.

AI powered cardiac imaging



AI powered cardiac imaging

	Aim of study	AI algorithm or commercial technique	Detail method/software	Diagnostic Efficiency[a]	Reference
Section recognition/ image acquisition	Automatic classification of cardiac views	AI algorithm	CNN	ACC = 98.3%	Ultrasound Med Biol, 2019 [19]
		AI algorithm	CNN	ACC = 97.8%	NPJ Digital Med, 2018 [12]
Segmentation	Left ventricular segmentation (provide accuracy improvement of the endocardial boundary recognition)	AI algorithm	Ant colony optimization	N/A	Biomed Mater Eng, 2014 [13]
		AI algorithm	Radial active contour method Snake	N/A	Comput Methods Programs Biomed, 2014 [20]
		AI algorithm	Iterative 3-D cross-correlation algorithm	N/A	Ultrasound Med Biol, 2014 [21]
		AI algorithm	Ant colony optimization	N/A	Biomed Mater Eng, 2014 [13]
	Right ventricular segmentation	AI algorithm	Sparse matrix transform/ wall thickness constraint feature	Dice = 90.8% (epicardial boundary), 87.3% (endocardial boundary)	Phys Med Biol, 2013 [22]
	Atrial and multi-chamber heart segmentation	AI algorithm	Active shape model/ fusion-imaging technology	Mean dice = 83.3% ~ 91.3% (LV)	Ultrasound Med Biol, 2015; IEEE Trans Ultrason Ferroelectr Freq Control, 2015 [23, 24]
LV assessment	Assessment of left heart function	Commercial technique	HeartModel (Philips)	r = 0.87 ~ 0.96/ r = 0.98	JACC: Cardiovascular Imaging, 2016; J Am Soc Echocardiogr, 2017 [25, 26]
		Commercial technique	AutoLV (TomTec Imaging system)	ICC = 1.0	J Am Coll Cardiol, 2015 [27]
		Commercial technique	AutoEF (BayLabs)	r = 0.95	Circ Cardiovasc Imaging, 2019 [28]
		AI algorithm	3D CNN	AUC = 0.92	J Am Soc Echocardiogr, 2020 [29]
		AI algorithm	PWC-Net	ACC = 97% ~ 98%	JACC Cardiovasc Imaging, 2021 [30]
		AI algorithm	Neural network	Intraclass correlation = 0.86 – 0.95 (AI and physician), 0.84 (novice using AI and physician)	Circ Cardiovasc Imaging, 2021 [31]

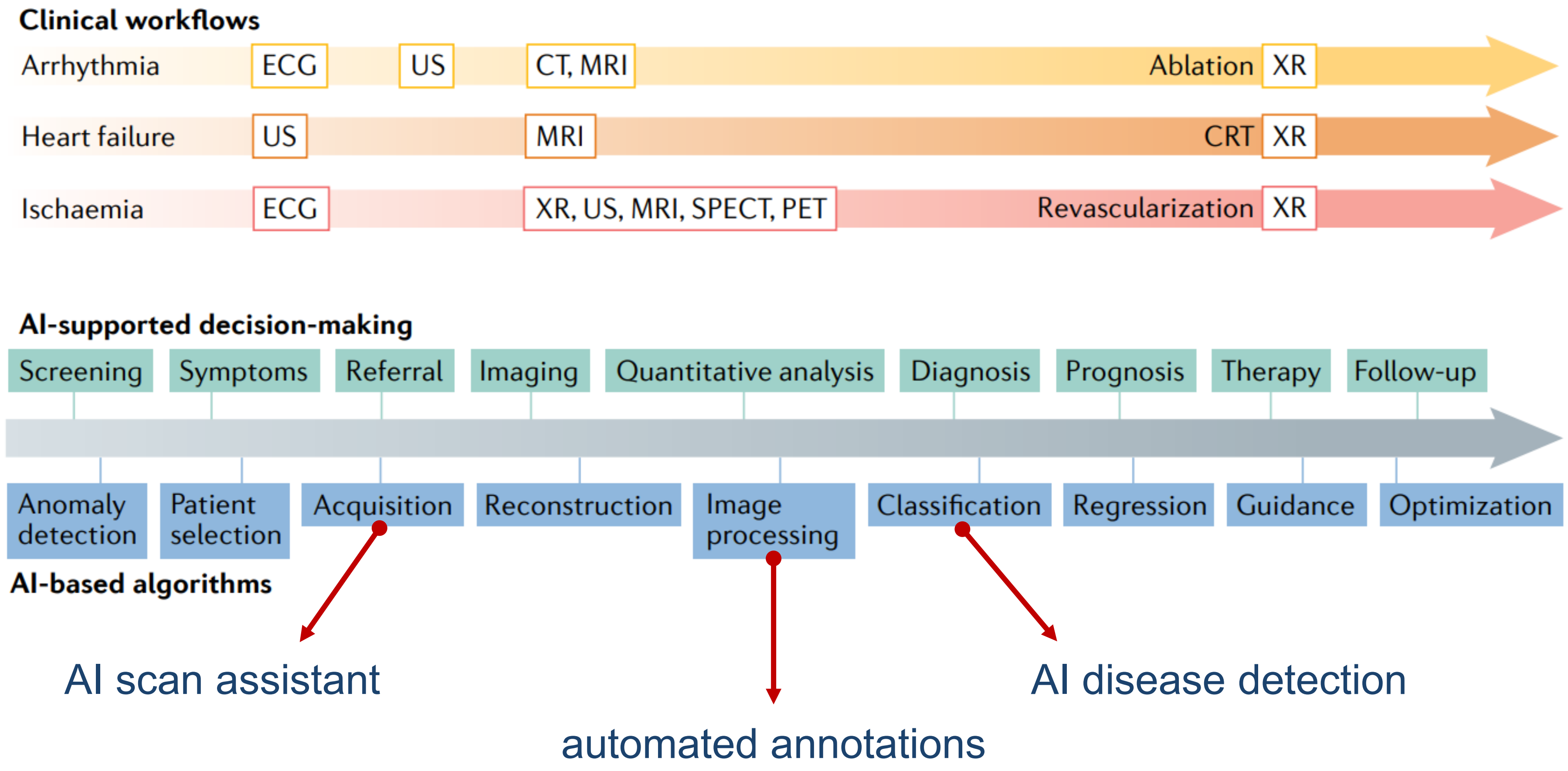
Zhou J, Cardiovascular Ultrasound 2021

Cardiac disease diagnosis	Valvular heart disease	Commercial technique	Proximal isovelocity surface area (PISA)	Intraclass correlation coefficients = 0.96	Circ Cardiovasc Imaging, 2013; J Am Soc Echocardiogr, 2012 [32, 33]
		Commercial technique	Real-time 3D volume color-flow Doppler (RT-VCFD)	*r* = 0.93	Int J Cardiovasc Imaging, 2015 [34]
		Commercial technique	Mitral Valve Navigator (Philips)	N/A	Echocardiography, 2016 [35]
		Commercial technique	Anatomical Intelligence in ultrasound (AIUS)	ACC = 89%	J Am Soc Echocardiogr, 2016 [36]
		AI algorithm	Anatomical affine optical flow	Intra- and interobserver variability = 0.85 and 0.65	Int J Cardiovasc Imaging, 2019 [37]
		AI algorithm	2D/3D CNN	Sensitivity (Recall) = 67%, PPV = 74% ~ 77%	Nat Commun, 2021 [38]
	Cardiomyopathy	Commercial technique	Myocardial strain analysis	N/A	Circ J, 2019 [39]
		AI algorithm	Associative memory classifier	AUC = 89.2%	Circ Cardiovasc Imaging, 2016 [40]
		AI algorithm	Support Vector Machine	AUC = 77.8%	AMIA Annu Symp Proc, 2014 [41]
	Coronary atherosclerotic heart disease	AI algorithm	discrete wavelet transform and texture feature analysis	AUC = 90% ~ 99%	JACC Cardiovasc Imaging, 2019 [42]
		Commercial technique	EchoPAC PC (GE)	*r* = 0.67 ~ 0.99	Echocardiography, 2015 [43]
		AI algorithm	A specialised software for MCE quantification	Sensitivity = 77% Specificity = 94%	Ultrasound Med Biol, 2017 [15]
		AI algorithm	Texture analysis	Highest accuracy = 79%	IEEE, 2016 [44]
	Intracardiac masses	AI algorithm	Feed-forward neural network	Accuracy = 91%	Comput Med Imaging Graph, 2006 [45]
		AI algorithm	Gray level co-occurrence matrix-based features/ ANN (Classification)	Mean sensitivity = 0.955 Specificity = 0.970	J Ultrasound Med, 2014 [46]

AI in cardiac imaging

- Introduction to AI
- AI applications in cardiac imaging:
  - **Automation for workflow optimization**
  - Integrative profiling for CV disease prediction / diagnosis / prognosis
- Challenges

Workflow optimization and education



https://www.youtube.com/watch?v=u37dF-dCH_0

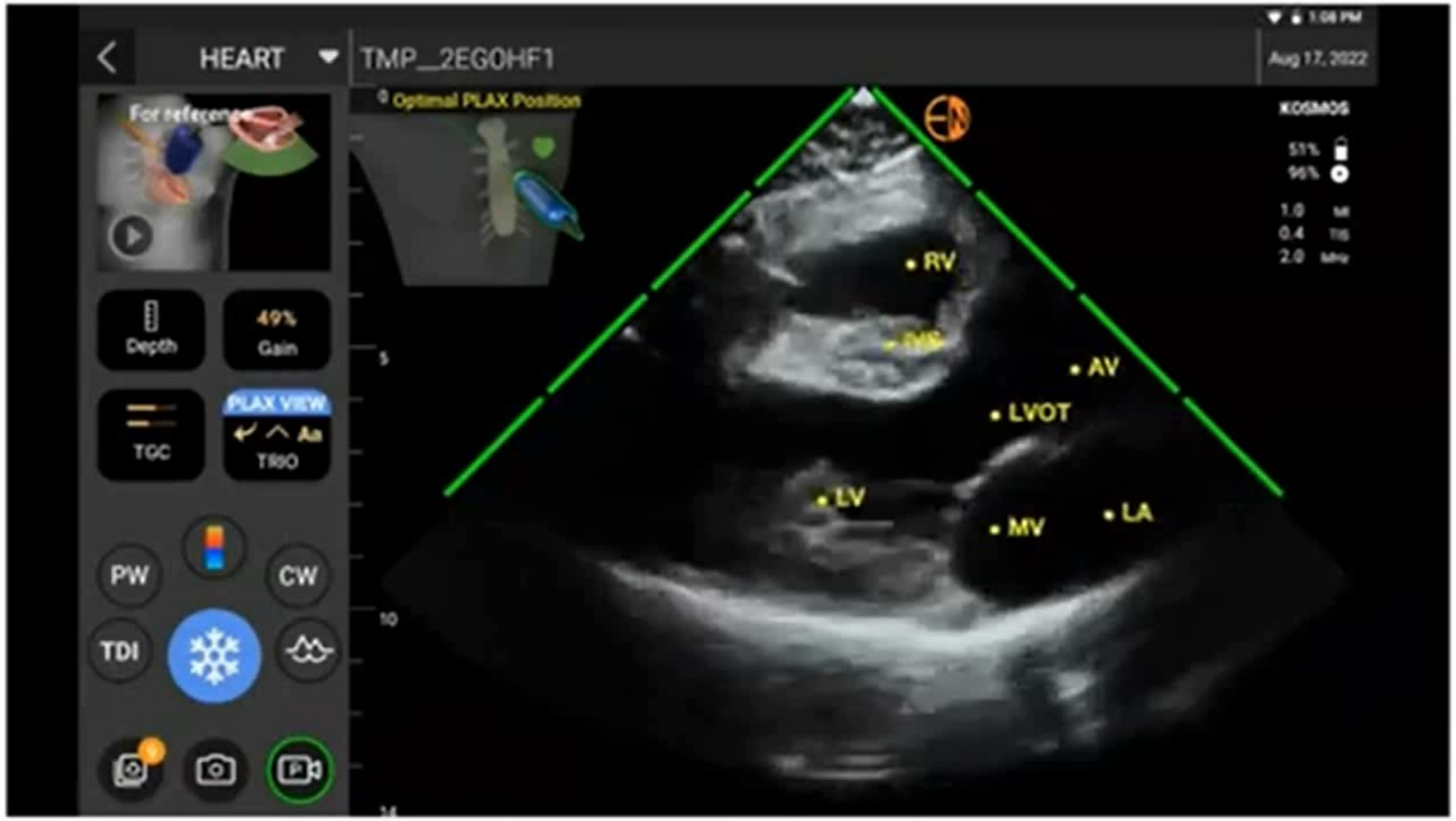
AI scan assistant

TRIO

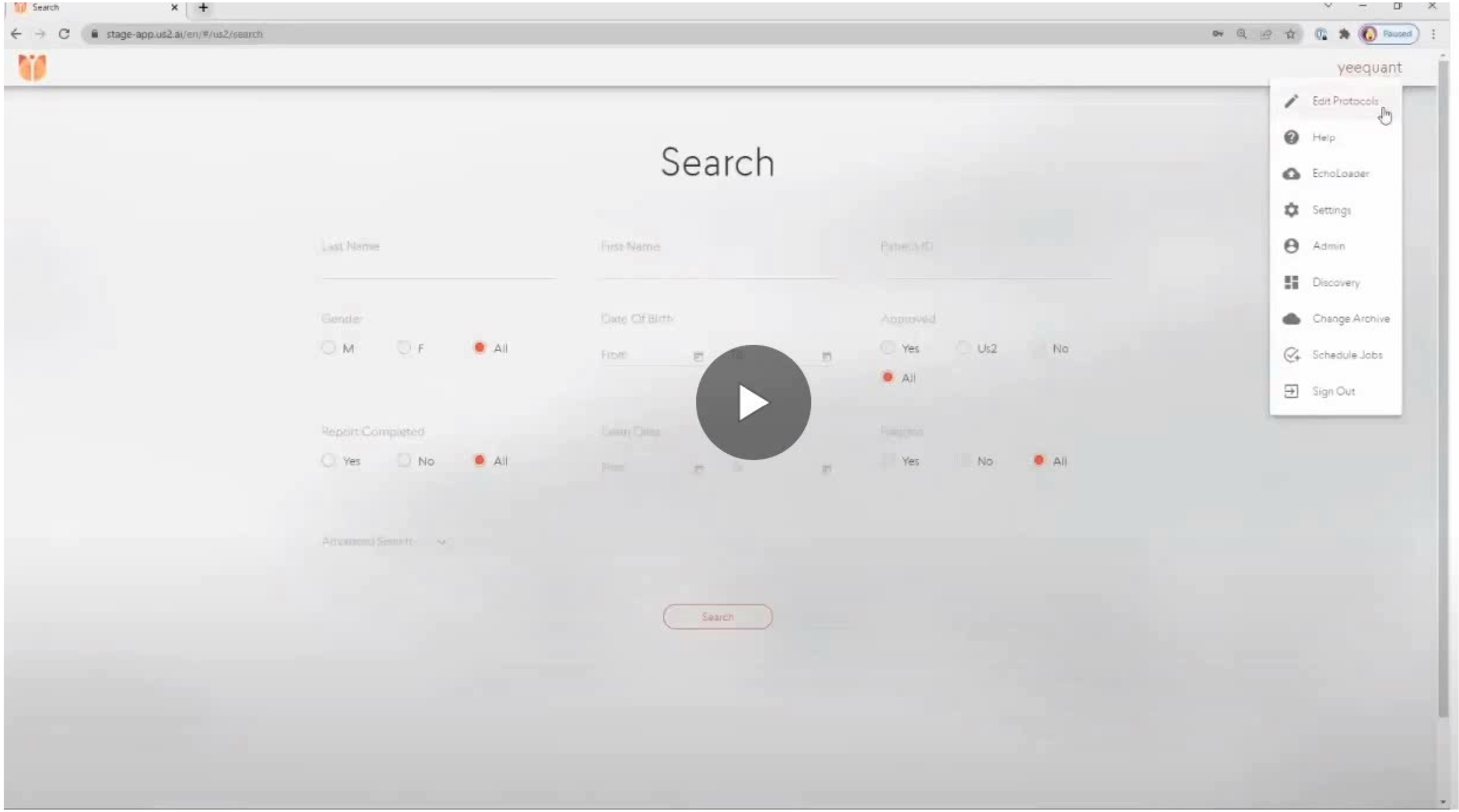
Automated grading, guiding, and labeling

Our AI TRIO helps scanners move quickly from novice to expert. Our anatomical detection techniques offer real time guidance for probe positioning in cardiac and FAST examinations. The highlighted bar system shows when you are in the optimal plane for measurement purposes or for assessing anatomical structures

- True scanning guidance in real-time
- Fast & accurate identification of cardiac structures
- Real-time grading of image quality
- Drive repeatability and reproducibility of key clinical measurements
- Accelerates user learning curves and improve confidence
- Provides data to support evidence based decision making



Fully automated echocardiogram interpretation and reporting



AI disease detection from echocardiography

Heart failure (HF)
HF with reduced ejection fraction | HF with mildly reduced ejection fraction | HF with preserved ejection fraction

Pulmonary hypertension & right heart failure

Hypertrophic cardiomyopathy

Cardiac amyloidosis

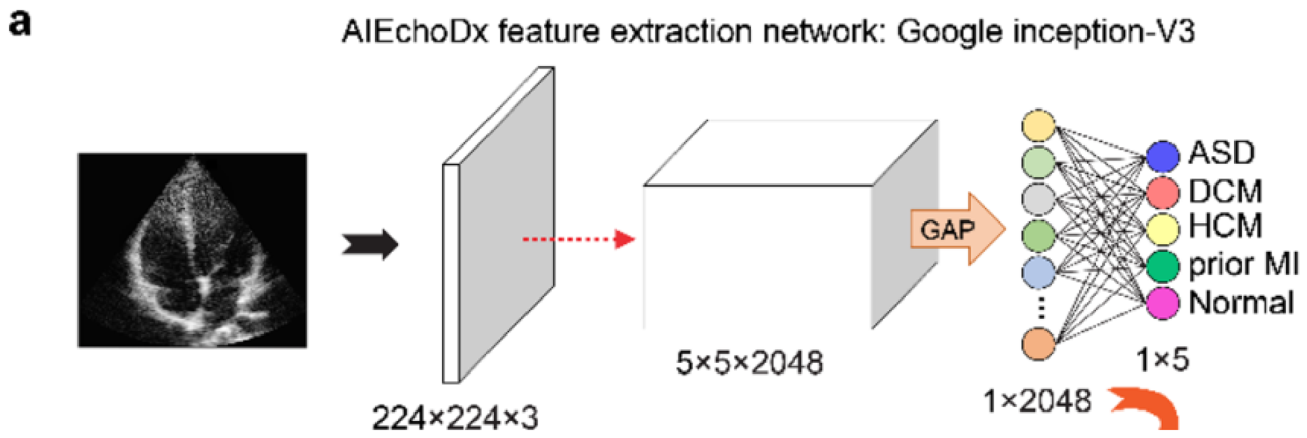
Valvular disease
Aortic stenosis | Mitral regurgitation | Tricuspid regurgitation

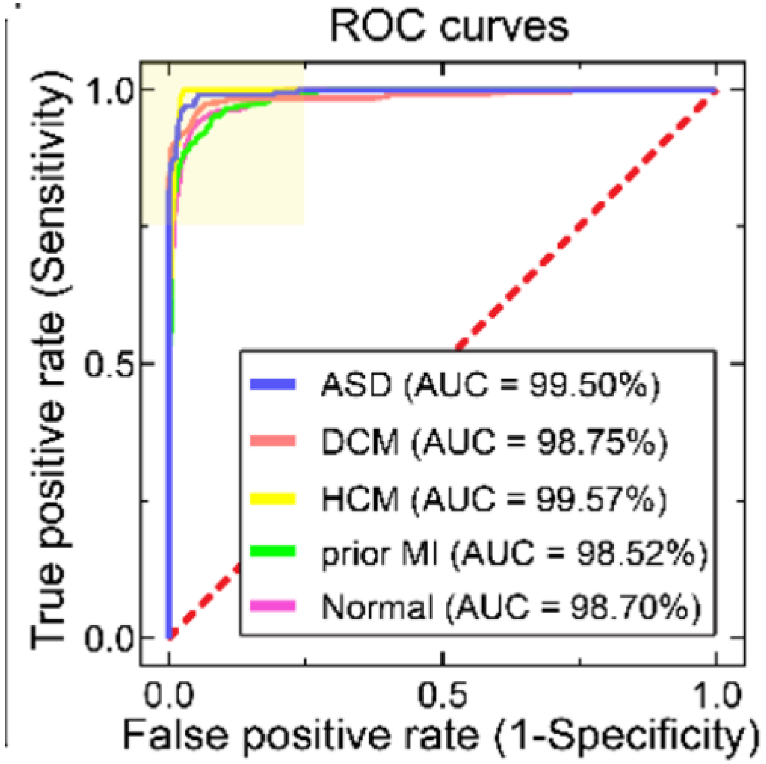
Ischemic heart disease (regional wall motion abnormalities)

Us2.ai software facilitates the possible detection of multiple disease conditions. All clinical conditions are $\boxed{\text{suggested based on international guidelines.}}$

US2.AI

AI disease detection from echocardiography





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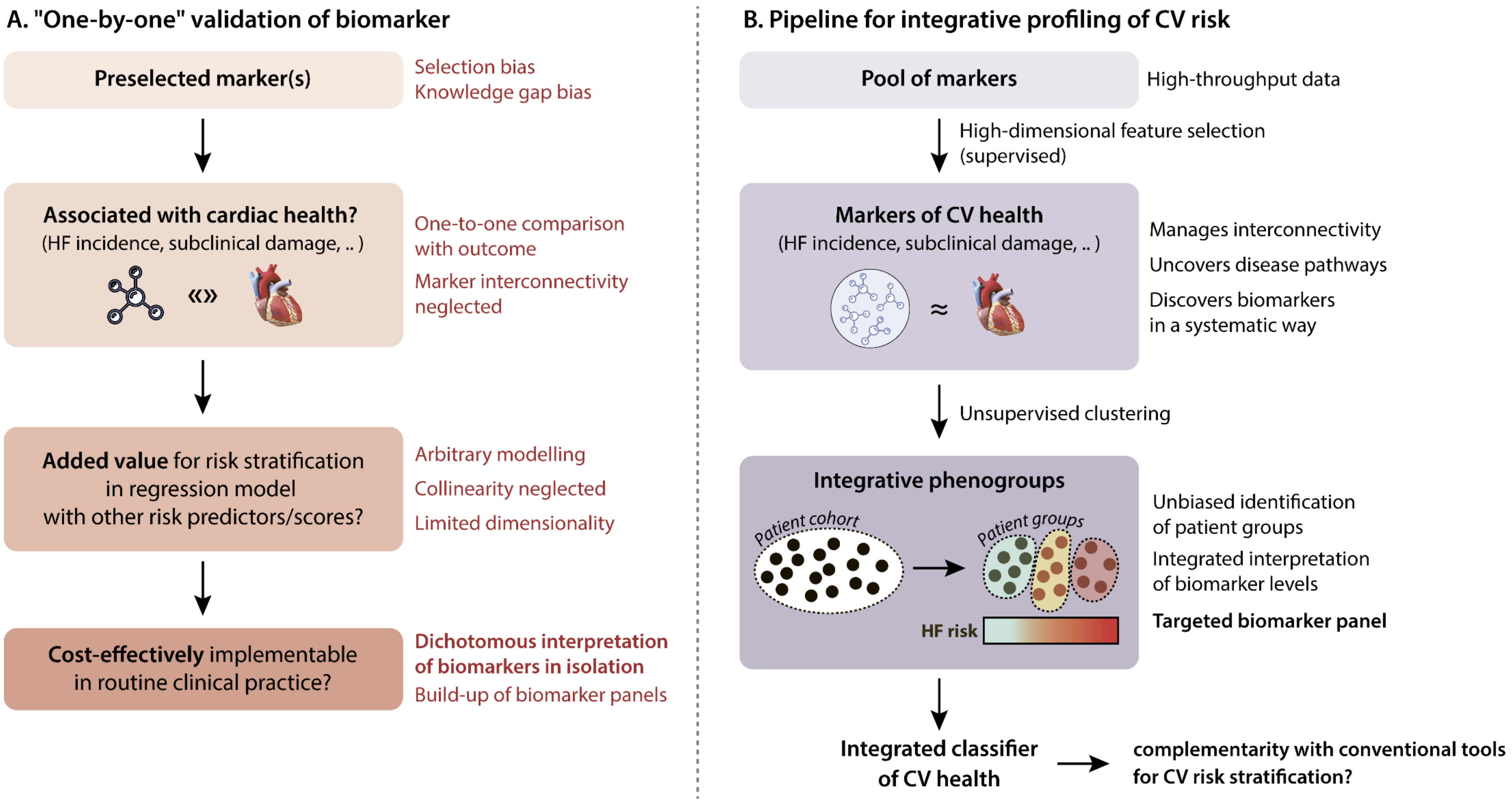
  - **Integrative profiling** for CV disease prediction / diagnosis / prognosis
- Challenges

Integrative profiling of cardiac health



CVD risk stratification based on routine clinical data

Patients with CV risk factors: Whom to refer to cardiac imaging?

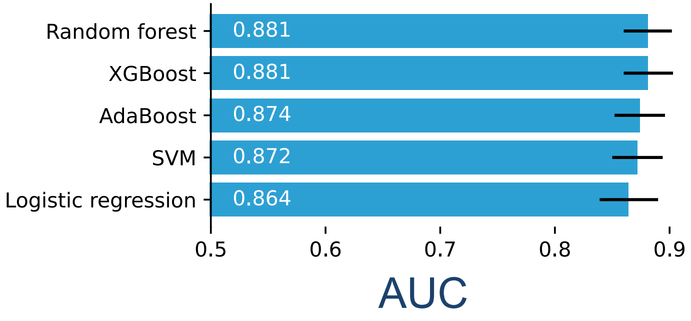
n=1407
(FLEMENGHO study)

Routine clinical data
(BP, ECG, biochemistry)
67 features

Supervised ML

LV hypertrophy
LV diastolic dysfunction

Early LV diastolic dysfunction



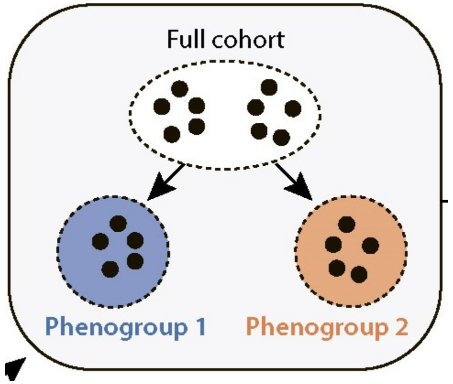
CVD risk stratification based on imaging data

How to interpret imaging data integratively and does it help predict future CV events?

n=1407
(FLEMENGHO)

21 echocardiographic / BP features

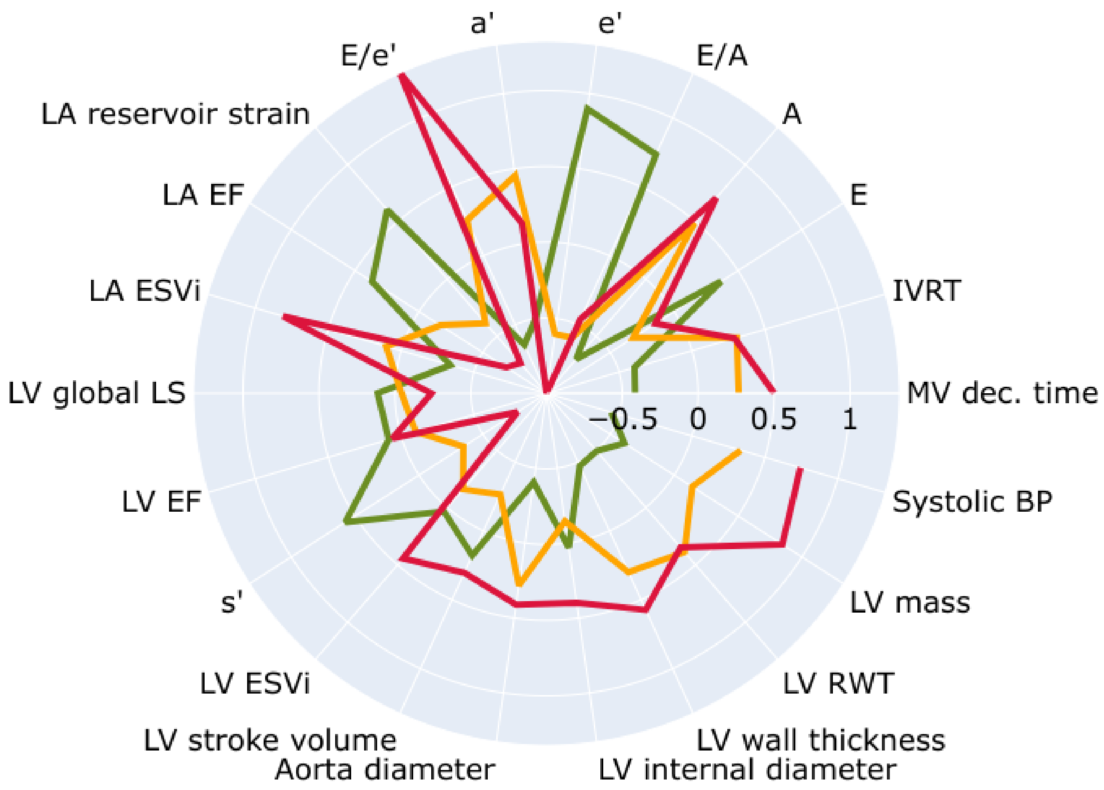
Unsupervised ML
(GMM)

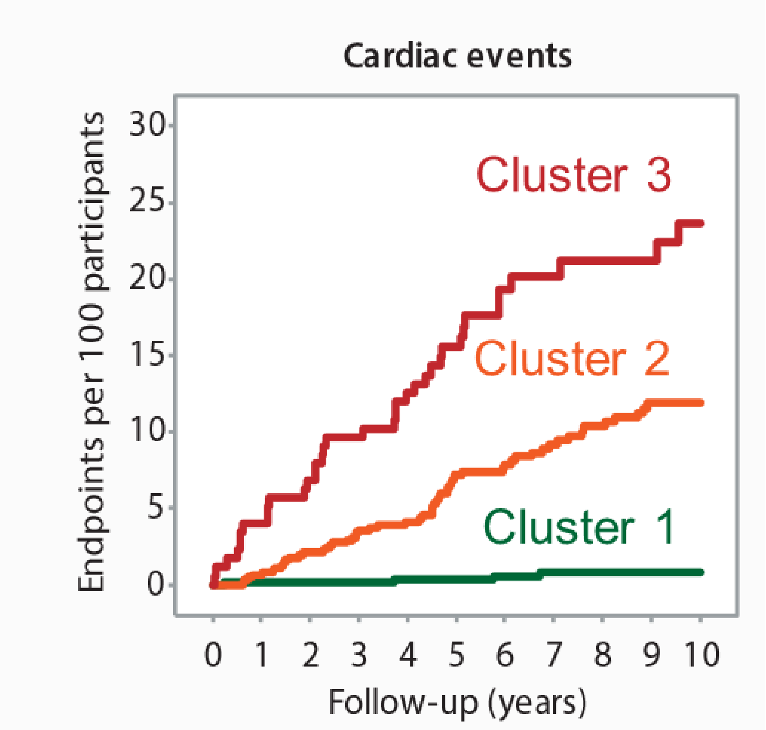


People clusters
('echo phenogroups')

predicting
CV events?

CVD risk stratification based on imaging data



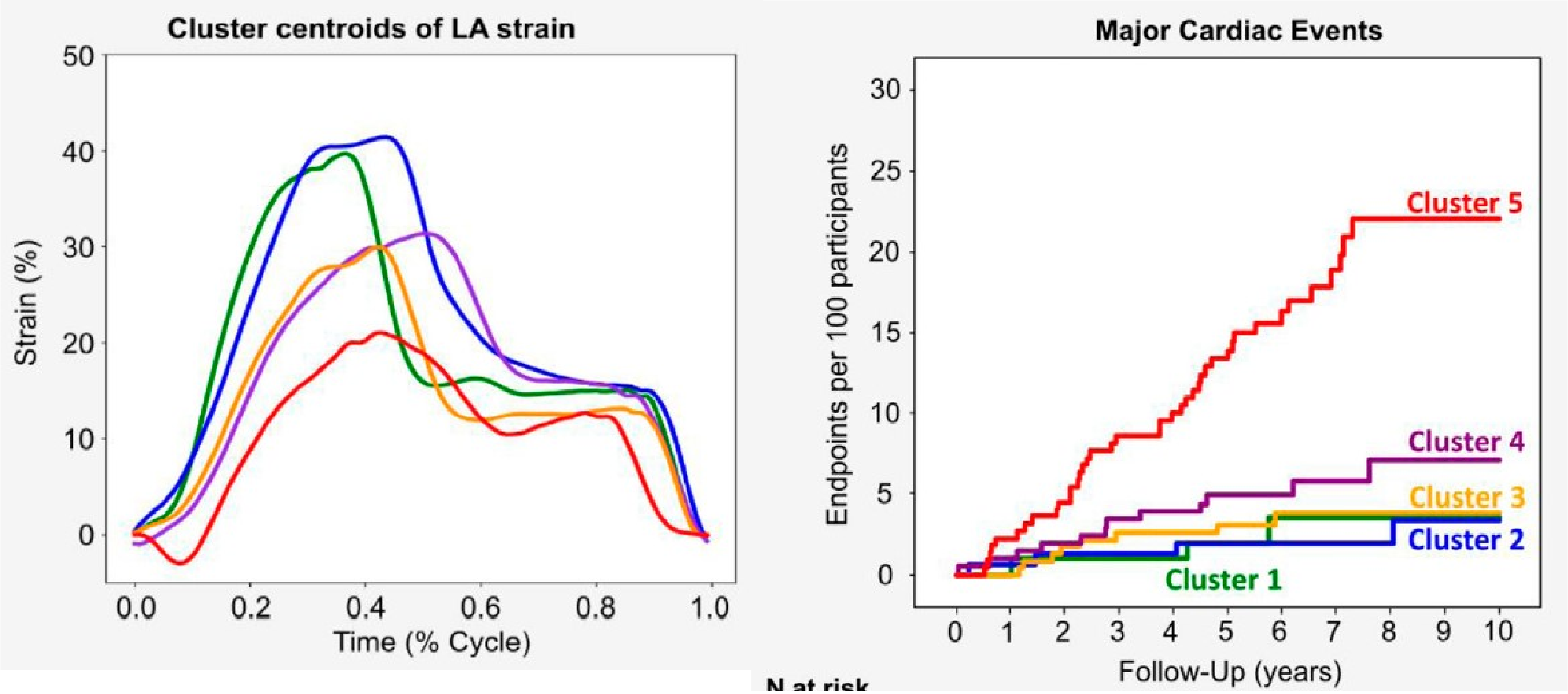


	Adjusted HR (95% CI)
Cluster 2 vs 1:	2.01 (1.86 - 3.50)
Cluster 3 vs 1:	1.84 (1.25 – 2.71)

CVD risk stratification based on imaging data

~ Echo time series

n=1407
(FLEMENGHO)



CVD risk stratification based on imaging data

How to interpret imaging data integratively and does it help predict future CV events?

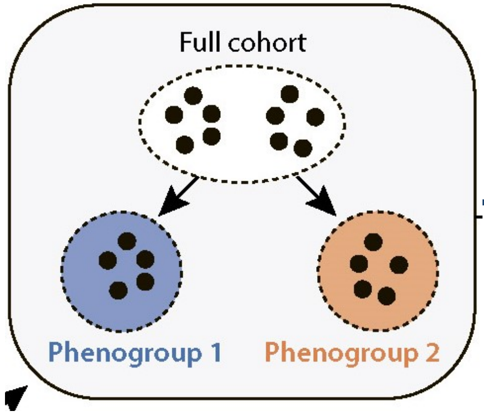
n=2280
(iCOMPEER)

Referred for CPET for various reasons

10 CPET features

Peak load, VO2/kg, HR,
O2 pulse, SBP and RER
VE/VCO2 slope
Borg score
%HR and %VO2 at VT1

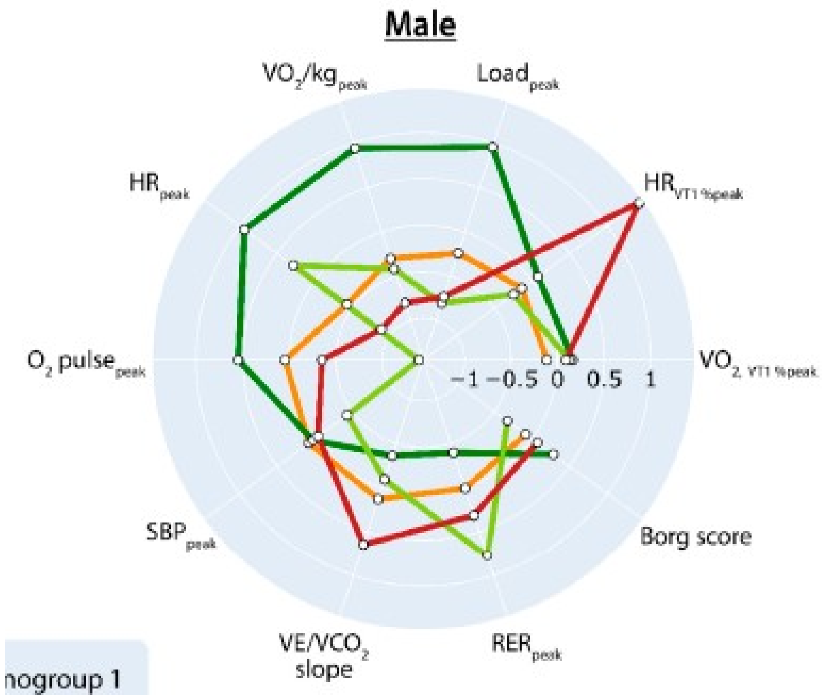
Unsupervised ML
(GMM)



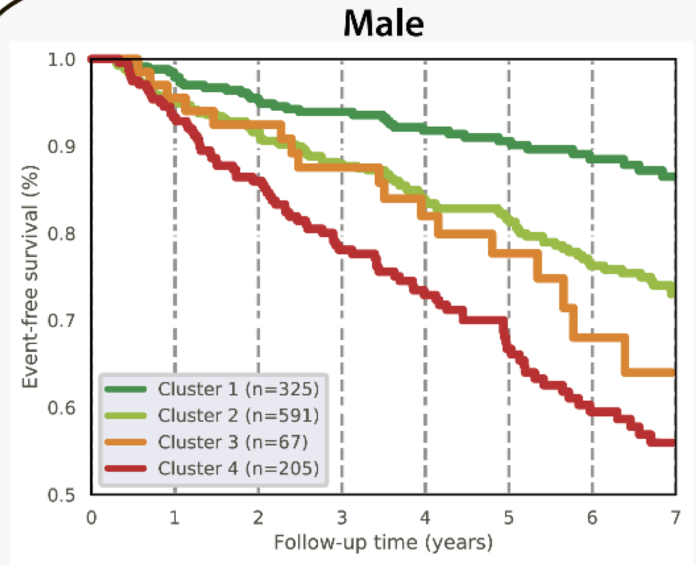
Patient clusters
(‘CPET phenogroups’)

Predicting
CV events?

CVD risk stratification based on imaging data



Incidence of cardiovascular events



<u>Adjusted HR (95% CI; *P* value) versus cluster 1</u>

Cluster 2 1.53 (0.90-2.60; *P*=0.11)

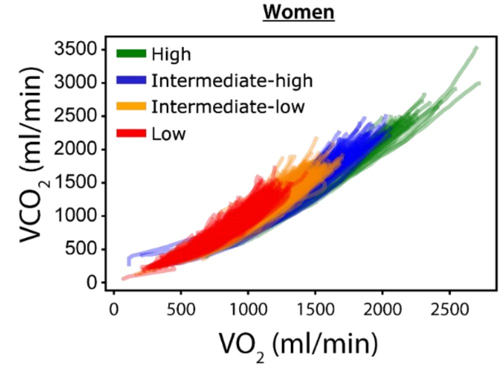
Cluster 3 1.51 (1.00-2.27; *P*=0.048)

Cluster 4 2.19 (1.31-3.66); *P*=0.0028)

Integrative CPET evaluation for CV risk stratification

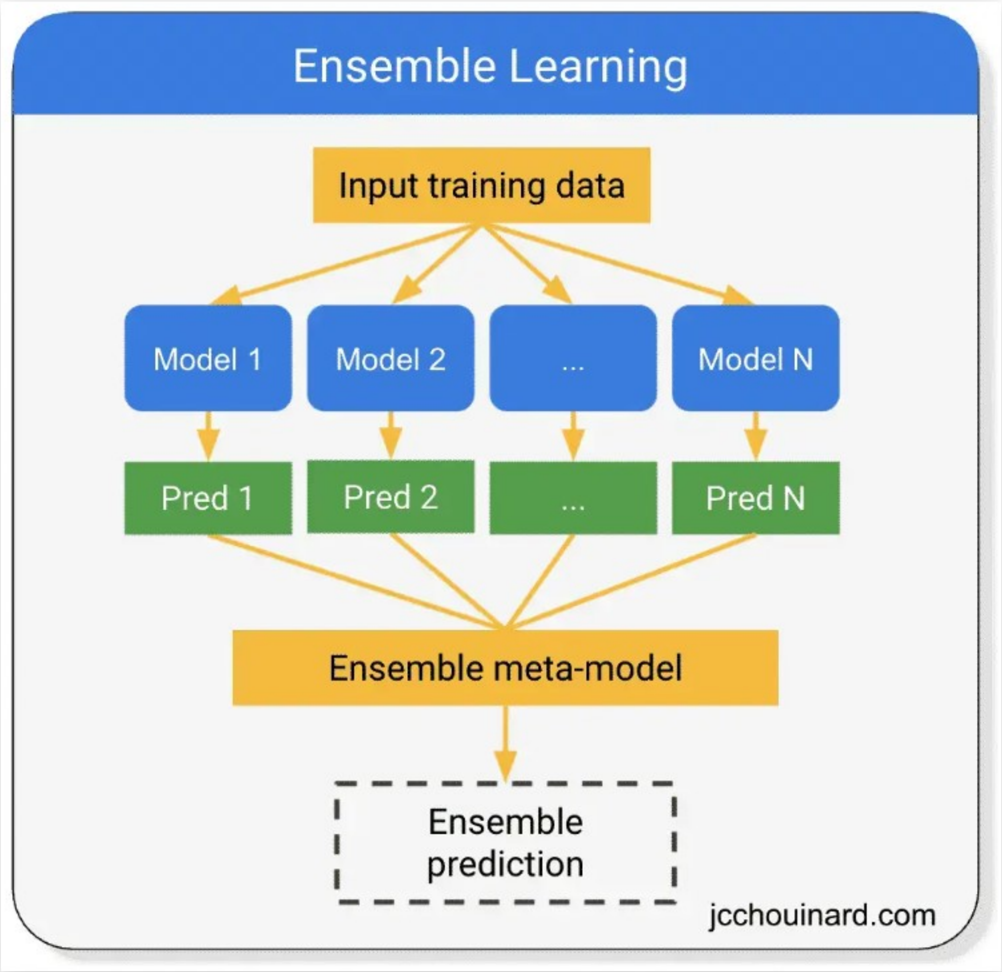
~ CPET time series

Phenogrouping using CPET raw data



Imaging-based phenogroups may improve CV risk stratification

The future: ensemble models



AI in cardiac imaging

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- **Challenges**

Challenges for AI in CV medicine

Clinical autopilot

Interaction engineers / clinicians

➔ bidirectional training

AI reporting and regulation

- engineer vs medical language
- methodology, QC, performance, ..
- Open code

Ethics

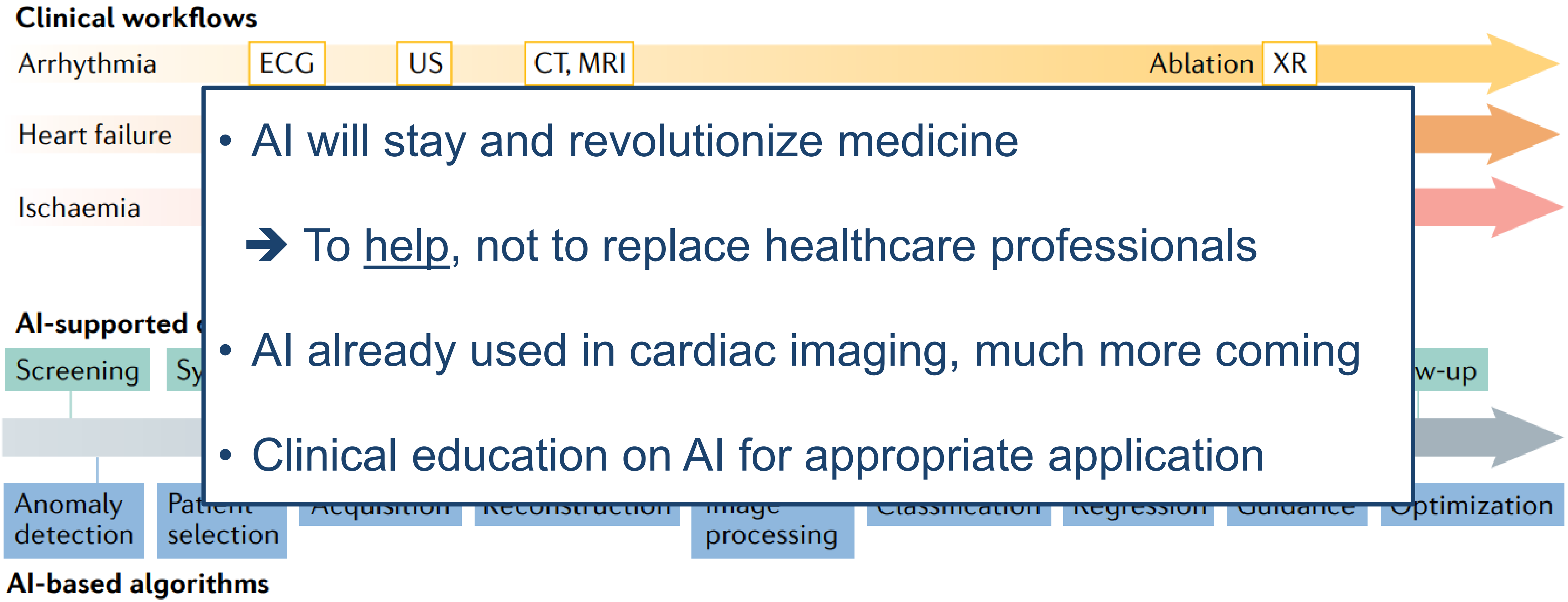
OPEN

Reporting guidelines for clinical trial reports for interventions involving artificial intelligence: the CONSORT-AI extension

Xiaoxuan Liu[1,2,3,4,5], Samantha Cruz Rivera[5,6,7], David Moher[8,9], Melanie J. Calvert[4,5,6,7,10,11,12], Alastair K. Denniston[2,3,4,5,6,13] and The SPIRIT-AI and CONSORT-AI Working Group*

Take-home messages

ESC on demand:
Artificial intelligence demystified
Can we trust artificial intelligence in cardiac imaging today?
Will AI replace cardiologists?



- AI will stay and revolutionize medicine

  ➔ To <u>help</u>, not to replace healthcare professionals

- AI already used in cardiac imaging, much more coming

- Clinical education on AI for appropriate application

Artificial Intelligence in Echocardiography: Workflow Efficiency & Patient Satisfaction

12:15 - 1:15PM EDT June 20th, 2021

CME & SDMS/CME Accredited Webinar

Jordan B. Strom
MD, MSc, FACC, FASE
Harvard Medical School
Boston, MA

Patricia A. Pellikka
MD, FACC, FAHA, FASE
Mayo Clinic
Rochester, MN

Partho Sengupta
MD, DM, FACC, FASE
WVU Heart & Vascular Institute
Morgantown, WV