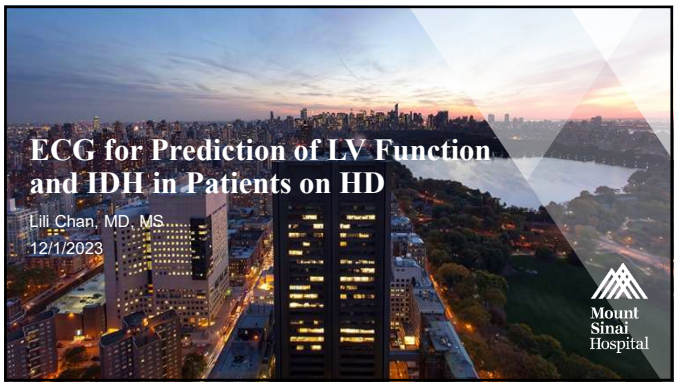
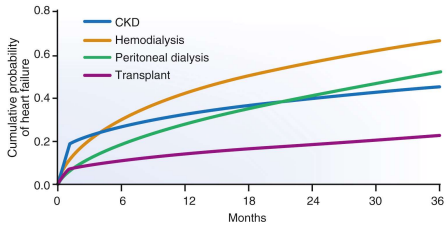


Conflicts of Interest

- Grant funding from NIH
- Consultant for CSL Vifor Pharma

Left Ventricular Ejection Fraction

Heart Failure in Patients on Dialysis



CKD: Incident general Medicare CKD patients, age 66 & older, 2001–2003 combined
ESKD: Incident ESKD patients, age 20 & older
Patients with CHF at baseline excluded. Probabilities unadjusted

House et al. KI June 2019

Abnormalities of Left Ventricle Precedes HF

- CRIC study of 417 participants
  - Echocardiograms at Year 1 and at dialysis start
- At an average of 2.9 years after dialysis initiation, 4% worsening in LVEF, P<0.001
- Every 1% decline in LVEF was associated with a 3% greater risk of mortality after ESRD

Variable	Change from CKD to ESRD	
	Unadjusted HR (95% CI)	Adjusted[1] HR (95% CI)
Ejection fraction, per 1% decline	1.04 (1.01, 1.05)	1.03 (1.00, 1.06)

The model is adjusted for age, sex, race, dialysis modality, cardiovascular disease, systolic blood pressure, number of anti-hypertensive med classes, diabetes, current smoker, and BMI

Bansai et al. AJKD Sep 2019

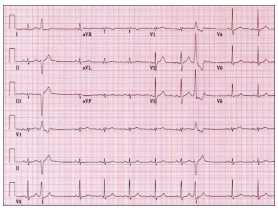
Current Diagnostic Paradigm

- Clinical Presentation:
  - Dyspnea
  - Orthopnea
  - Dependent edema
- CXR:
  - specific but only moderately sensitive in diagnosing HF
- ECG:
  - Rhythm disturbances
  - Evidence of prior myocardial damage
- Echocardiogram
  - Gold standard to evaluate LV function

- Cost from $1000-3000
- Can have take weeks to months to schedule

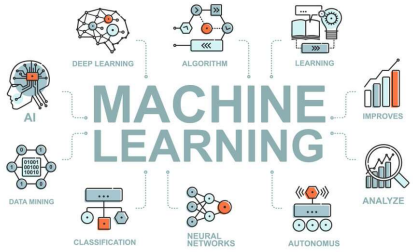
The ECG

- Surface level record of the electrical activity of the myocardium
- Voltage and complex morphology corresponds to the state of the heart
- Some features invisible to naked eye



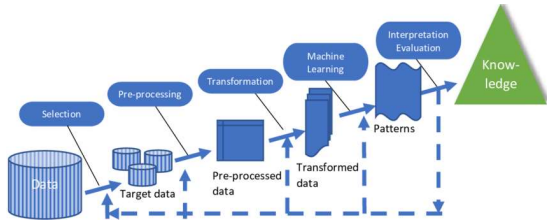
Vaid A et al. JACC: Cardiovascular Imaging (2021)

Machine learning

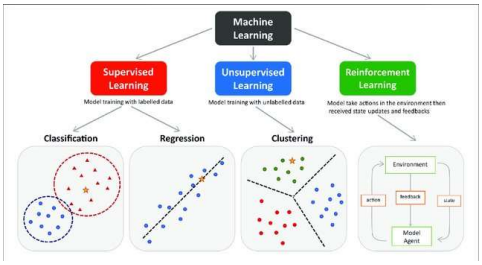


What is Machine Learning?

- Branch of artificial intelligence that enables a computer to learn from training data and improve over time with little to no human input



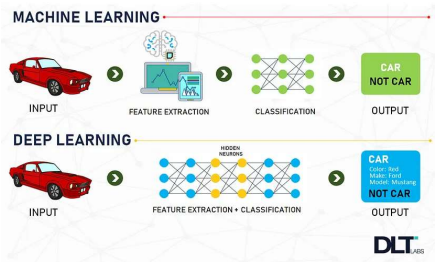
Types of Machine Learning



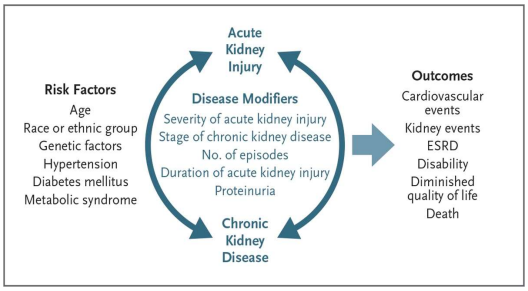
Peng et al. Frontiers in Pharmacology Sept 2021

Deep Learning

- Subset of ML that is based on representation learning and artificial neural networks



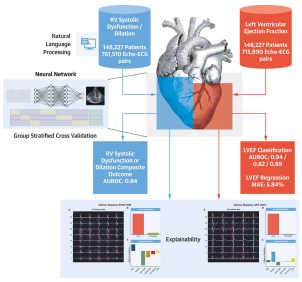
Machine Learning for All Stages of Kidney Disease



Kimmel et al NEJM

DL for LVEF from the ECG

- Can quantify low LVEF (<40%) with an Area Under Receiver Operating Characteristic Curve of 0.94
- Much faster and more inexpensive than going for a Transthoracic Echo



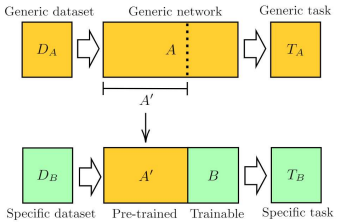
Vaid A et al. JACC: Cardiovascular Imaging (2021)

Patients with ESKD on HD

- Hemodialysis positively associated with increased risk of heart failure initially manifesting as Left Ventricular Systolic Dysfunction
- Can be screened using ECGs
- **Small patient population**

Transfer Learning

- Utilize the expertise of a model trained on one task for an adjacent task
- Training on 2nd task: *Fine-tuning*
- Gets a better model – faster, and with **much less data**



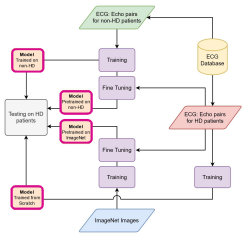
Andrea Mari, Thomas R. Bromley, Josh Izaac, Maria Schuld, and Nathan Killoran. Transfer learning in hybrid classical-quantum neural networks. arXiv:1912.08278 (2019)

Design

- ECGs paired to LVEF from Echo (ECG: Echo pairs)
- HD patients: 2,168 | ECG: Echo pairs: 18,626
- Non-HD patients: ~150,000 | ECG: Echo pairs: ~700,000

Model	Trained on	Fine-tuned on
Trained from scratch	HD patients	-
Pretrained on Imagenet	1.4M ImageNet Images	HD patients
Large LVEF	Non-HD patients	-
Large LVEF	Non-HD patients	HD patients

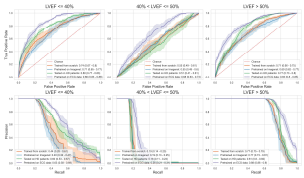
Akhil Vaid



Vaid et al. CJASN July 2022

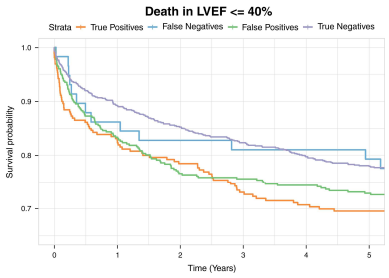
Improved Performance with Transfer Learning

Training method	AUROC: Value (95% CI) LVEF ≤ 40%	LVEF 41-50%	LVEF > 50%
HD patients	0.74 (0.67 - 0.8)	0.55 (0.49 - 0.61)	0.71 (0.66 - 0.75)
ImageNet → Fine-tuned on HD data	0.71 (0.65 - 0.77)	0.55 (0.49 - 0.6)	0.69 (0.62 - 0.77)
Non-HD patients	0.80 (0.77 - 0.83)	0.51 (0.41 - 0.61)	0.77 (0.73 - 0.80)
Non-HD → Fine-tuned on HD data	**0.86 (0.83 - 0.88)**	**0.68 (0.63 - 0.73)**	**0.83 (0.80 - 0.85)**



Vaid et al. CJASN July 2022

Mortality for Deep Learning Predicted LVEF



Adjusted for demographics, CAD and comorbidities

Vaid et al. CJASN July 2022

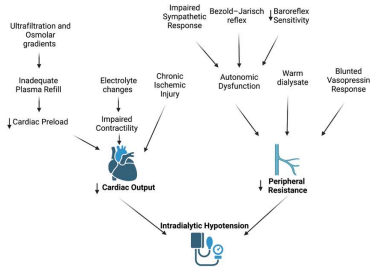
Summary 1

- Deep learning can determine LVEF accurately from EKGs in patients on maintenance dialysis
- This prediction is more accurate if using pretrained models on non dialysis patients and then fine tuned for patients on dialysis (transfer learning)
- A DL determination of low LVEF is highly predictive of future mortality

Intradialytic Hypotension

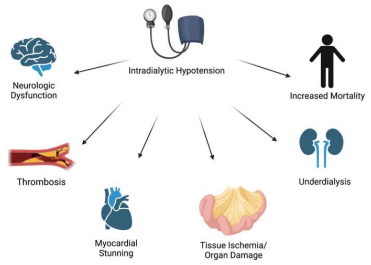
Pathogenesis of IDH

- Decreased cardiac output
- Decreased peripheral resistance



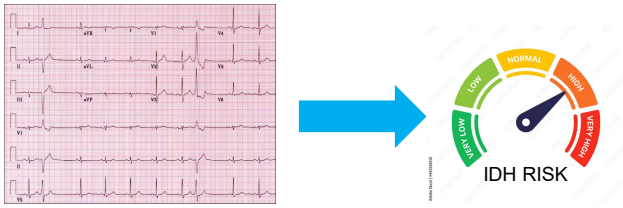
Yildiz et al. Int Urol Nephrol Oct 2022

Adverse clinical outcomes of IDH



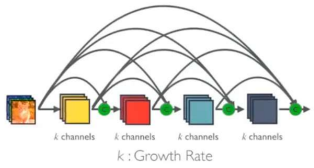
Yildiz et al. Int Urol Nephrol Oct 2022

Can we use ECG to predict IDH risk?



Methods

- ECG waveform data from Mount Sinai Health Systems hospitals in New York City
- Identified starting and ending times of inpatient HD procedures with flow sheets
  - IDH defined as a SBP ≤90 mm Hg
- Only ECGs within 48 hours of an HD procedure were included
- Model structure was a 2-D CNN
  - Densenet 201: pretrained on images from ImageNet

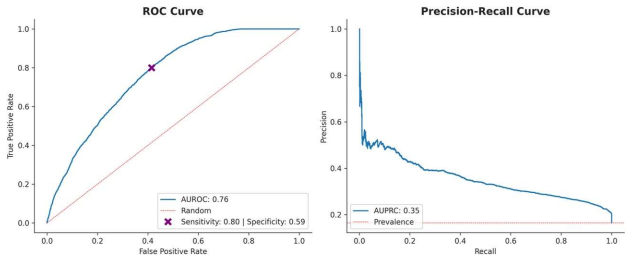


Patient characteristics

Characteristics	Overall (ECGs=86,362)	IDH (ECGs=12,437)	No IDH (ECGs=73,925)
Age, mean (SD)	62.3 (14.12)	63.24 (13.45)	62.69 (14.09)
Male patients, %	60.9%	60.0%	60.9%
Racial groups: %			
White	19.5%	22.6%	19.0%
Black	11.3%	11.6%	11.6%
Hispanic	5.3%	5.0%	5.3%
Asian	2.9%	2.2%	3.0%
Other/unknown	61.0%	58.6%	61.1%
SBP before starting HD session, mean (SD)	133 (28)	106 (21)	137 (26)

Vaid et al. Kidney360 Sept 2023

Performance of our model



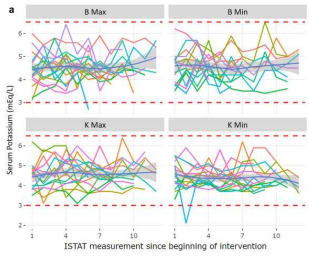
Vaid et al. Kidney360 Sept 2023

Dyskalemia

Intersession Variability in K is High

- N=19
- Patients randomized to 4 different dialysates
  - K Max: Hypokalemia avoidance
  - K Min: Hyperkalemia avoidance
  - B Max: Acidosis avoidance
  - Bmin: Alkalosis avoidance

Intervention	Percentage of predialysis chemistry values outside of listed range of the monthly laboratory value within individual subjects (95% confidence interval)	
Serum potassium values	**± 0.5 mEq/l**	**± 1.0 mEq/l**
B Max	38% (29–46)	13% (8–20)
B Min	44% (35–54)	12% (7–19)
K Max	35% (27–43)	11% (6–17)
K Min	34% (26–42)	7% (3–13)

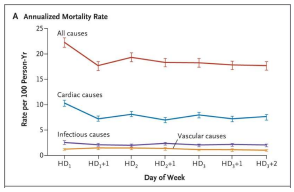


Pun et al. KI Reports Aug 2023

Higher Rates Mortality after Long Interdialytic Interval

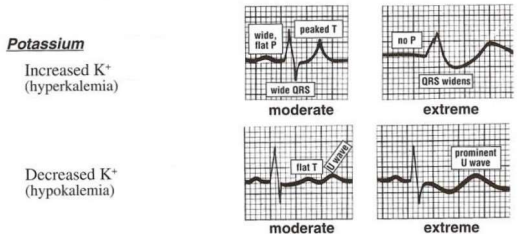
- Higher all cause and cardiac mortality after the long interdialytic interval in patients who are on thrice a week dialysis
- Hypothesized to be attributed to:
  - Fluid overload
  - Higher uremic toxins
  - Rapid electrolyte (e.g. potassium) shifts

Patients treated with same dialysate based off of monthly blood work



Foley et al. NEJM Sept 2011

Notable ECG Changes at Extreme Serum Potassium Levels



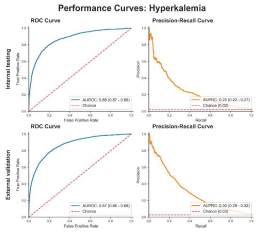
Manual of Medicine

Study Methods

- ECG waveform data from Mount Sinai Health Systems hospitals in New York City
- >600,000 patients with an ECG within 24 hours of a serum potassium level
- The model architecture was a ConvNeXt Large, a purely convolutional neural network developed by Meta and pre-trained on ImageNet.
- The cohort was split 80:20 into training and test sets.
- Primary outcome was K>6 mEq/L within 24 hours of an ECG

Performance of Model for Hyperkalemia

- 12087 (2%) of patients had a K>6 mEq/L
- The model achieved an AUROC of 0.88 and an AUPRC of 0.25 on internal testing, and an AUROC of 0.87 and AUPRC of 0.30 on external validation

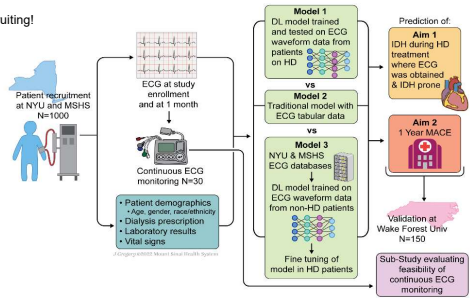


Summary #2

- Deep learning can predict IDH using ECG in hospitalized patients on HD
- Deep learning can be used to identify hyperkalemia (K>6 mEq/L) using ECG in hospitalized patients on HD

What is next?

- We are recruiting!



Thank You/Any Questions?

Mount Sinai Hospital