UHN Toronto General Toronto Western Princess Margaret Toronto Rehab Michener Institute

BRAIN-TO

Structural MR imaging

Acquisition & Applications

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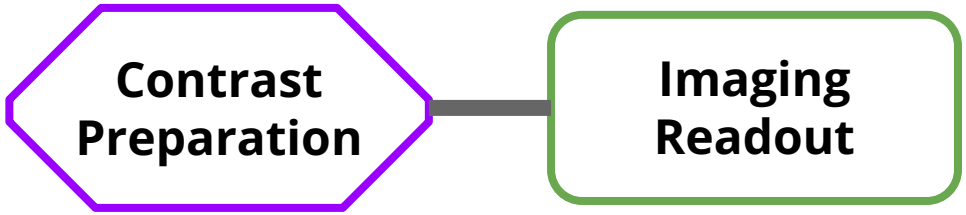
Syllabus

1. **Structural imaging sequences**
    - The two main ingredients
    - Image contrasts - T1w, T2w, T2*
    - (exogenous contrast-free) vascular imaging
2. **Multi-modal imaging**
    - Combination in image space
    - Combination in data space
3. **Spatial resolution**
4. **Practical considerations**

Structural imaging sequences

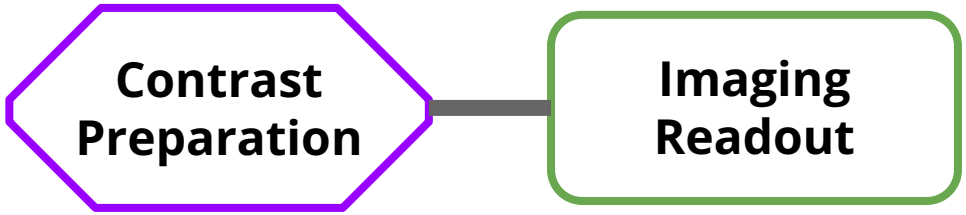
Two base ingredients

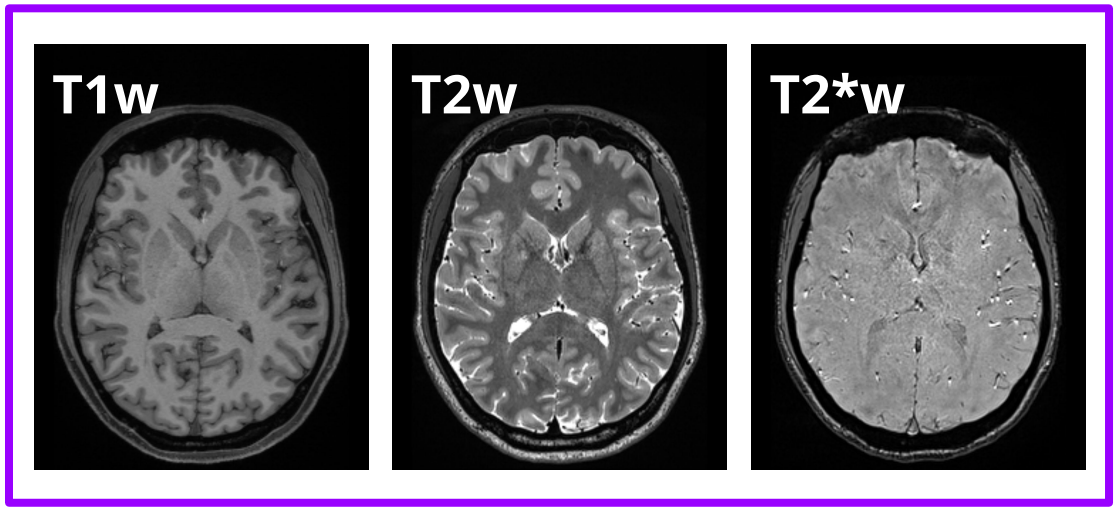


- Important for routine structural imaging
- Makes the sequence T1-weighted, T2-weighted etc.
- Parameters like TR, TE and TI can modulate contrast

- Determines 2D or 3D
- Controls the amount of spatial distortions
- Typically unchanged for routine clinical scans

Structural imaging sequences

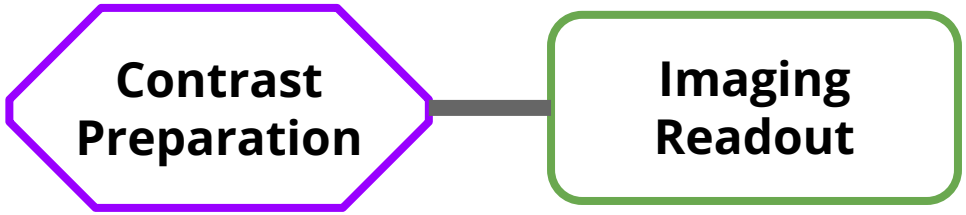




Different **contrast preparation with *same* readout**

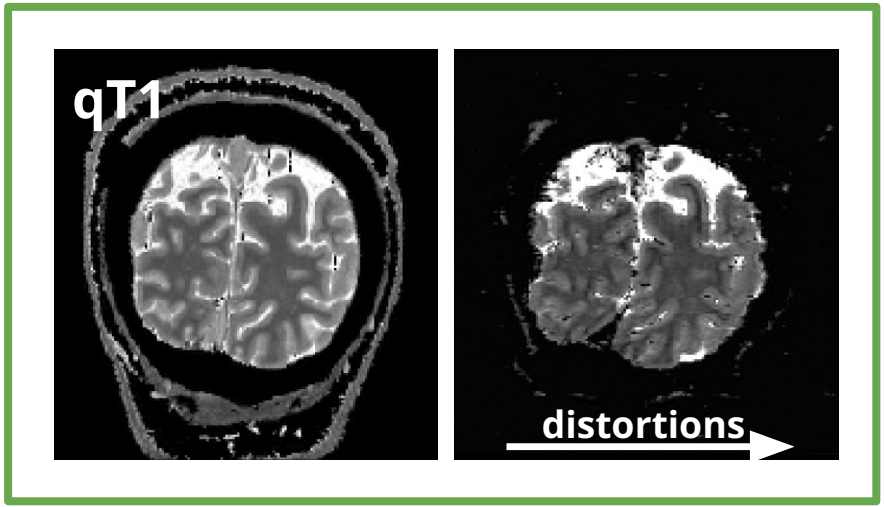
- **Negligible spatial discrepancies**
- **Routine clinical scans**

Structural imaging sequences



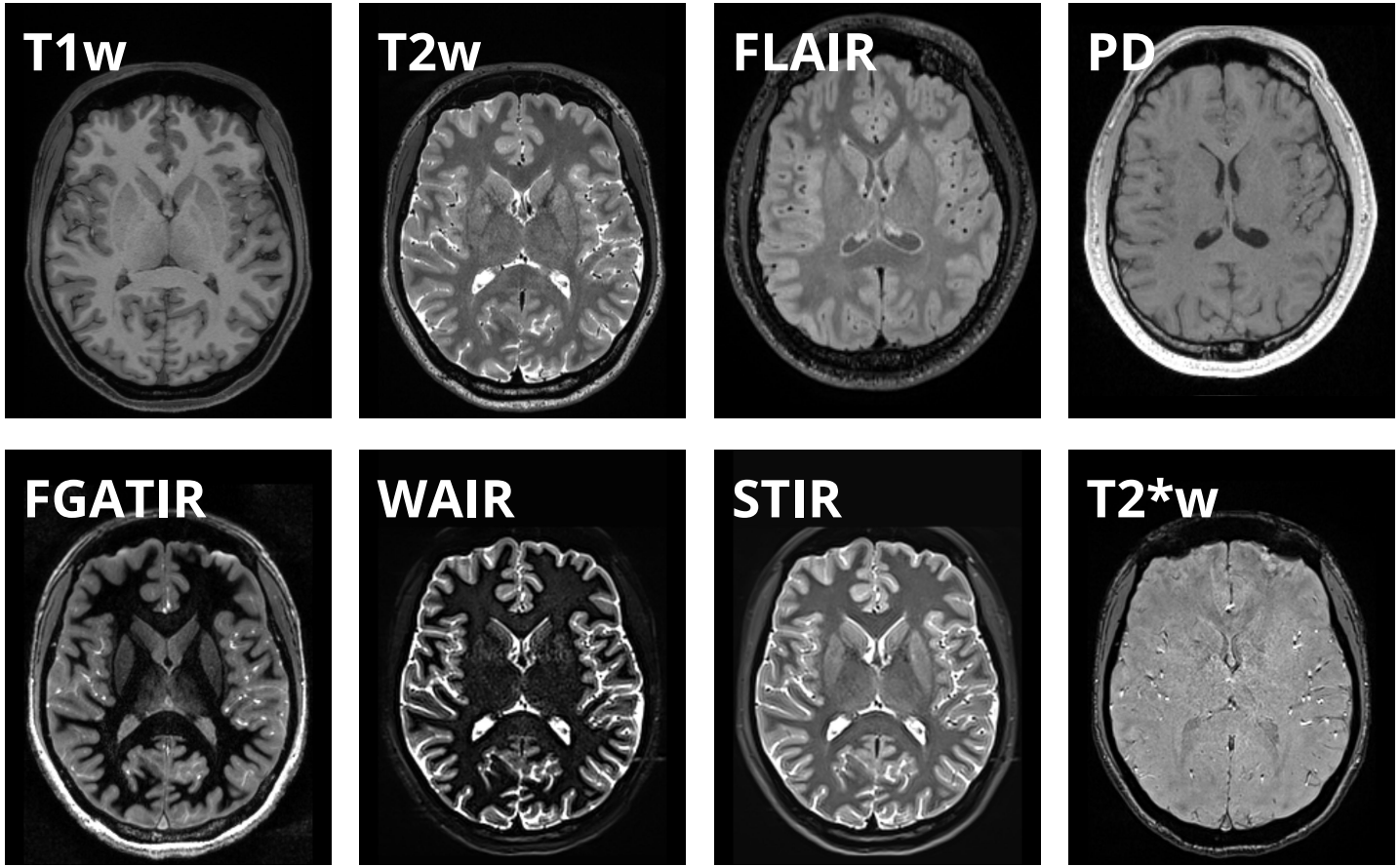
Same **contrast preparation with** ***different*** **readout**

- **Visible spatial discrepancies**
- **Limited use-cases (e.g. 7 T fMRI)**



Renvall et al. 2016, Kashyap et al. 2018, Sanchez-Panchuelo et al. 2021

Plethora of structural contrasts



- Can selectively emphasise a certain tissue
- Can be used with/without contrast-agent
- Can be combined (multi-modal)

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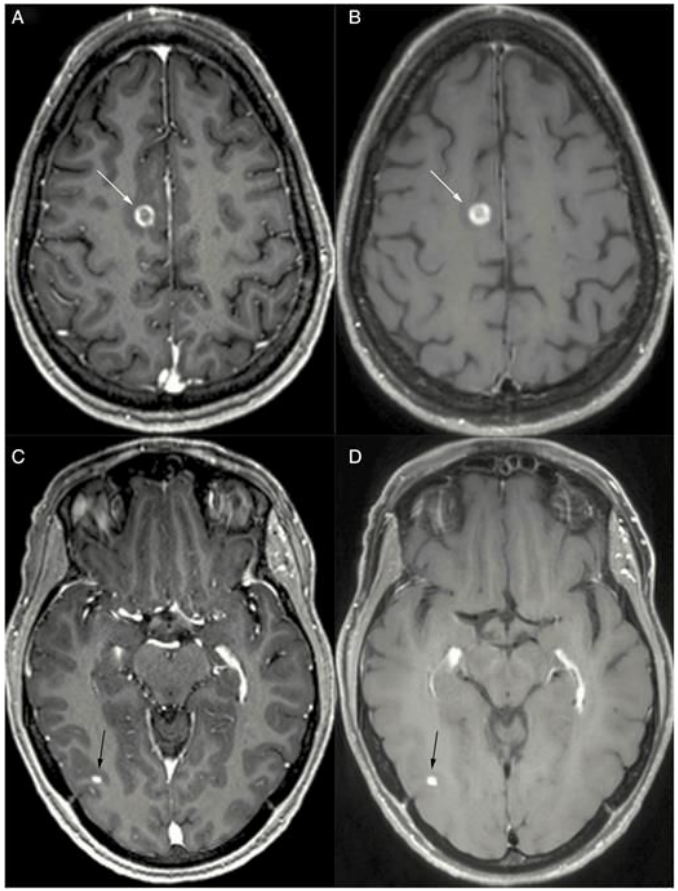
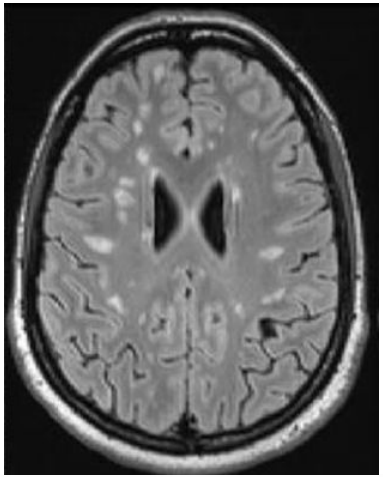
T1-weighted imaging

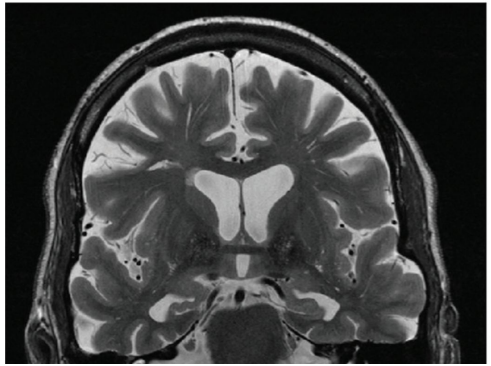


- Workhorse of structural imaging
- Excellent tissue contrast at high-resolution
- Acquired within 5-6 mins
- Clinic:
  - routine structural exam
  - pre-surgical planning
  - (with contrast) tumours, abscesses etc.
- Research:
  - Anatomical reference
  - Tissue segmentation and morphometry
  - Works with all community-standard post-processing software

Kaufmann, TJ et al., 2020

T2-weighted imaging

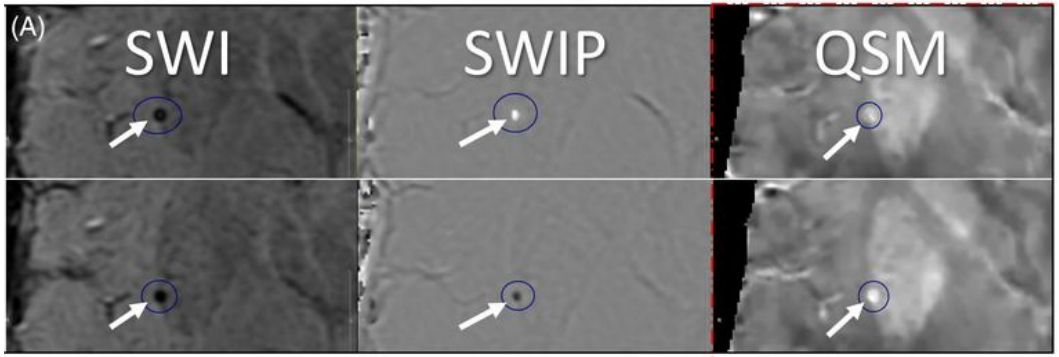




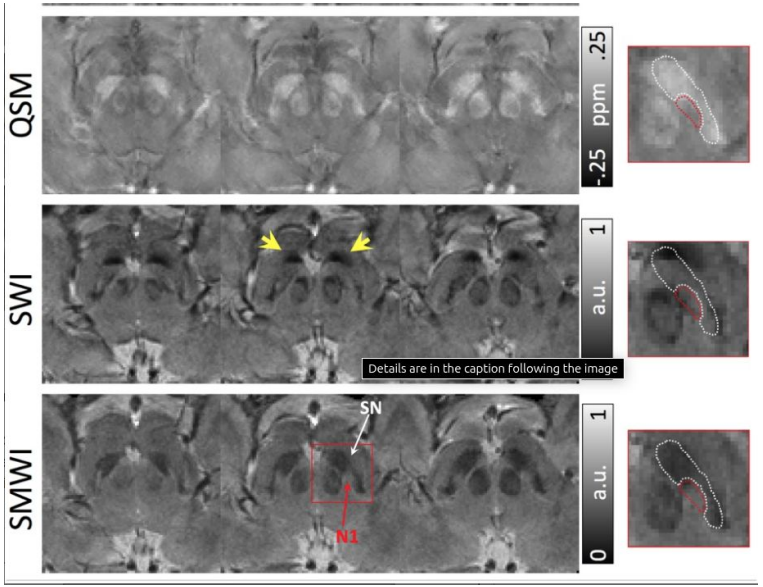
- Workhorse of pathology detection
- Better sensitivity to water content than T1w
- Acquired within 3-4 mins
- Clinic:
  - Routine pathology screening
  - Oedema, infracts, tumours, abscesses
  - Perivascular spaces, ventricular size
- Research:
  - Lesion quantification (e.g., stroke, MS)
  - Useful for pial-surface optimisation in Freesurfer recon-all
  - T1w/T2w Ratio images (a.k.a. myelin maps) supporting other microstructure imaging (DWI)

(top) La Rosa et al. 2020, (bottom) Niazi, M. et al., 2018

T2*-weighted imaging (GRE)



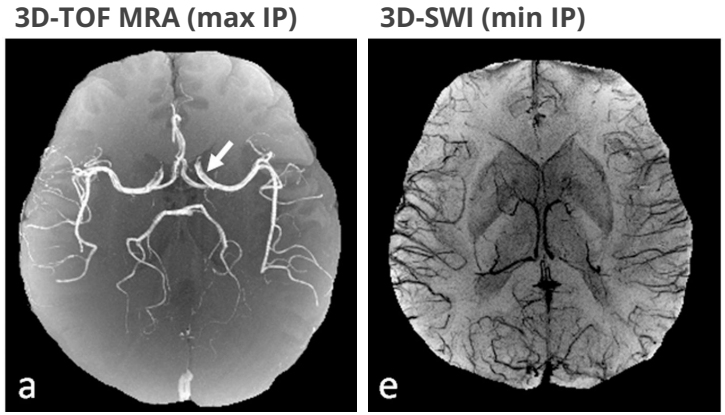
- Sensitive to local inhomogeneities (blood, iron, air etc.)
- SWI, QSM and venograms from same data
- Clinic:
  - Specialised scans for microbleeds, haemorrhages
  - thrombosed veins and other venous anomalies

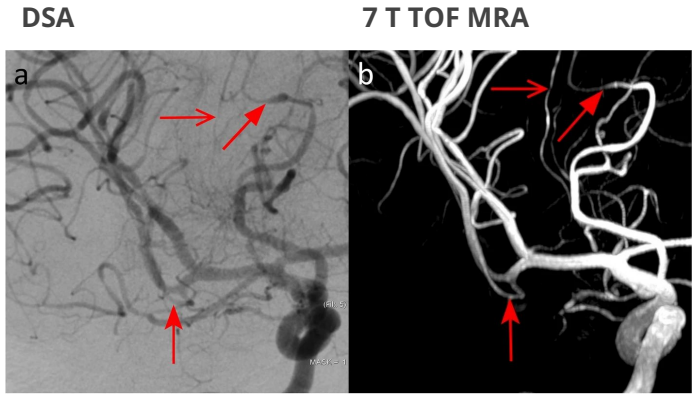


- Research:
  - Iron changes in neurodegeneration
  - Emerging biomarker for disease progression and differential diagnoses

(left) Lee, K et al. 2022, (right) Nam et al. 2018

Contrast-free vascular imaging

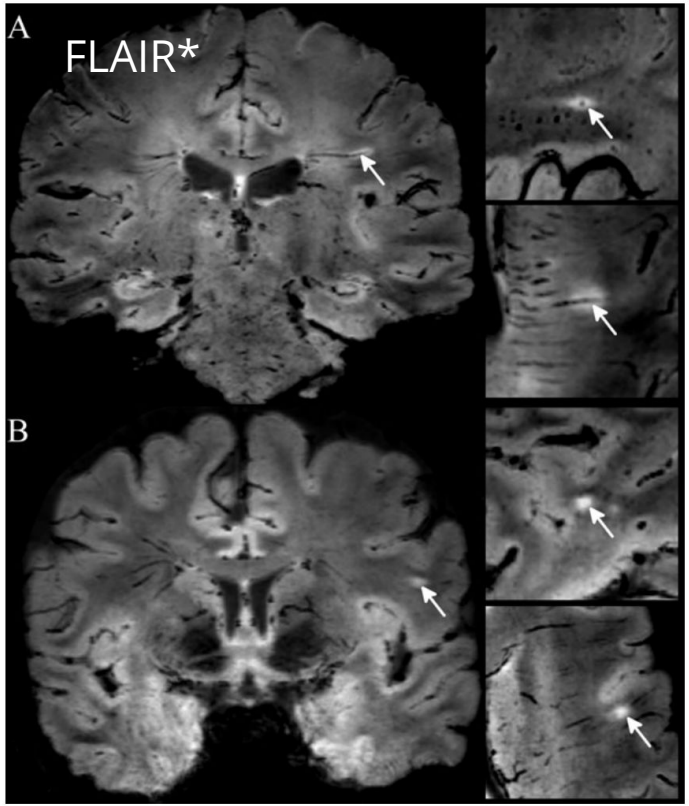




(top) Liu, S et al., 2016, (bottom) Cosottini et al. 2024

- No contrast required = safe for renal patients or if contraindicated
- Time-of-Flight (TOF) MRA
  - Exploits flow-related enhancement to visualize arteries
  - Excellent for detecting intracranial aneurysms, stenoses, and vessel anatomy
- Susceptibility Weighted Imaging (SWI)
  - Sensitive to venous blood, deoxyhemoglobin, and microbleeds
  - Provides high-resolution visualization of veins, venous anomalies, and microvascular structures

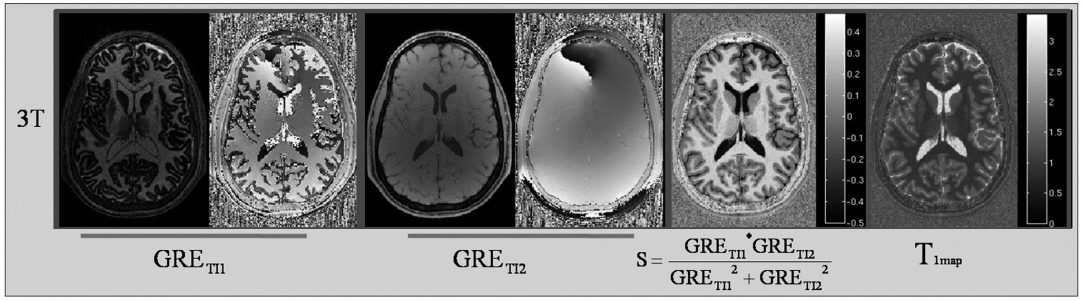
Multi-modal MR (combining images)



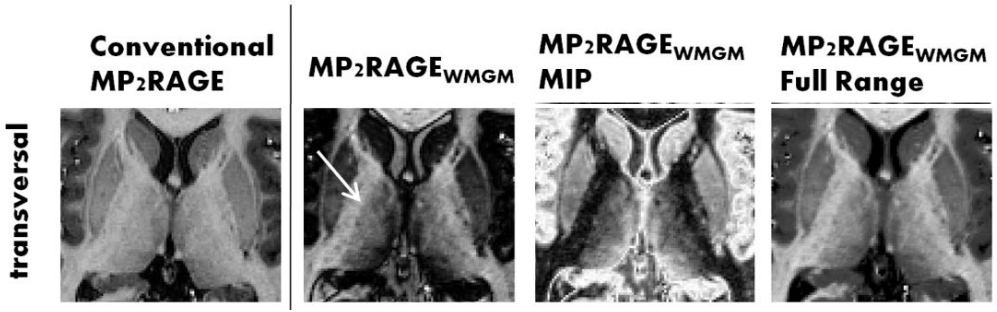
FLAIR* central vein sign discrimination
Solomon, AJ et al. 2016

- **Enhanced lesion detection and characterisation**
- **Often combining T2*w data with T1w and/or T2w contrasts**
- **Emerging avenue of research for imaging biomarker development**

Multi-modal MR (combining images)

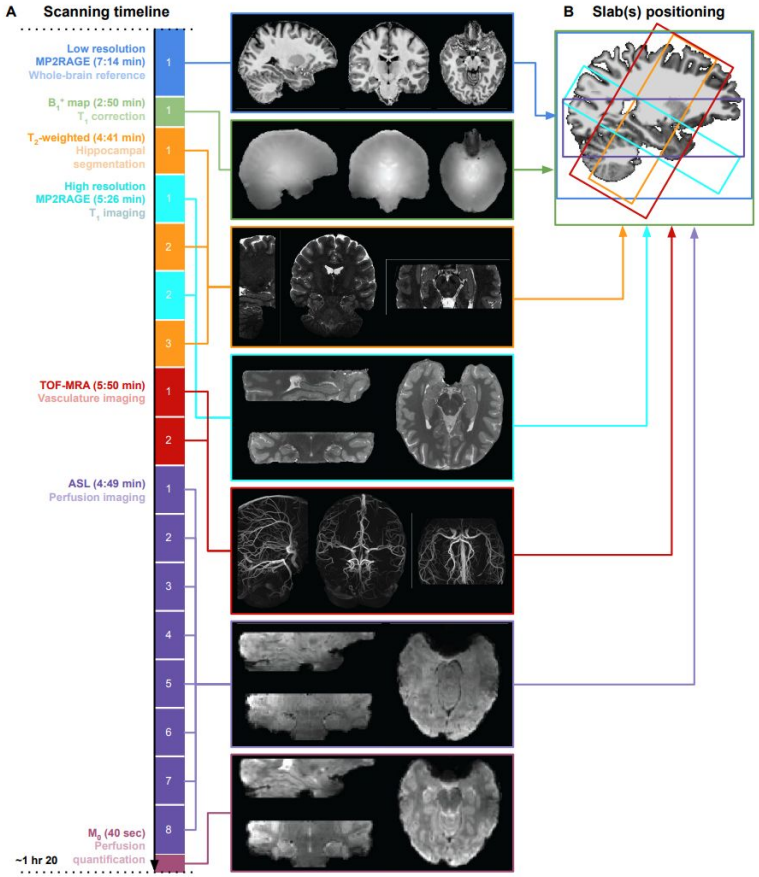


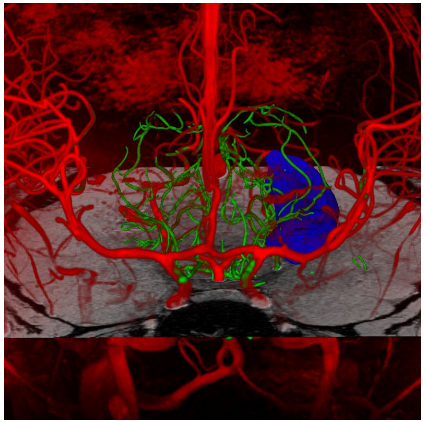
- Longer acquisition time
- Improved anatomical delineation at high field strengths (≥3T)
- Quantitative T1 map (for ‘free’)
- Requires additional processing before morphometric analysis (see - https://github.com/srikash/presurfer)

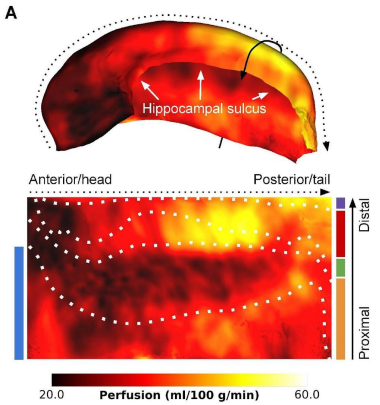


MP2RAGE (Marques et al. 2010, 2013)

Multi-modal MR (combining data)





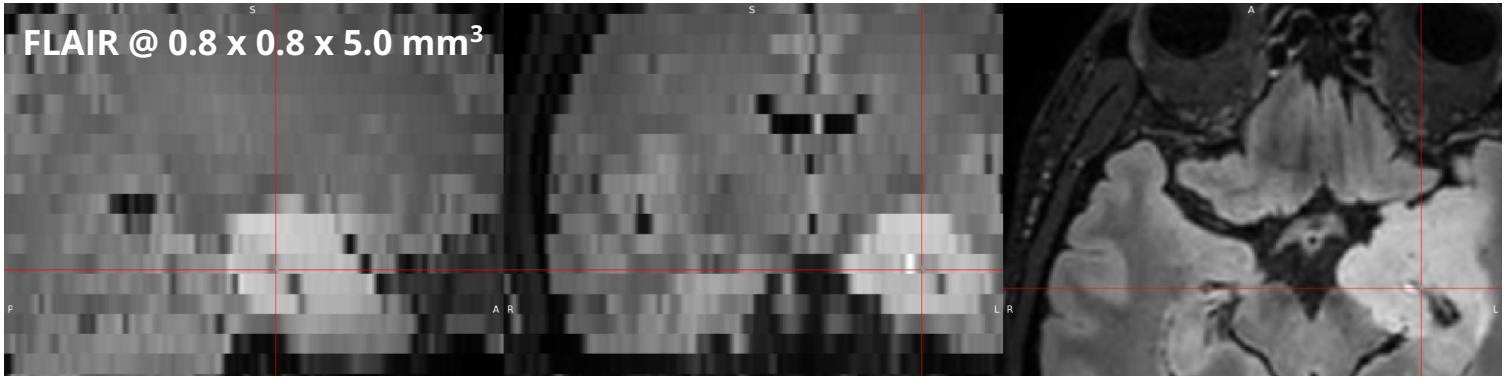


- **Careful alignments and segmentation of multiple imaging contrasts (at 7 T)**
- **Combining cortical thickness, myelination, blood flow, vascular reconstruction**
- **With a unified anatomical coordinate system (https://github.com/khanlab/hippunfold)**
- **Multi-faceted view into hippocampal health**

Haast & Kashyap et al., PNAS 2024

Spatial resolution

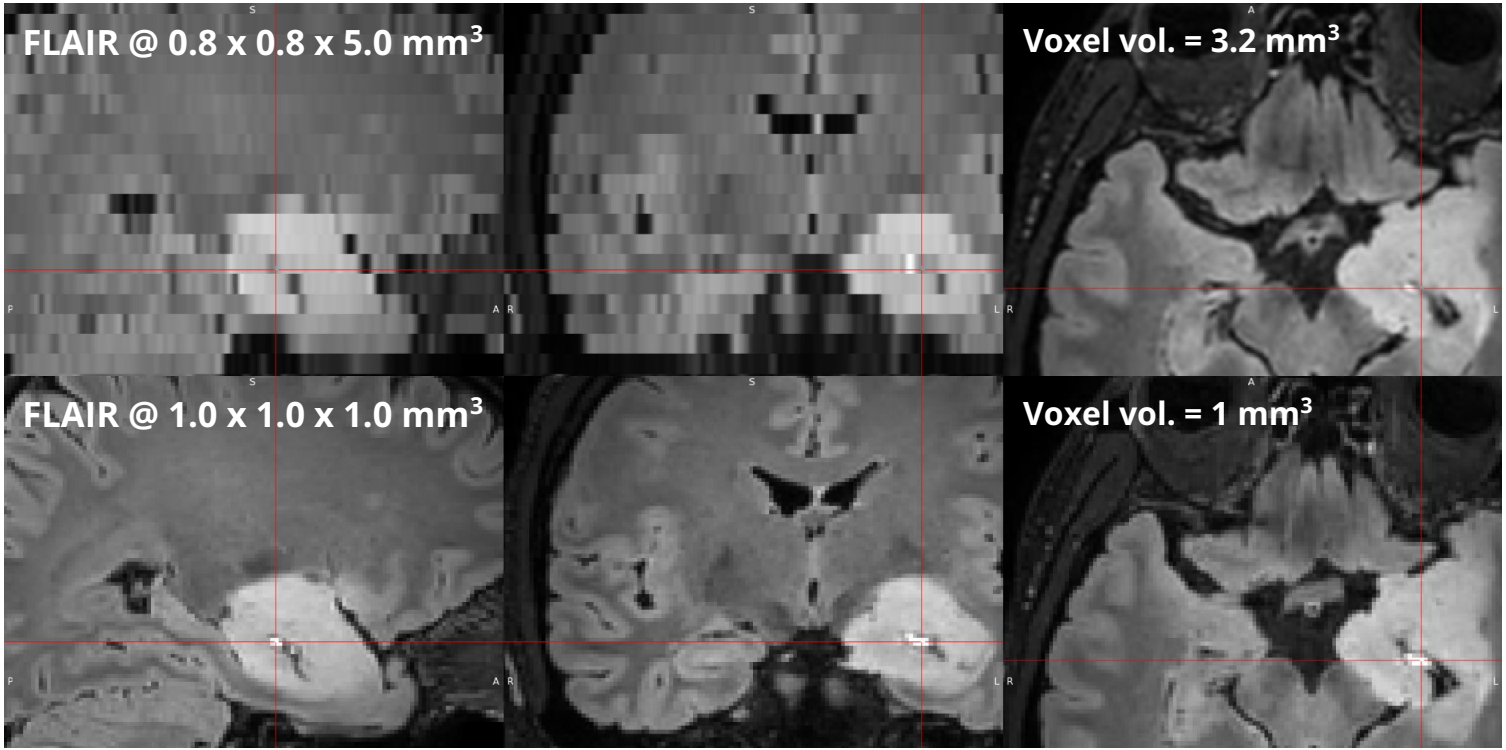
The appropriate contrast alone is insufficient



* protocol can read 0.4 x 0.4 mm in-plane (acquired data is *nearly* always @ 0.8 mm with 2x upsampling)

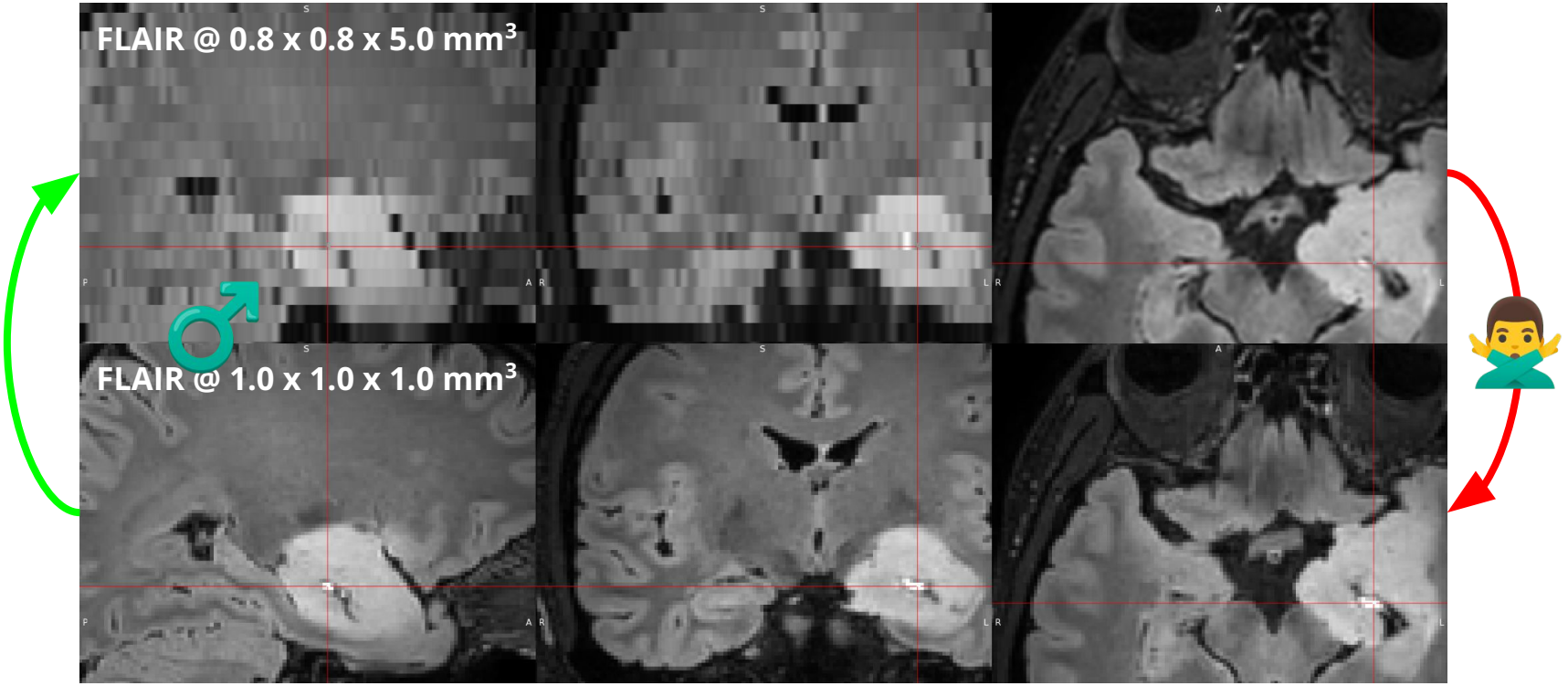
Spatial resolution

Both the right contrast and the right spatial resolution are essential for accurate MRI diagnosis and analysis.



Spatial resolution

Information lost in acquisition cannot be recovered.
Always acquire high-resolution.



Practical considerations

1. Head coil choice (Siemens Prisma)

20 ch – Head/Neck

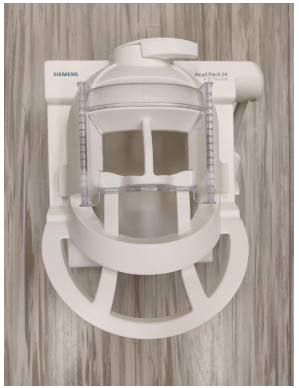
Largest inner volume = roomy fit

Lowest acceleration capability

32 ch – Head

‘Average’ inner volume

Better acceleration capability



64 ch – Head/Neck

Smaller inner volume = snug fit

Best acceleration capability

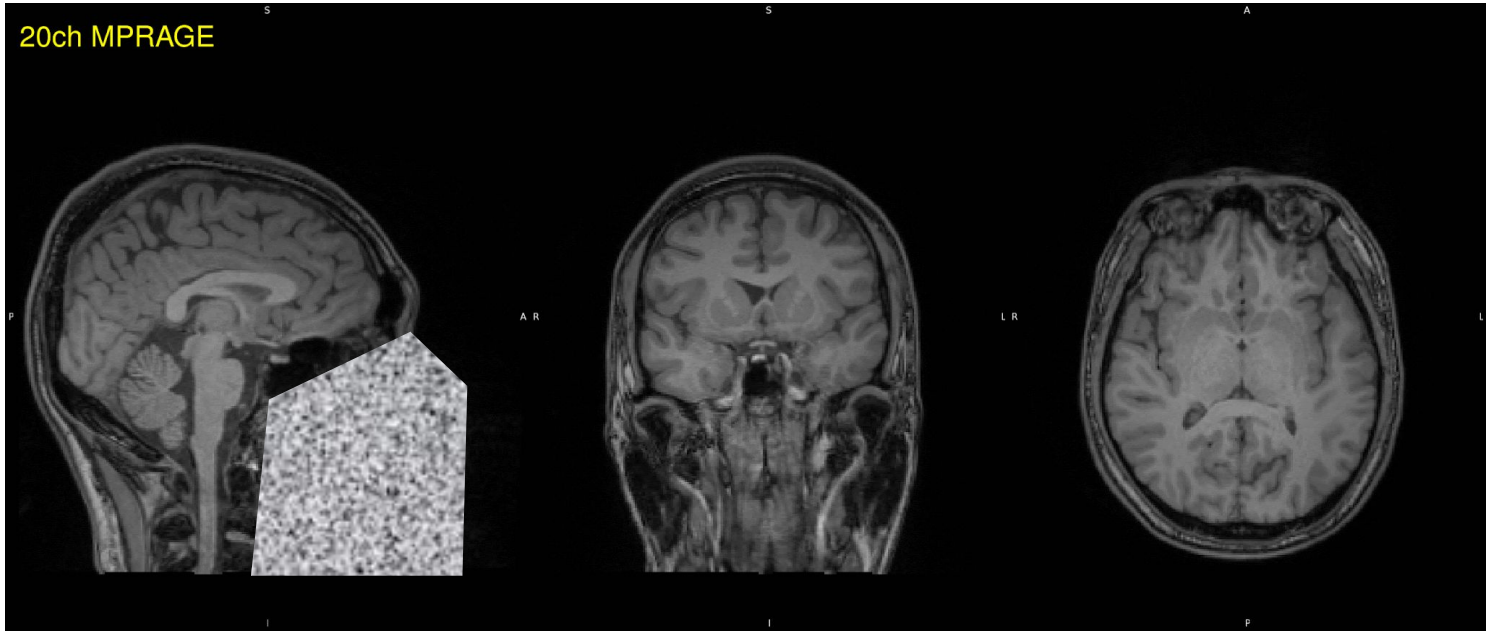
Patients < < **Preference** > > **Researchers**

TAKE AWAY

Head+Neck coils are recommended if cervical spine is of clinical interest.

Practical considerations

1. Head coil choice (Siemens Prisma)



TAKE AWAY

Head+Neck coils are recommended if cervical spine is of clinical interest.

Structural imaging sequences are robust to minor coil-specific differences.

Practical considerations

2. Let the analysis inform acquisition

Example 1 - Will you need a quantitative T1 map for an analysis (perfusion modelling)? Consider acquiring an MP2RAGE.

Example 2 - Does your research need perivascular space segmentation? Ensure you acquired a T2w SPACE.

Example 3 - Acquire multi-echo GRE instead of a single-echo. Not a dramatic increase in time needed but offers flexibility to do SWI, venogram, QSM etc.

Think ahead. A dedicated scan (+5 mins) can save many hours in post!

Practical considerations

3. Availability of protocols

Clinical · Neurology

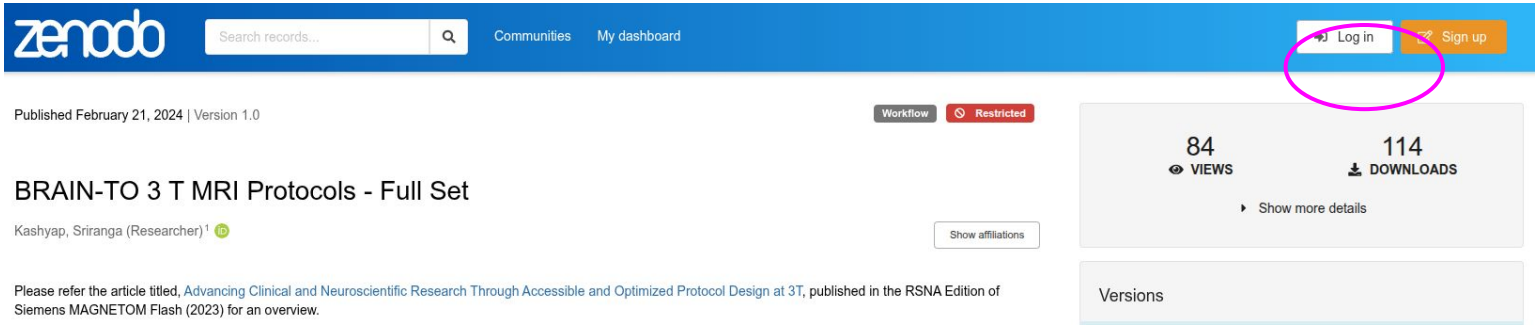
MAGNETOM Flash (85) 3/2023

Advancing Clinical and Neuroscientific Research Through Accessible and Optimized Protocol Design at 3T

Sriranga Kashyap, Ph.D.[1]; Kâmil Uludağ, Ph.D.[1,2,3,4]

Design principles

- No custom sequences
- Isotropic Voxels
- TA < 6 mins per scan*
  * exceptions apply
- Optimised for head coil



TAKE AWAY

Tested for use with community-standard tools (FSL, Freesurfer, CAT12 etc.)

https://github.com/BRAIN-TO/bto_mri_protocols_info

Summary

- MRI offers peerless versatility for structural imaging
  - Many contrasts: T1, T2, T2*, FLAIR, SWI etc., possible with changing preparation and readout methods
- Clinical and research applications
  - Routine structural and pathology detection (T1w, T2w, FLAIR)
  - Quantitative mapping and morphometry (T1w/T2w ratio, T2*, QSM)
  - Contrast-free high-resolution vascular imaging (TOF, SWI)
  - Using contrast and/or multi-modal combinations like FLAIR* (emerging biomarkers)
- Spatial resolution matters as much as the contrast
- Practical considerations
  - Selecting the right coil and protocol for coverage (brain, cervical spine, etc.)
  - Accessible, well-tested ‘modern’ MRI protocols for ease of adoption

Additional resources

MR Academy

https://www.ismrm.org/online-education-program/
https://www.youtube.com/playlist?list=PLbkiZxYoulu7B9JWoVVx5xT0Ta5x2smiH

MRI TOGETHER · A GLOBAL WORKSHOP ·

https://mritogether.esmrmb.org/25m/

https://www.youtube.com/playlist?list=PLeDygc8TN_J5TKU7Z06ucjkvsfEYI6_AJ

Acknowledgements

BRAIN-TO

Dr. Kâmil Uludağ
Dr. Lars Kasper (now @ ToNI)
Dr. Tim Zhe Wu (now @ Siemens/SRI)
(and all labmates)

UHN Krembil Brain Institute

Dr. Alexandre Boutet
Dr. Jürgen Germann
Dr. Paula Alcaide Leon

Western University · Canada

Dr. Ali Khan
Dr. Roy Haast (now @ Aix-Marseille Université)
Dr. Jordan de Kraker (now @ McGill)

Maastricht University

Dr. Benedikt Poser
Dr. Dimo Ivanov
Dr. Laurentius Huber (now @ MGH)