AI for Rapid CMR: Parametric Mapping

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Declaration of Financial Interests or Relationships

Speaker Name: Nicole Seiberlich

I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

Company Name: Siemens
Type of Relationship: Research Support, Royalties for MRF
Qualitative Imaging vs. Quantitative Mapping

Balanced SSFP

T₁ Map
Different Tissue Properties → Different Pathologies

Parametric Mapping = Rapid CMR?

Instead of

We could

Shorten CMR scan time

Parametric Mapping = Rapid CMR?

Instead of

Stop scan after sufficient info has been collected
Reduce burden on physician readers
Role of Artificial Intelligence in CMR Mapping

Accurate and reproducible tissue property maps

Conversion of tissue property maps into "conventional" images

Automated Scanning and Interpretation
Role of Artificial Intelligence in CMR Mapping

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AI to accelerate $T_1$ mapping


AI-facilitated motion correction for improved $T_1$ mapping

AI for multi-parametric approaches


Cardiac Magnetic Resonance Fingerprinting\textsuperscript{1,2}

**Time-Varying Pulse Sequence**

- Bloch equation simulation (including cardiac rhythm from ECG)

**Highly Undersampled Non-Cartesian Acquisition**

- Golden angle spiral ($R=48$)

- $T_1 = 500\,\text{ms}$, $T_2 = 50\,\text{ms}$
- $T_1 = 1000\,\text{ms}$, $T_2 = 50\,\text{ms}$
- $T_1 = 1000\,\text{ms}$, $T_2 = 100\,\text{ms}$

**MRF Dictionary**

**Quantitative Maps**

- $T_1$
- $T_2$


Courtesy of Jesse Hamilton
Fingerprint Generator Network

Time needed to simulate ~30,000 fingerprints:

- **5 min**
  - Bloch equation simulation
  - Compiled MATLAB Mex
  - 12 parallel cores

- **30 ms**
  - Neural network
  - Tensorflow / Keras
  - GPU

Fully-Connected Network

- $T_1$
- $T_2$
- RR
- $RR_1$
- $RR_2$
- $RR_M$

Magnetization ($M_z$) vs. Time

Complex-valued signal evolution

($N = \# \text{ of TRs}$)


Slide Courtesy of Jesse Hamilton
Self-Supervised Training of cMRF Deep Image Prior

Image Reconstruction Network (U-Net) *untrained*

Parameter Estimation Network (fully-connected) *untrained*

Fingerprint Generator (fully-connected) *pre-trained*

NUFFT

Loss 1

Loss 2

temporal subspace to time domain

k-space sampling masks

Slide Courtesy of Jesse Hamilton
Cardiomyopathy Patient Example: Reduced Motion Artifacts

MRF
15HB Breathhold
250ms Acquisition Window
Low-Rank Reconstruction

MRF
5HB Breathhold
150ms Acquisition Window
Deep Image Prior

Conventional Mapping

AI leads to shorter scan and better maps!
cINN-cMRF provides accurate predictions for parameter maps in 3.2 seconds without the need of additional dictionary generation

- Simulated test data evaluated on the cINN-cMRF achieves excellent agreement with ground truth (EPG and pattern matching based) maps
- SSIM > 0.84 and low relative errors for myocardium
- Further work will investigate the inclusion of a latent space in the network, improvements to simulated data and tuning of the network for in-vivo data
Role of Artificial Intelligence in CMR Mapping

Accurate and reproducible tissue property maps

Conversion of tissue property maps into "conventional" images

Automated Scanning and Interpretation
Synthetic MRI for Multiple Contrasts

\[ S = M_0 \left( 1 - \exp \left( -\frac{T_{IR}}{T_1} \right) \right) \]

\[ S = M_0 \exp \left( -\frac{TE}{T_2} \right) \]

\[ S = M_0 \left( 1 - 2 \exp \left( -\frac{TI}{T_1} \right) \right) \]

T1 and PD weighted

TR 250ms  TR 500ms  TR 1000ms  TR 2000ms

TE 20ms  TE 40ms  TE 75ms  TE 120ms

TI 100ms  TI 600ms  TI 1000ms  TI 2000ms

5 seconds!
Patient with Ischemic Cardiomyopathy

MRF Post-Contrast $T_1$

MRF Post-Contrast $T_2$

Synthetic Multicontrast LGE

Conventional LGE

MagIR

Dark-Blood T2IR

Gray-Blood T2IR

Optimized

Not yet informed by AI but…..
Contrast-Free Enhancement via Deep Learning?

A Scan protocol

- Pilots and planning (3 minutes)
- Pre-contrast cine frames (5 minutes)
- Native T1-mapping (5 minutes)
- IR-weighted images
- Parametric T1-map

~15 minutes

~25 minutes

Next Step ➔
Move to comprehensive synthetic imaging via Parametric Mapping + AI

Role of Artificial Intelligence

Accurate and reproducible tissue property maps

Conversion of tissue property maps into "conventional" images

Automated Scanning and Interpretation
Automated analysis of $T_1$ maps

**Fig. 5** Myocardial $T_1$ mapping at five short axial slices (apex to base from left to right respectively) of the left ventricle of one patient. Automatically reconstructed map before (a) and after (b) pruning overlaid on a $T_1$ weighted image with shortest inversion time; (c) Manually reconstructed $T_1$ map. The contours in (c) represent the myocardium region of interest manually selected by the reader.
Automated diagnosis using quantitative mapping and AI


What could AI do with more tissue properties, collected in a consistent fashion?
Role of AI and Parametric Mapping in Rapid CMR

- Accurate and reproducible tissue property maps
- Conversion of tissue property maps into “conventional” images
- Automated Scanning and Interpretation
Smart CMR exam via AI-enabled parametric mapping

- Collect 3D free-running (no breathholding, gating, or contrast?) isotropic data to quantify multiple tissue properties

3D T1 & T2 maps and whole-heart CINE imaging (2mm isotropic) from a single 3 minute scan
Smart CMR exam via AI-enabled parametric mapping

- Collect 3D free-running (no breathholding, gating, or contrast?) isotropic data to quantify multiple tissue properties

- Output standardized maps / synthetic images showing function and tissue characteristics

- Stop data collection once sufficient info is available according to AI physician assistant

Role of AI and Parametric Mapping in Rapid CMR
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