APPLICATIONS OF 7T MRI IN NEURORADIOLOGY

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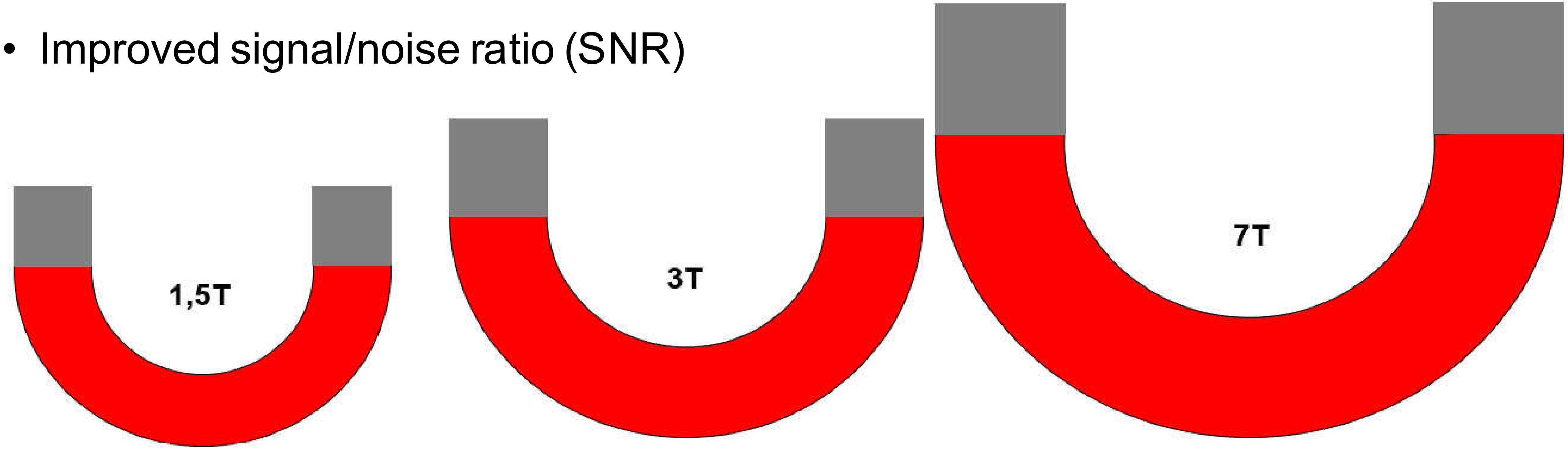
OUTLINE

- I. 7T MRI : Overview
- II. Clinical applications in neurovascular diseases
- III. Clinical applications in neuroinflammatory diseases
- IV. Clinical applications in mental health
- V. Clinical applications in neurodegenerative diseases
- VI. Regional project « ARIANES »

7T MRI

- Increase in B0
- Increased proton resonance frequency
  - → need to increase RF wave power
  - → more energy delivery (measured in W/kg) / heating of local tissues
  - → difficulty in homogeneizing B0 & B1+ / image inhomogeneity
- Modification in T1 and T2 relaxation times
- Improved signal/noise ratio (SNR)



Improved spatial resolution

7T VS 3T

	Advantages	Disadvantages
Specific absorption rate		Increase in energy delivery
T1	TOF, ASL, Lesser gadolinium need	Increase acquisition time
T2		Diffusion
T2*	SWI, BOLD	
SNR (signal/noise ratio)	Improved spatial resolution	
Chemical shift	Improved fat saturation Improved spatial resolution	Increase in chemical shift
Magnetic susceptibility	SWI, BOLD	Increase in susceptibility artifact
Dielectric effect		Variable signal loss

II . CLINICAL APPLICATIONS OF 7T MRI IN NEUROVASCULAR DISEASES

NEUROVASCULAR

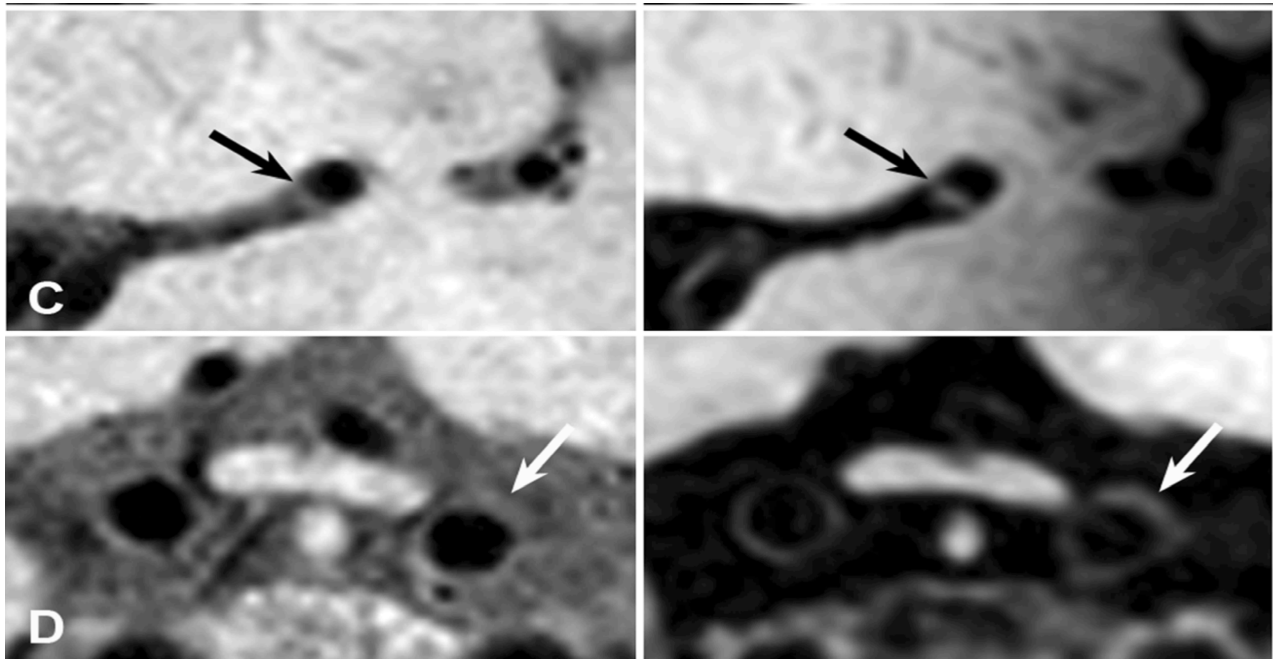
Currently no application in stroke to guide thrombolysis or thrombectomy.

Application in the workup of stroke :

- intracranial atheromatous disease

NEUROVASCULAR

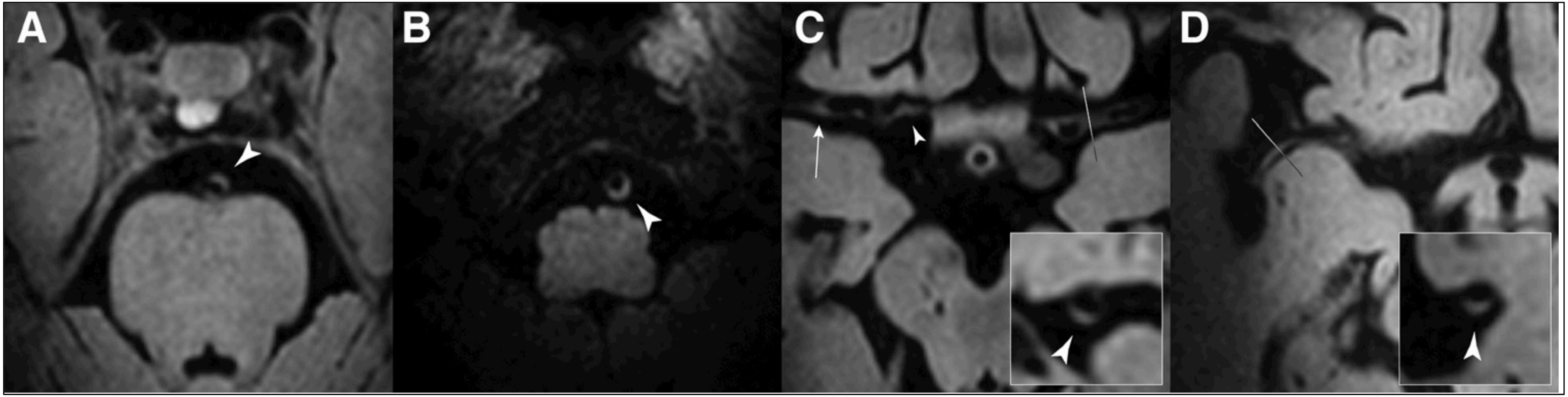
Better definition of lesion load on 7T MRI in asymptomatic elderly patients



Harteveled et al 2017

NEUROVASCULAR

→ 7T MRI helps separate out risk factors from wall abnormalities in circle of Willis arteries.



Zwartbol et al 2019

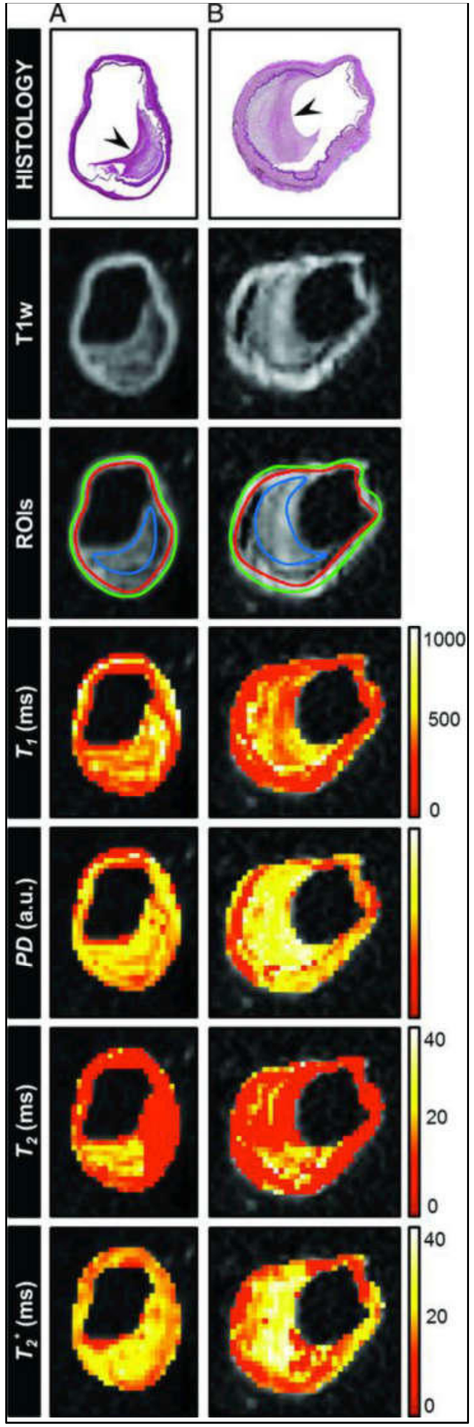
Significantly more lesions in elderly, hypertensive, type 2 diabetes
→ Change in treatment plan in risk factors in symptomatic patients with no other cause for stroke ?

NEUROVASCULAR

Future goal: *in vivo* study of plaque composition, possible *ex vivo* with sequences not available for clinical use.

→ Differentiate between plaque components based on T1 shortening value.

Harteveled et al 2016



NEUROVASCULAR

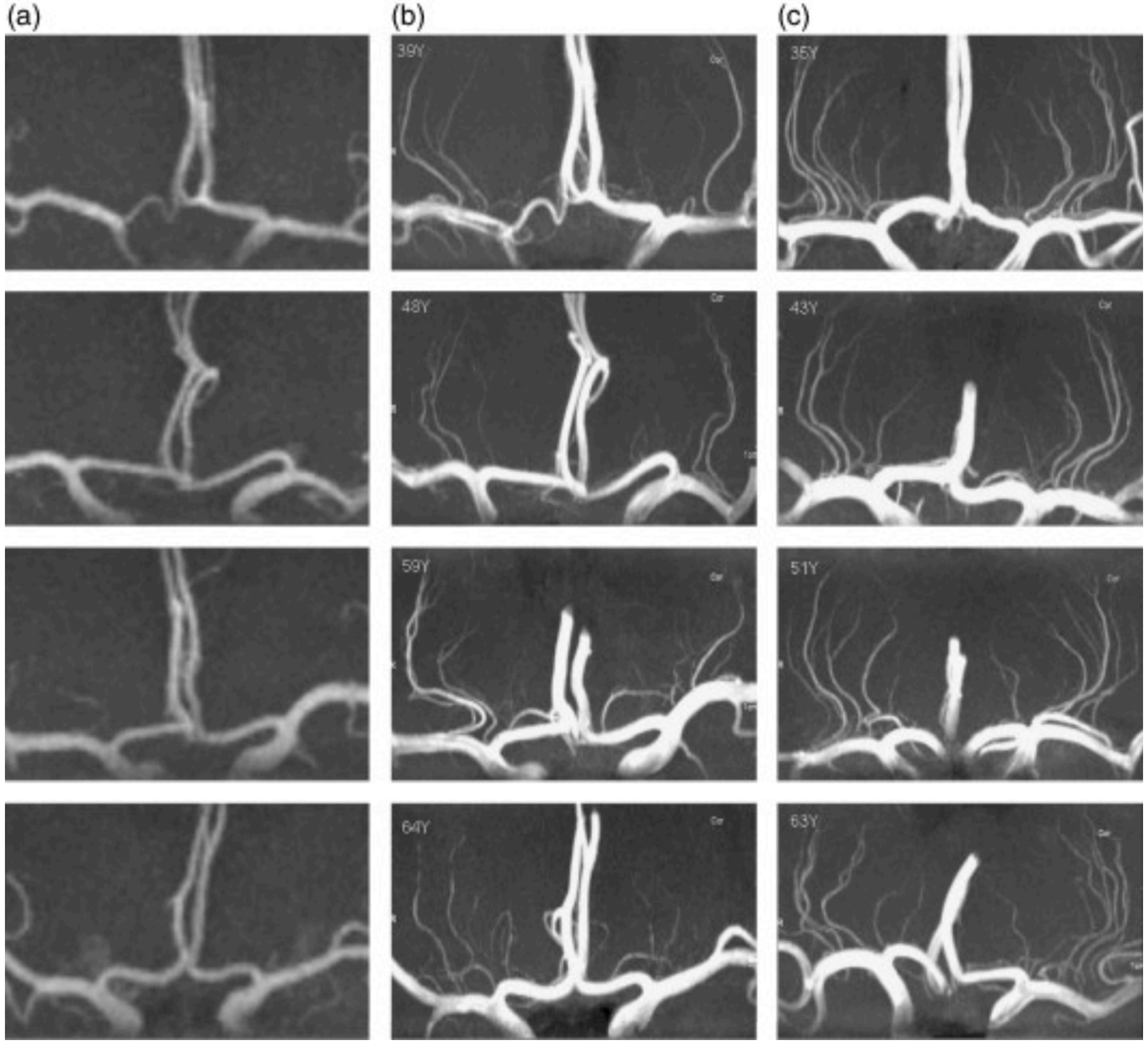
Stroke workup :

- intracranial atheromatous disease

- Small artery disease (lipohyalinosis)

NEUROVASCULAR

Better morphological definition of lenticulo-striate arteries (lacunar strokes).

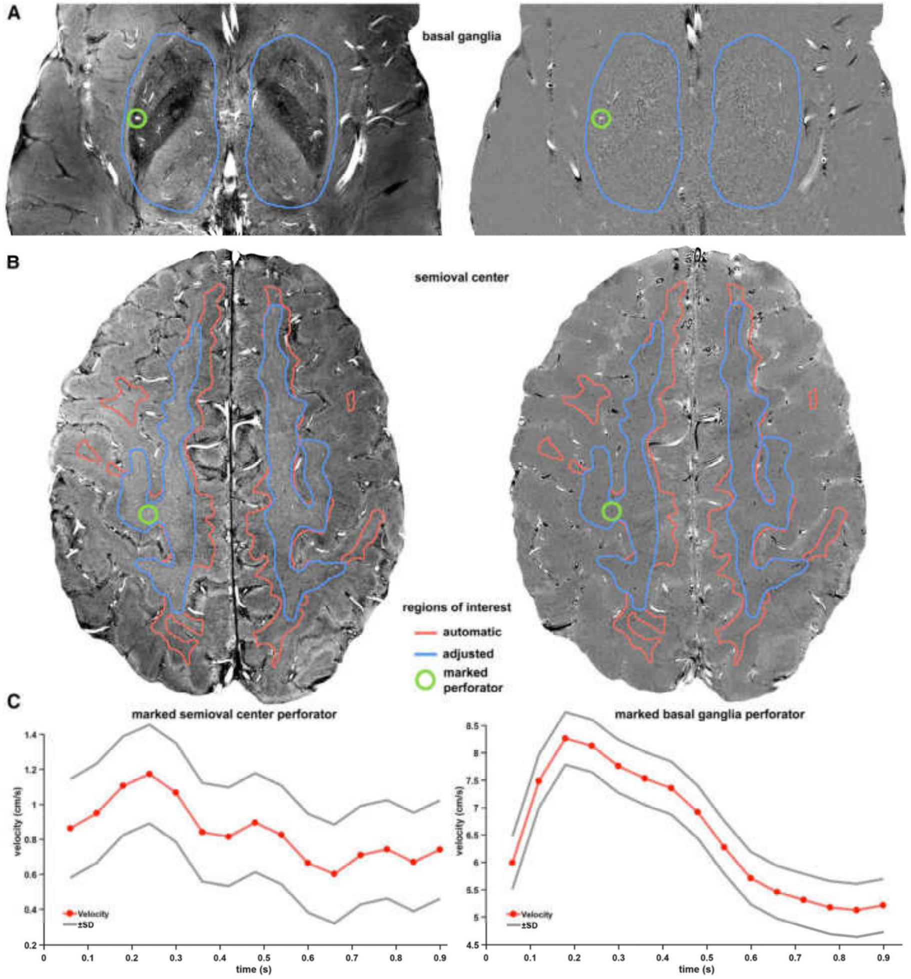


Decrease in number
of lenticulo-striate arteries

Kang et al 2010

NEUROVASCULAR

Also functional evaluation of perforating arteries.
Physiopathological confirmation.

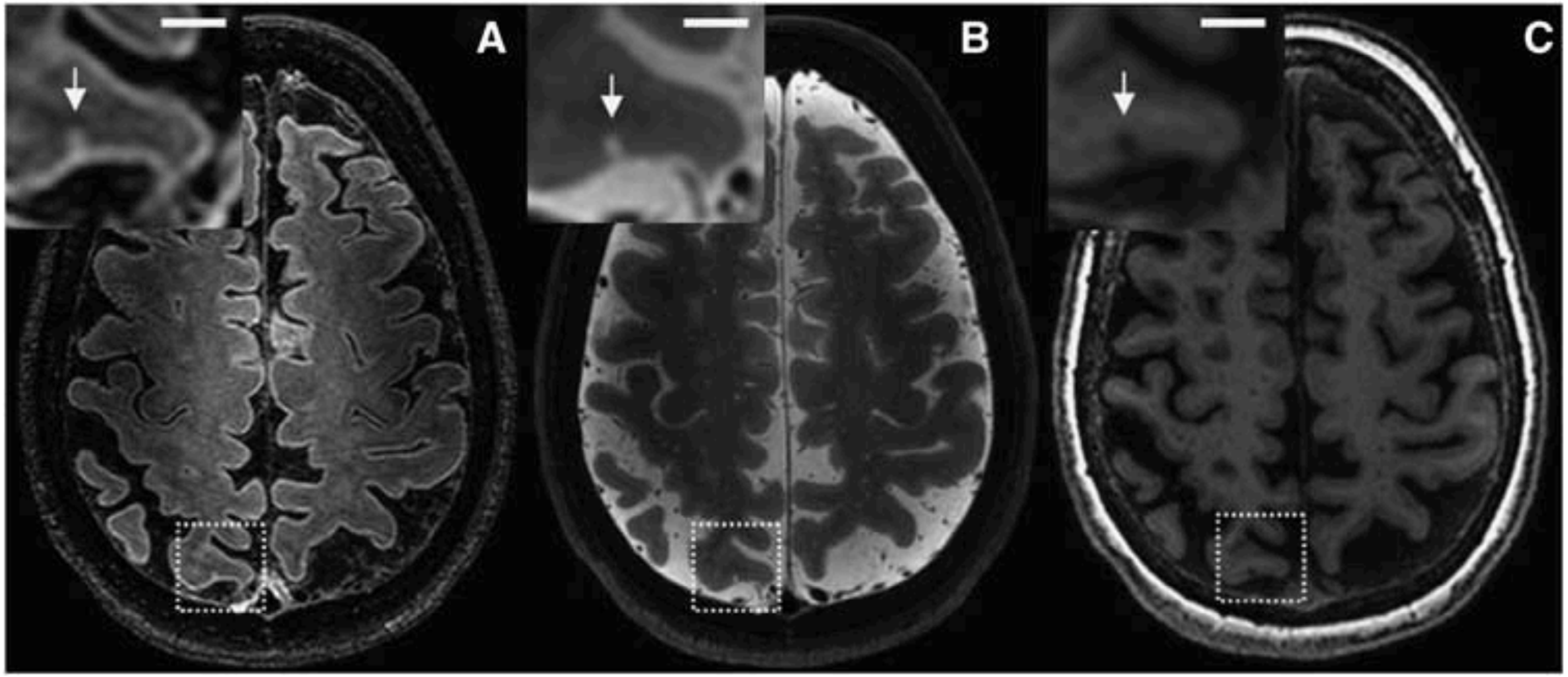


Higher pulsatility index in patients compared to controls.

Geurts et al 2019

NEUROVASCULAR

Currently no application in stroke to guide thrombolysis or thrombectomy.
Application in stroke workup.
Biomarkers for neurodegenerative disease (especially vascular dementia).



Detection of cortical micro-infarctschronic microbleeds. Topography can suggest type of dementia.

Van Veluw et al 2013

NEUROVASCULAR

Currently no application in stroke to guide thrombolysis or thrombectomy.

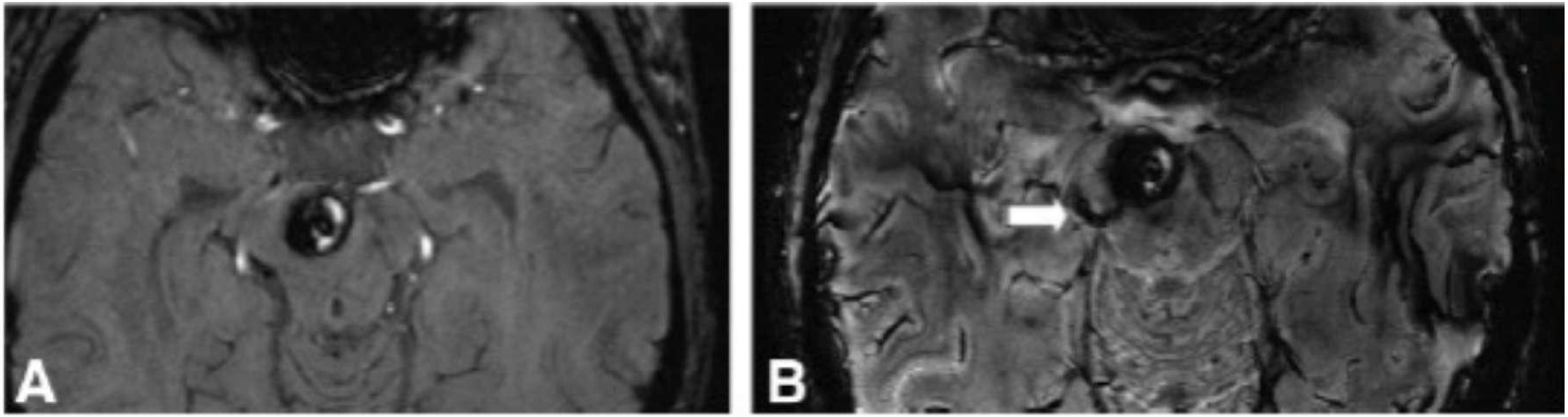
Application in stroke workup.

Biomarkers for neurodegenerative disease (especially vascular dementia).

Improved detection of cavernomas (type IV) and draining vein.

NEUROVASCULAR

Improved magnetic susceptibility leading to improved detection of hemorrage, particularly in cavernomas.



Frischer et al 2012

NEUROVASCULAR

Currently no application in stroke to guide thrombolysis or thrombectomy.

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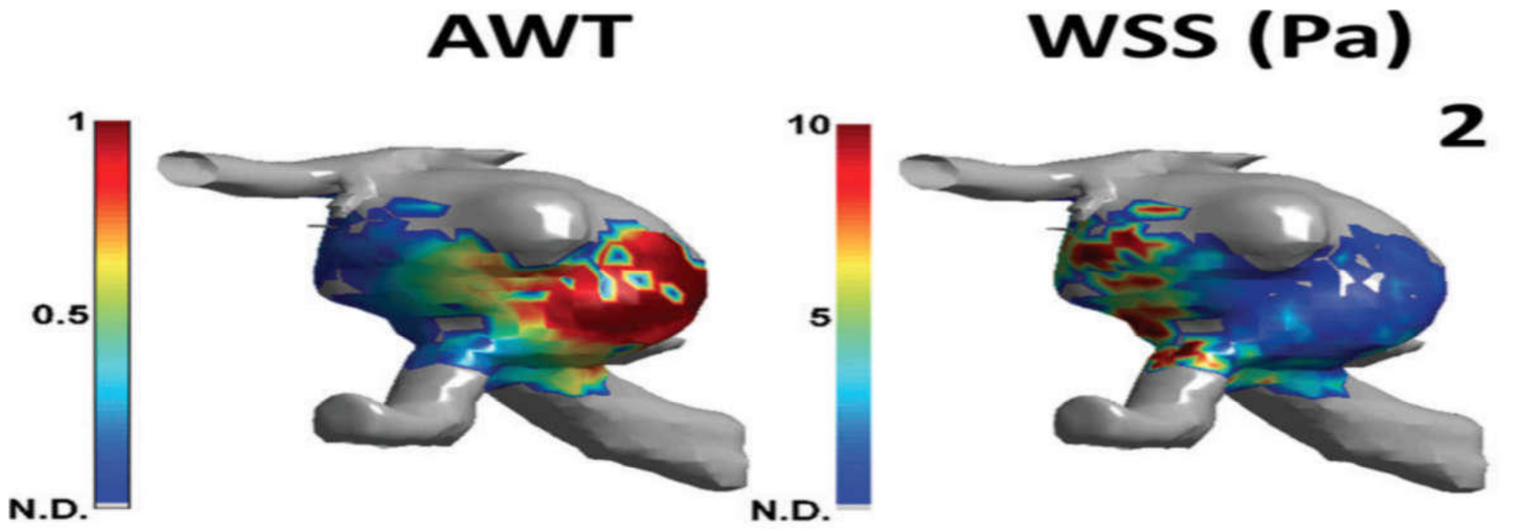
Biomarkers for neurodegenerative disease (especially vascular dementia).

Improved detection of cavernomas (type IV) and draining vein.

Unruptured cerebral aneurysms

NEUROVASCULAR

Development of technique which has allowed to show inverse correlation between unruptured aneurysm wall thickness and friction strain on vessel wall.



Blankena et al 2016

Important for the study of pathological mechanisms leading to aneurysm growth and rupture → prediction of rupture risk.

NEUROVASCULAR

Currently no application in stroke to guide thrombolysis or thrombectomy.

Application in stroke workup.

Biomarkers for neurodegenerative disease (especially vascular dementia).

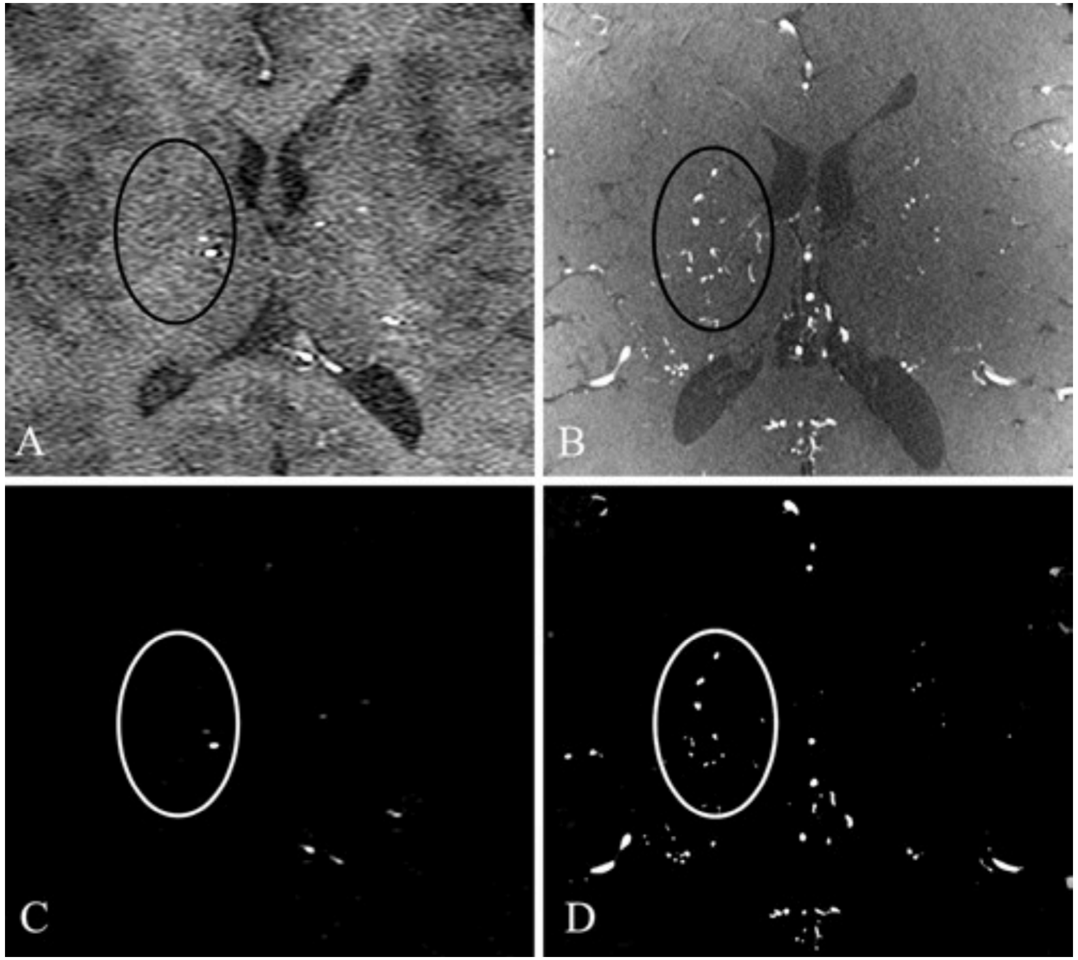
Improved detection of cavernomas (type IV) and draining vein.

Unruptured cerebral aneurysms

Replacement for DSA (Digital Subtraction Angiography).

NEUROVASCULAR

7T MRI could replace DSA for the diagnosis / followup of certain diseases,
i.e. Moya-Moya disease or syndrome in pediatric population.



Current diagnostic criteria suggest that arterial stenosis / occlusion + abnormal arteriolar network are sufficient for diagnosis.

Deng et al 2016

III . CLINICAL APPLICATIONS OF 7T MRI IN NEUROINFLAMMATORY DISEASES

NEUROINFLAMMATORY

Multiple Sclerosis

Demyelinating disease

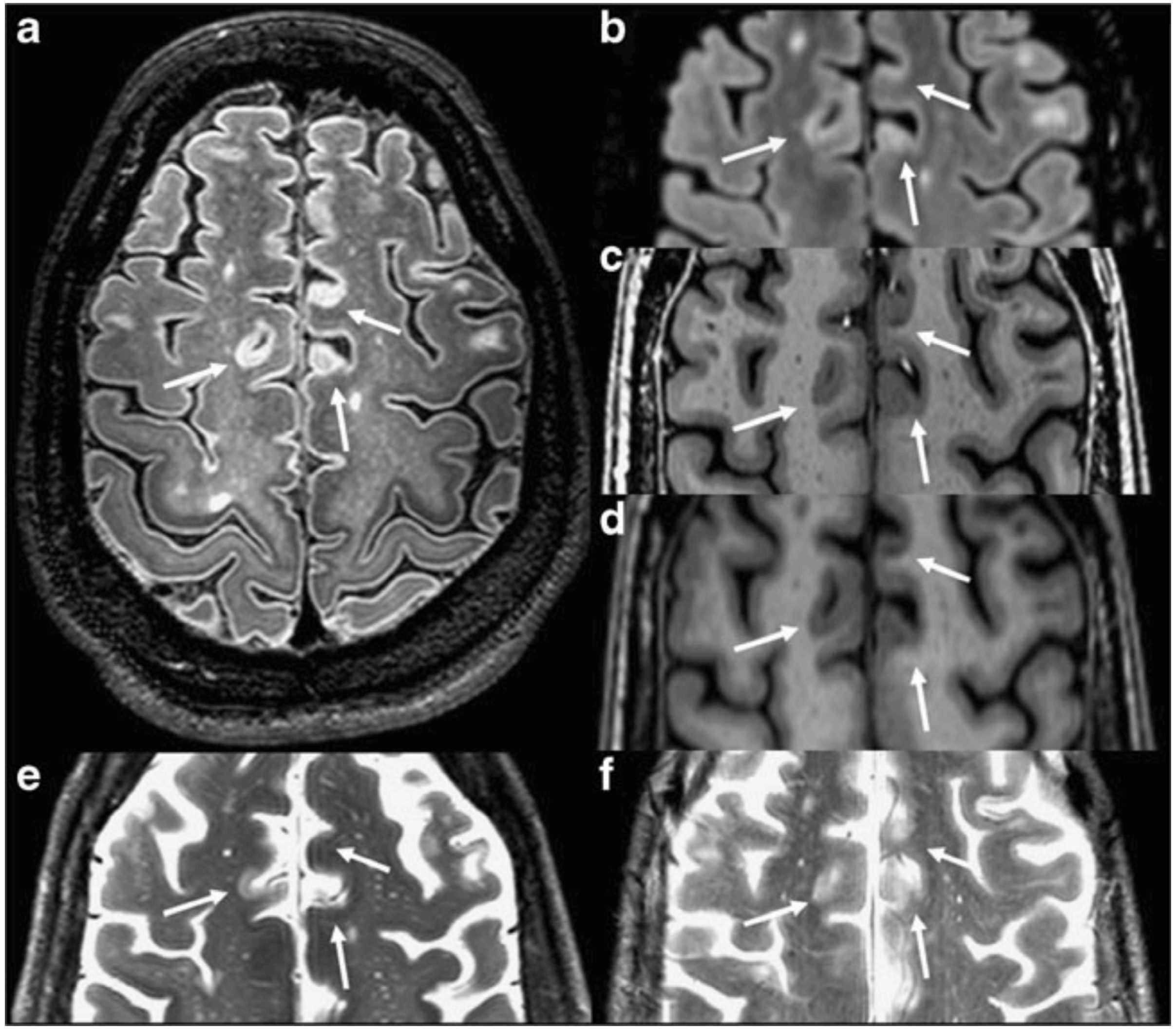
Hyperintense T2-FLAIR lesions

MRI : diagnosis / followup / prognosis
& rule out differential diagnoses (NMO +++)

NEUROINFLAMMATORY

Recently introduced in criteria
for spatial dissemination : **cortical lesions**.

→ **augment diagnostic specificity for MS**



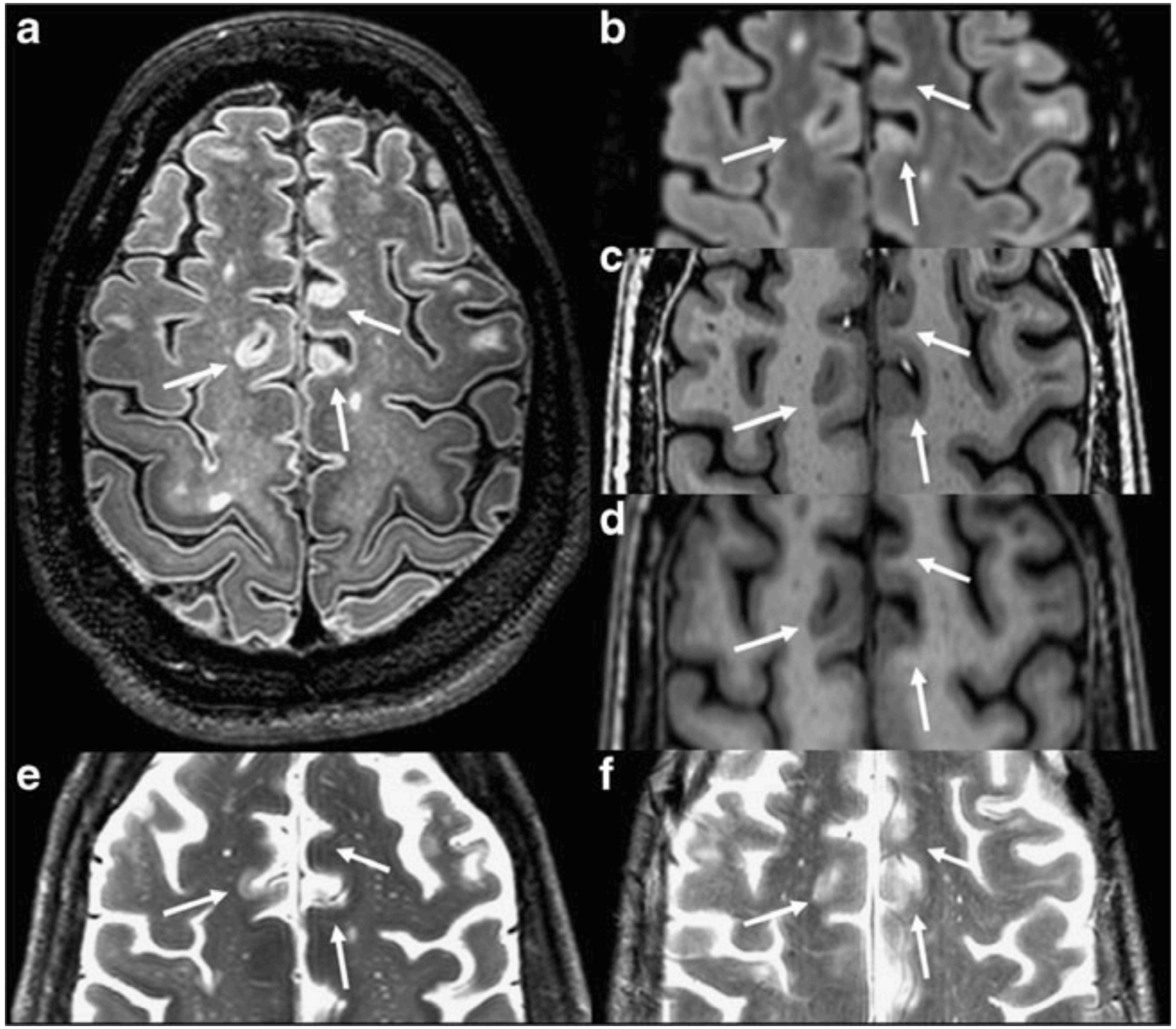
De Graaf et al 2013

NEUROINFLAMMATORY

Recently introduced in criteria
for spatial dissemination : **cortical lesions**.

→ augment diagnostic specificity for MS

→ more gray matter lesions detected on 7T MRI (Kollia et al 2009, De Graaf et al 2013, Kilsdonk et al 2016)



De Graaf et al 2013

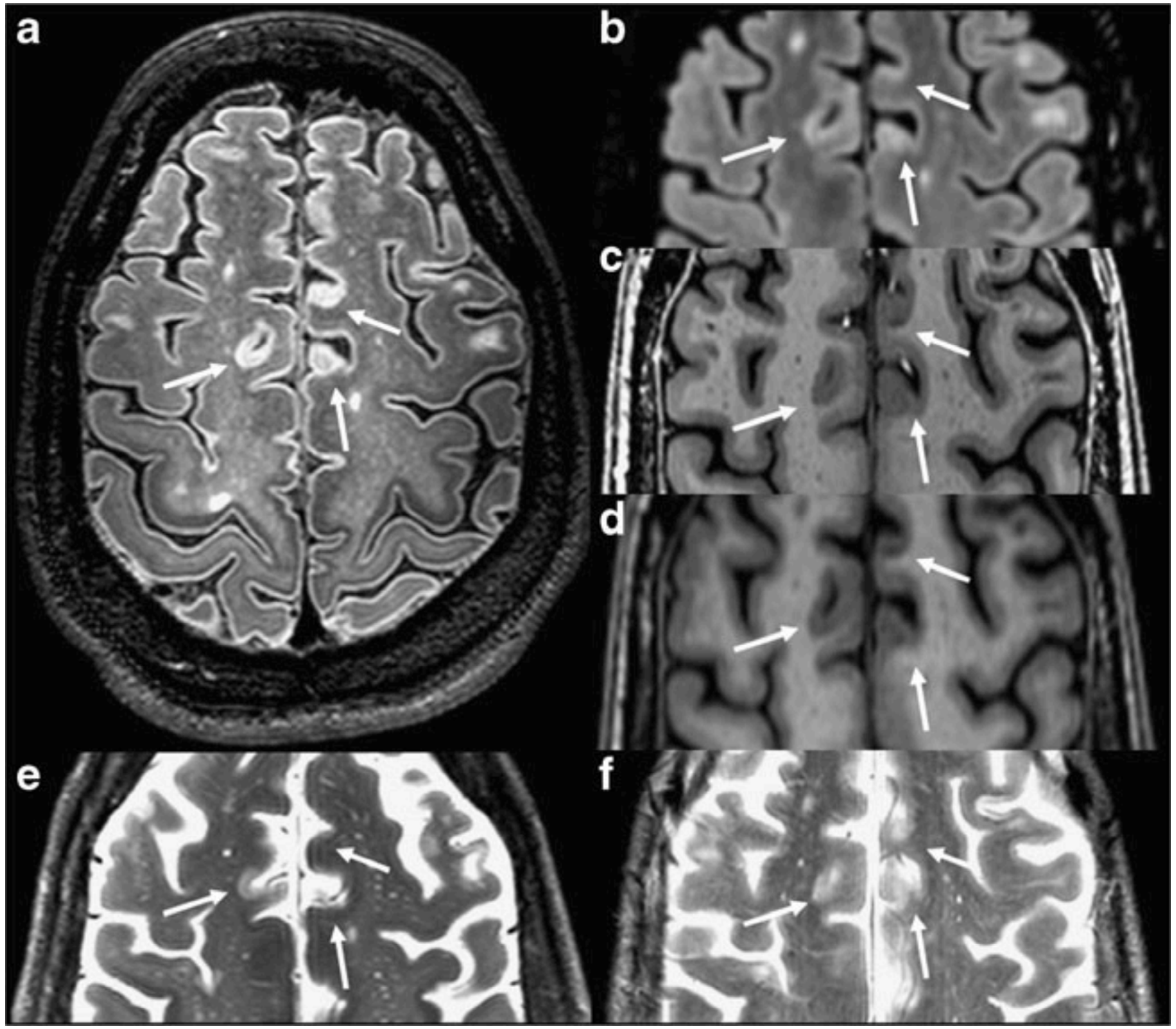
NEUROINFLAMMATORY

Recently introduced in criteria
for spatial dissemination : **cortical lesions**.

→ augment diagnostic specificity for MS

→ more gray matter lesions detected
on 7T MRI (Kollia et al 2009, De Graaf et al 2013, Kilsdonk et al 2016)

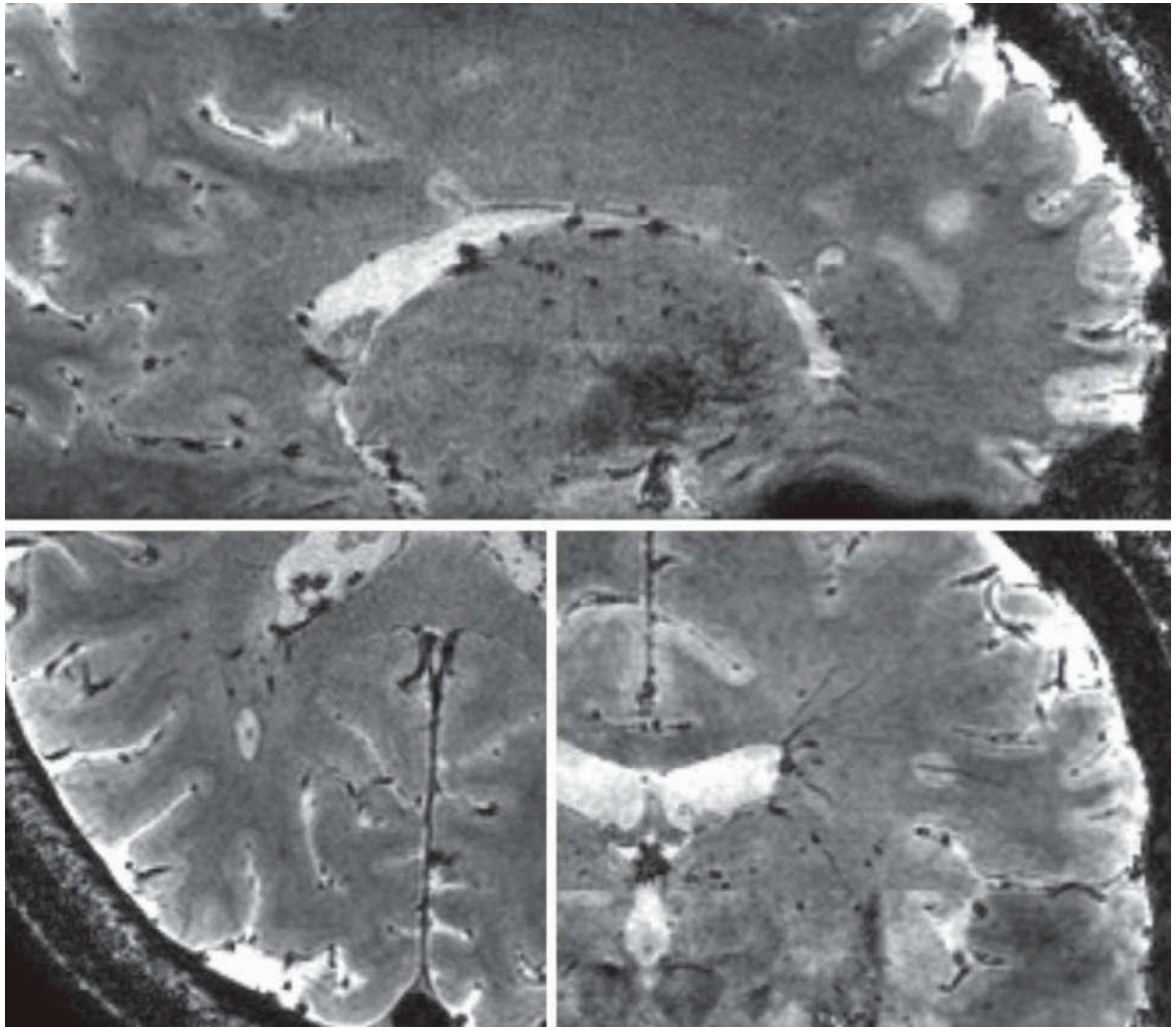
→ **strong association with physical and mental disability** (Harisson et al 2015)



De Graaf et al 2013

NEUROINFLAMMATORY

Central Vein sign recently described in MS diagnostic criteria.

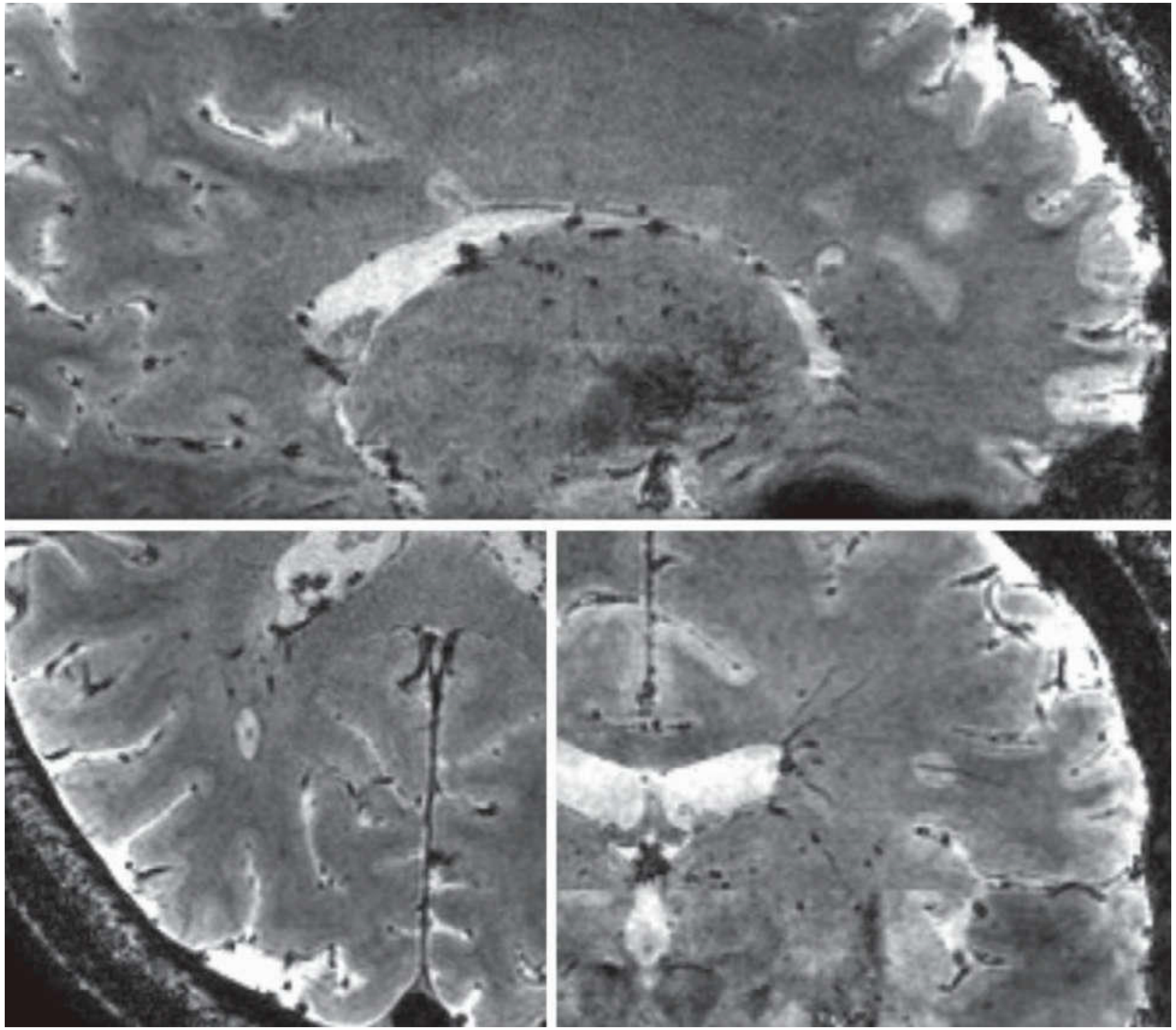


Mistry et al 2013

NEUROINFLAMMATORY

Central Vein sign recently described in MS diagnostic criteria.

More frequently seen on 7T MRI compared to 3T (Tallantyre et al 2009)



Mistry et al 2013

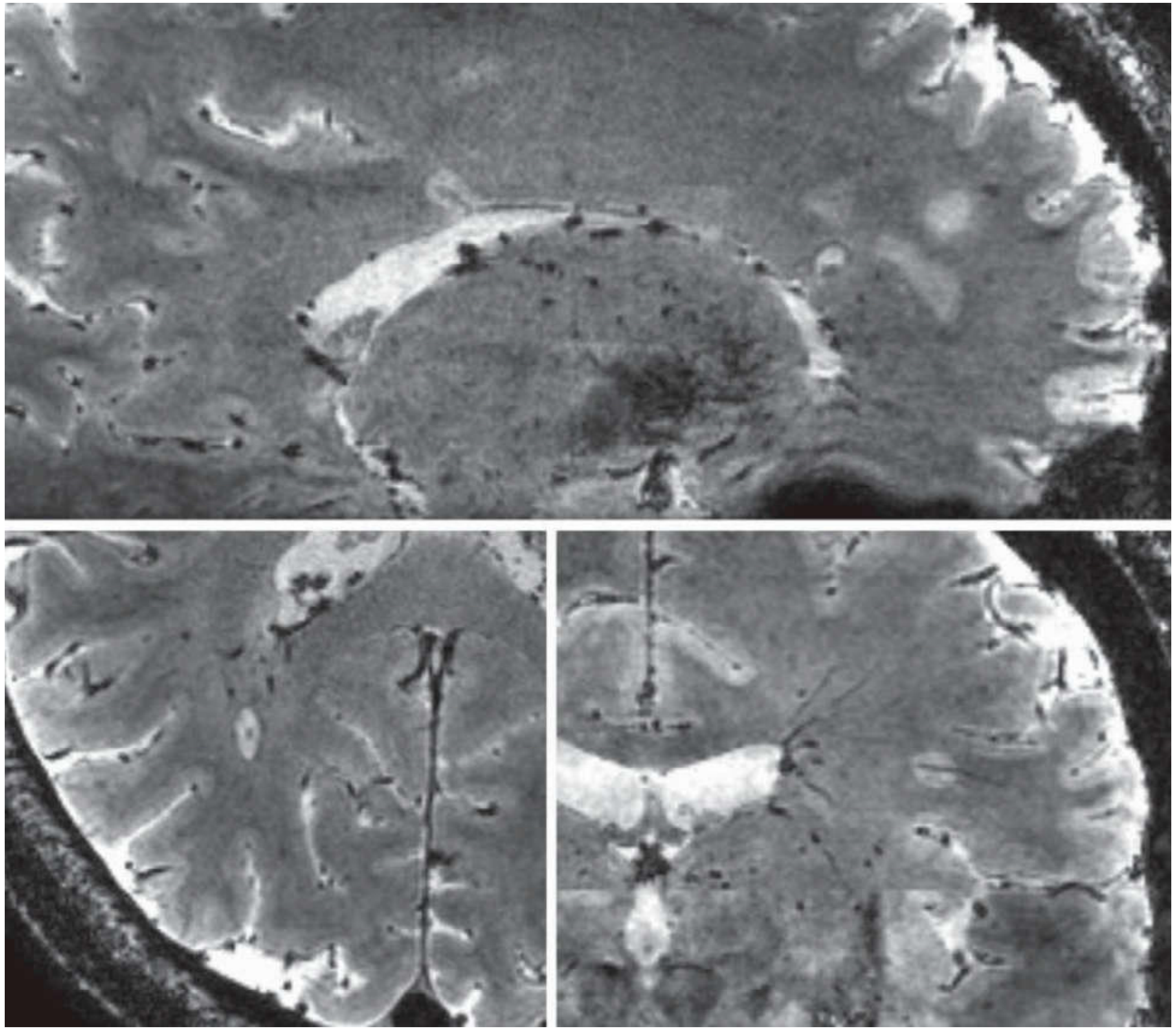
NEUROINFLAMMATORY

Cut-off in > 40% lesions in T2 hypersignal with **central vein** diagnostic characterization of MS.

→ vs vascular hypersignal
(Kilsdonk et al 2014)

→ vs hypersignal in NMO
(Sinnecker et al 2012)

→ vs hypersignal in Susacdisease
(Wuerfelet al 2012)

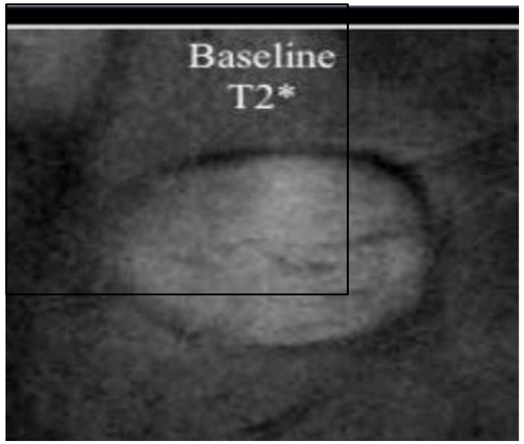


Mistry et al 2013

NEUROINFLAMMATORY

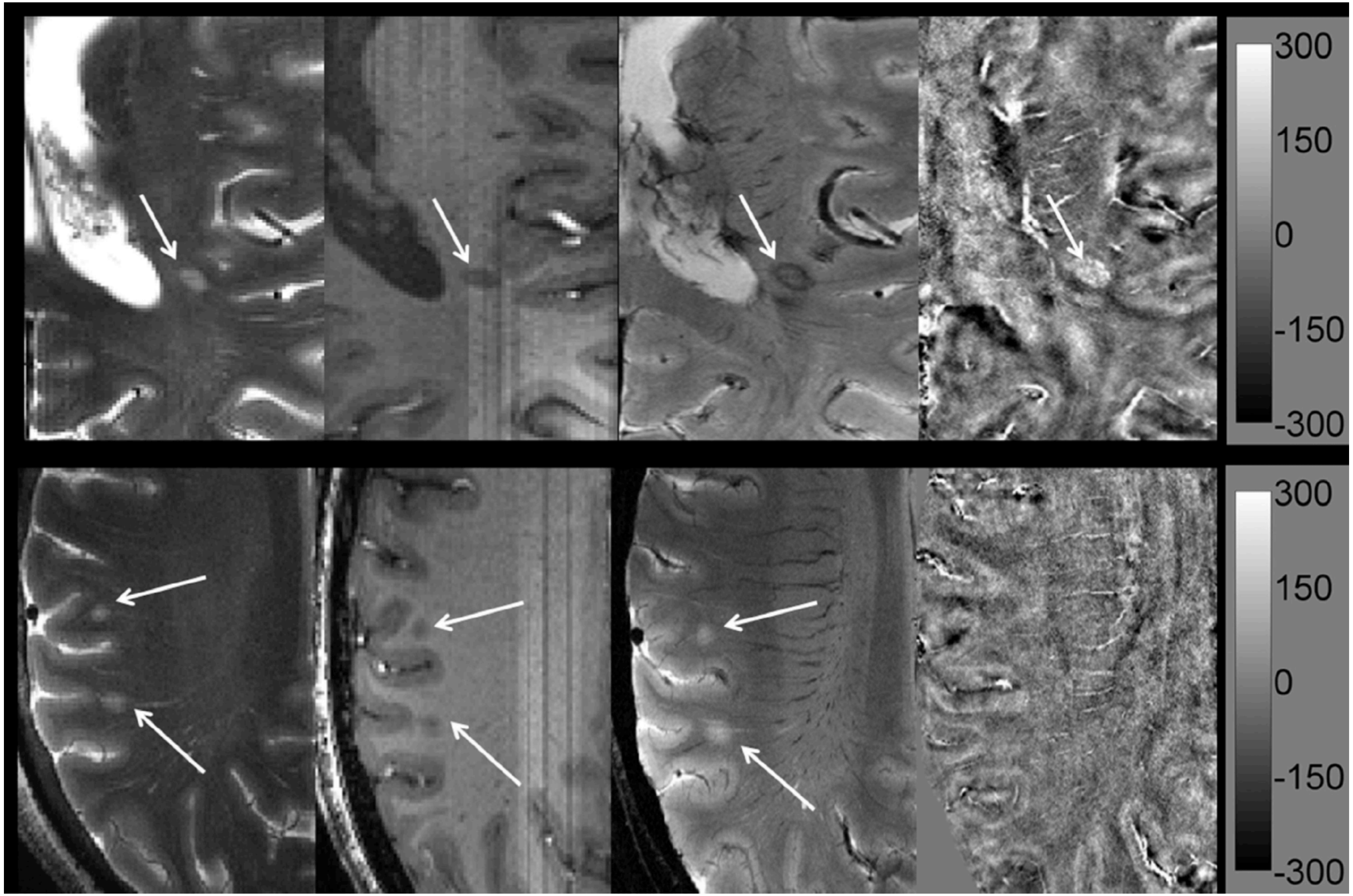
Paramagnetic Rim sign

→ vs NMO
(Chawla et al 2016,
Sinnecker et al 2016)



Absinta et al 2013

Chawla et al 2016



NEUROINFLAMMATORY

Central vein sign

+ **Paramagnetic Rim sign**

+ **Cortical lesions** (recently introduced criterion, but categorized as juxta-cortical lesions)

= MRI Biomarkers for MS

More conspicuous on 7T MRI

Significantly helps rule out differential diagnoses (ECTRIMS 2019 - Stockholm)

IV. CLINICAL APPLICATIONS OF 7T MRI IN MENTAL HEALTH

MENTAL HEALTH

High prevalence

3rd most common pathology after cancer and cardiovascular diseases (WHO)

1 in 5 French citizen has mental health disease (Institut Montaigne)

Economic burden

Direct and indirect costs estimated at 110 Billion Euros in France

Only 2% of biomedical expenditures in France (21 million Euros – Institut Montaigne)

Few or no biomarkers for the diagnosis and follow up of patients

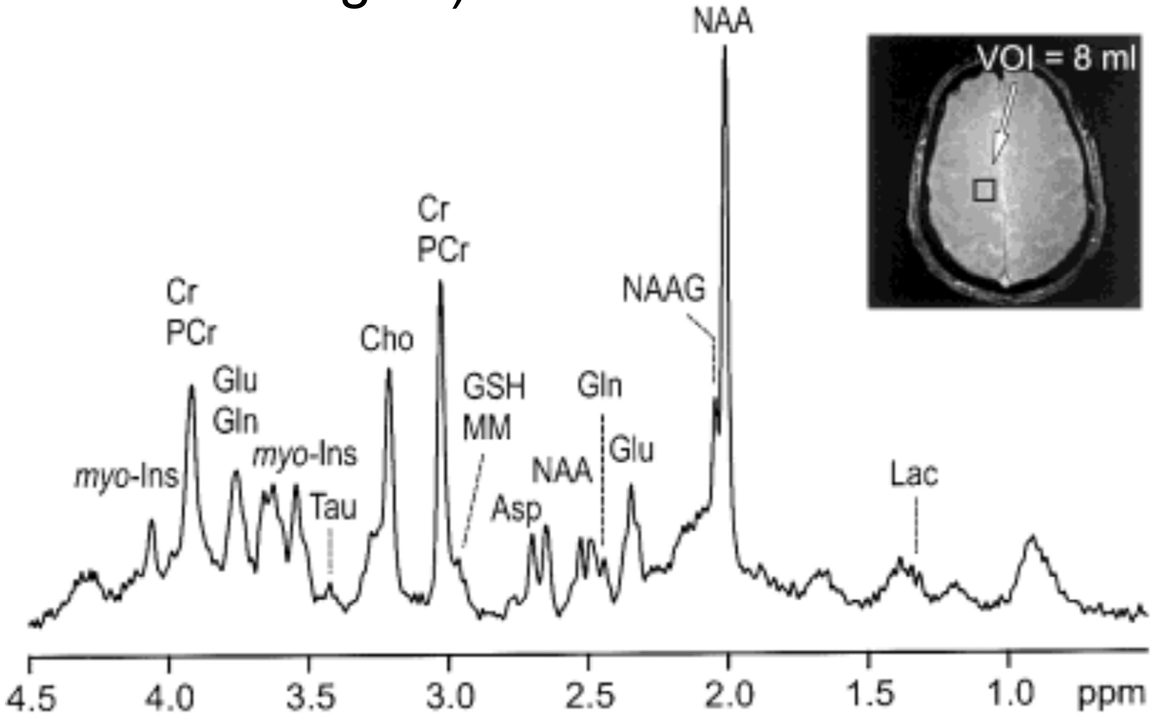
Role for high and ultra-high field imaging in the near future ?

MENTAL HEALTH

Advantages of ultra-high field MRI

Better spectral resolution

Metabolic evaluation, separation between Glutamate and Glutamine (impossible at lower field strengths)

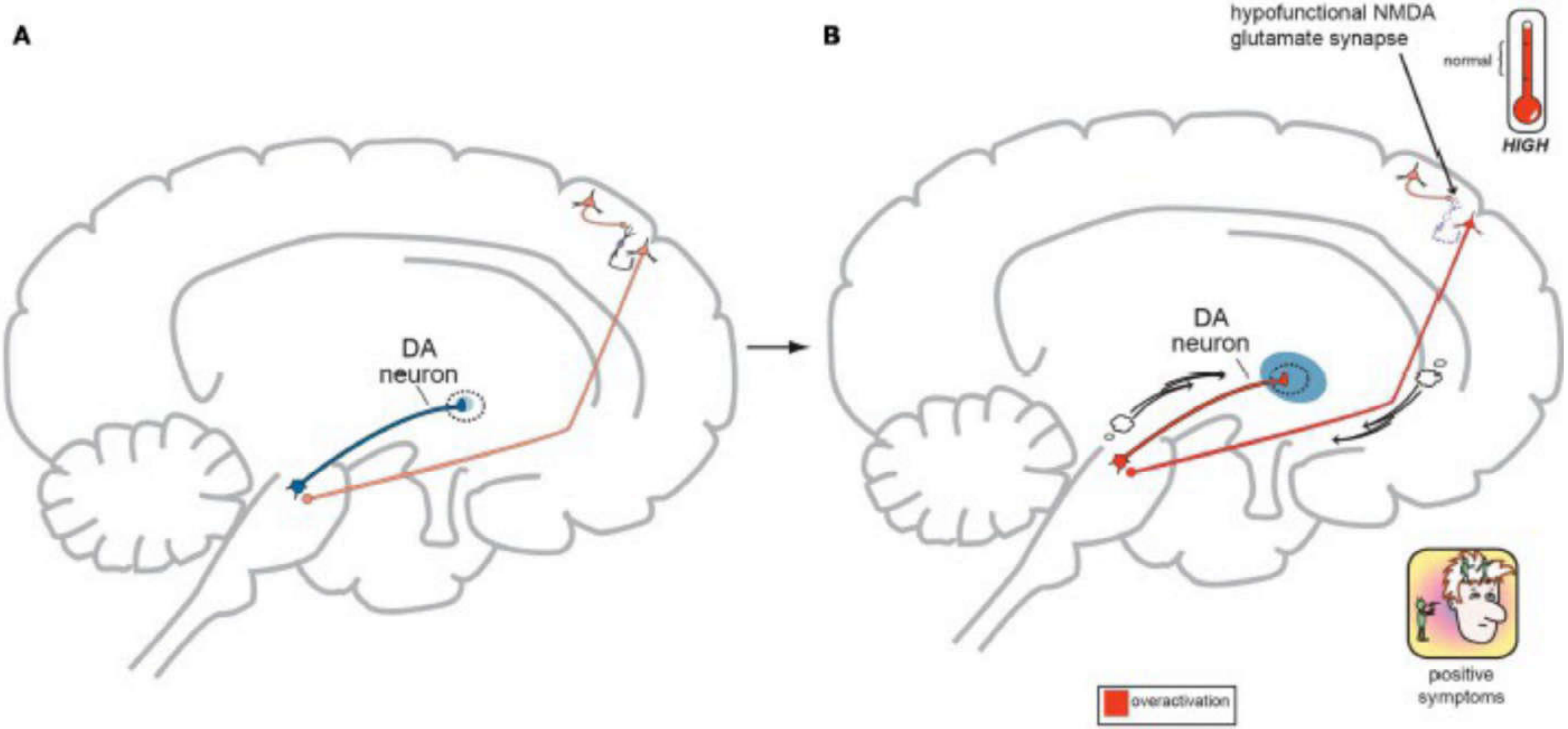


Tkac et al 2001

MENTAL HEALTH

Better spectral resolution

→ Validation of metabolic pathophysiological hypotheses, particularly in schizophrenia



Stahl, 4ème édition, 2015

MENTAL HEALTH

Better spectral resolution

→ Validation of metabolic pathophysiological hypotheses, particularly in schizophrenia

→ Changes in neurotransmitter concentrations in patients with first psychotic event

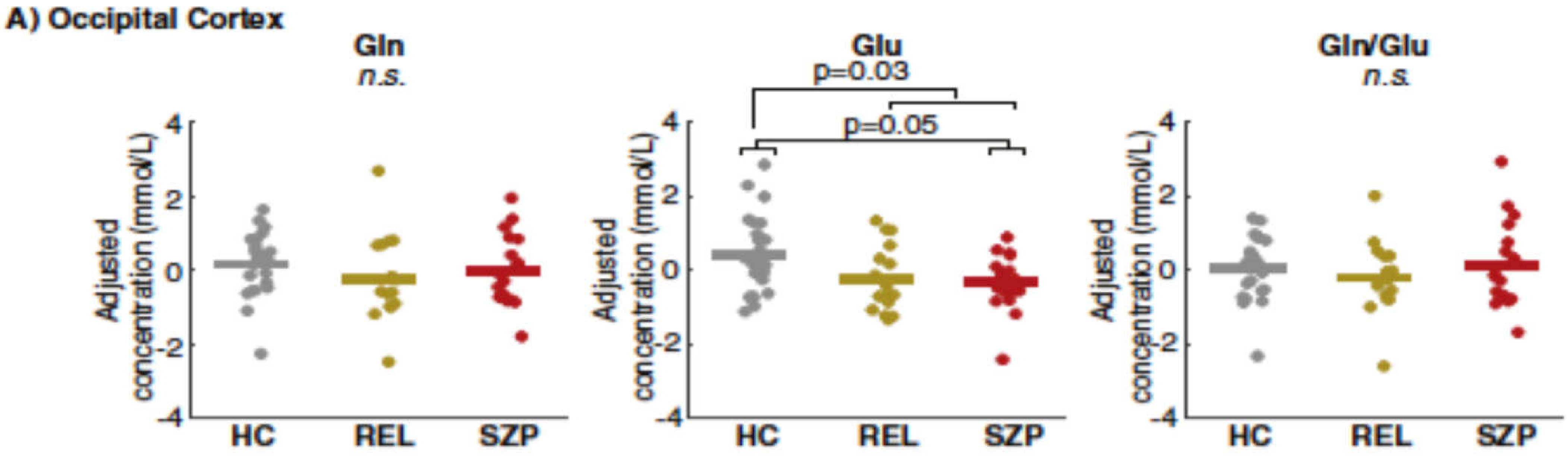
(Wang et al 2019)

MENTAL HEALTH

Better spectral resolution

→ Validation of metabolic pathophysiological hypotheses, particularly in schizophrenia

→ Perturbation of glutamatergic pathway in related patients (REL ; Thakkar et al 2017)



MENTAL HEALTH

Better spectral resolution

In vivo modelisation, neurotransmitter anomalies in other mental health diseases

→ Anorexia nervosa (Godlewska et al 2017)

→ Depressive disorders (Taylor et al 2017)

Identification of therapeutic targets and evaluation of effectiveness of potential treatments (Li et al 2016, Cai et al 2012, Masaki et al 2016)

MENTAL HEALTH

Advantages of ultra high field imaging

Better spectral resolution

Metabolic evaluation, separation between Glutamate and Glutamine not possible at low field

Increased magnetic susceptibility

BOLD effect more pronounced → improved functional MRI and neuronal network evaluation

MENTAL HEALTH

Increased magnetic susceptibility

BOLD effect more pronounced

→ improved functional MRI and neuronal network evaluation

→ Improved differentiation between oxyhemoglobin-rich arterial blood (following task) and veinous blood (deoxyhemoglobin).

MENTAL HEALTH

Increased magnetic susceptibility

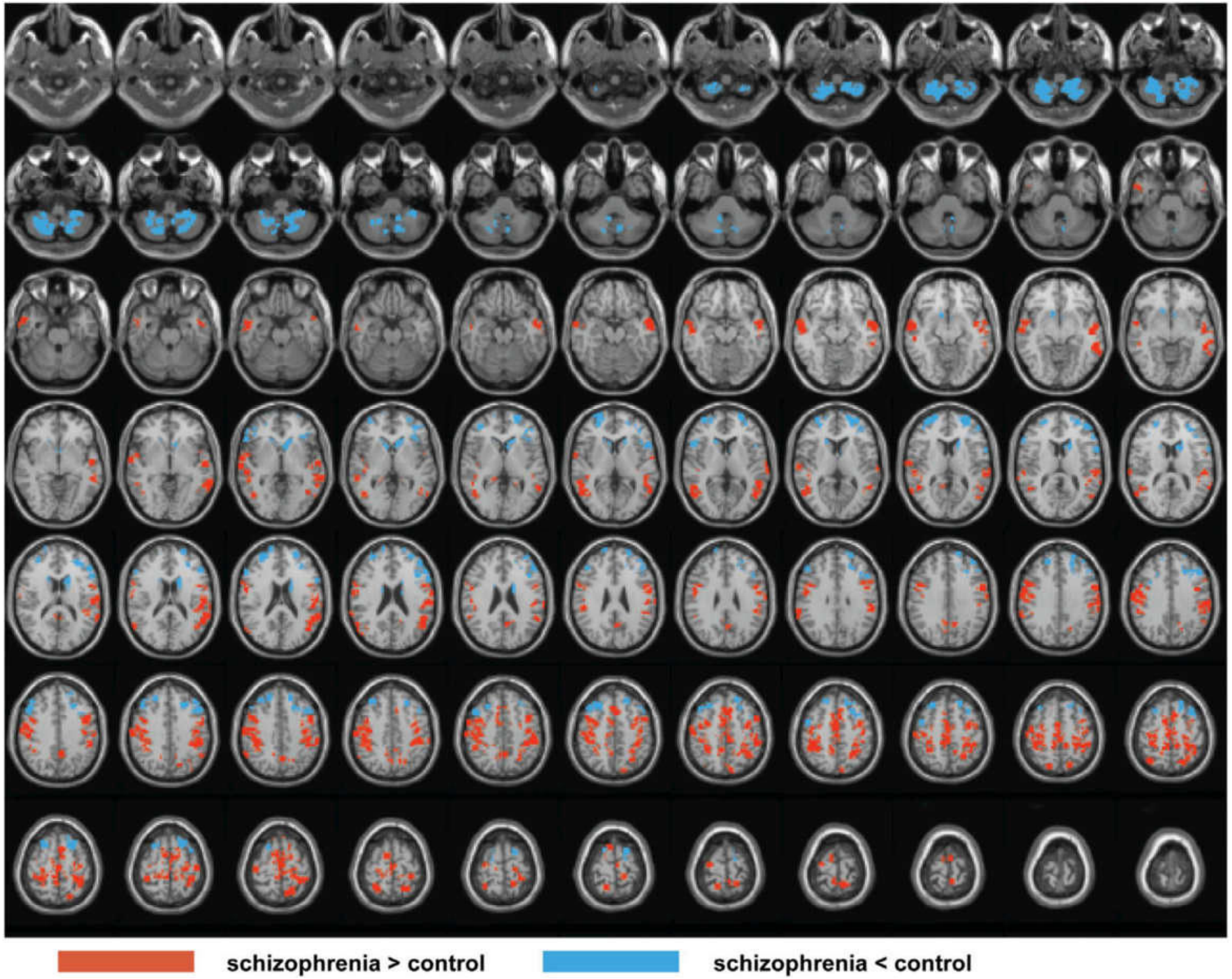
BOLD effect more pronounced

→ improved functional MRI and neuronal network evaluation

→ In patients with schizophrenia, **alteration of neuronal network** :

- at rest (réseaux sous corticaux et auditifs, Lottman et al 2019 ; réseaux thalamo corticaux, Hua et al 2019)
- during a cognitive task (Overbeek et al 2019)

MENTAL HEALTH



Hua et al 2019

MENTAL HEALTH

Increased magnetic susceptibility

BOLD effect more pronounced

→ improved functional MRI and neuronal network evaluation

→ fMRI : MRI biomarker for early treatment response ?

De-activation of «default-mode network» during task of facial emotion discrimination
= early response to treatment (EDC – Escitalopram ; Spies et al 2017)

MENTAL HEALTH

Advantages of ultra-high field imaging

Better spectral resolution

Metabolic evaluation, separation between Glutamate and Glutamine not possible at low field

Increased magnetic susceptibility

BOLD effect more pronounced → improved functional MRI and neuronal network evaluation

Better spatial resolution

Increased precision in morphometric and volumetric studies

MENTAL HEALTH

Better spatial resolution

Increased precision in morphometric and volumetric studies

→ Increased volume of hypothalamus in patients treated vs not treated for mood disorder compared to normals (Schindler et al 2019)

→ Significant correlation between volume of habenular complex and severity of depressive disorder in untreated patients (Schmidt et al 2017)

→ Could improve precision of neuroanatomic signature recognized on lower field imaging (De Pierrefeu et al 2018), allowing to predict transition to psychosis in patients with first psychotic event

MENTAL HEALTH

Better exploration of physiopathological modeling, validation and large scale study with 3T MRI

Future objectives :
→ Identify new therapeutic targets

→ MRI biomarkers to predict response to treatment to assist diagnosis
(in case of atypical clinical presentation or early diagnosis at syndromic stage)

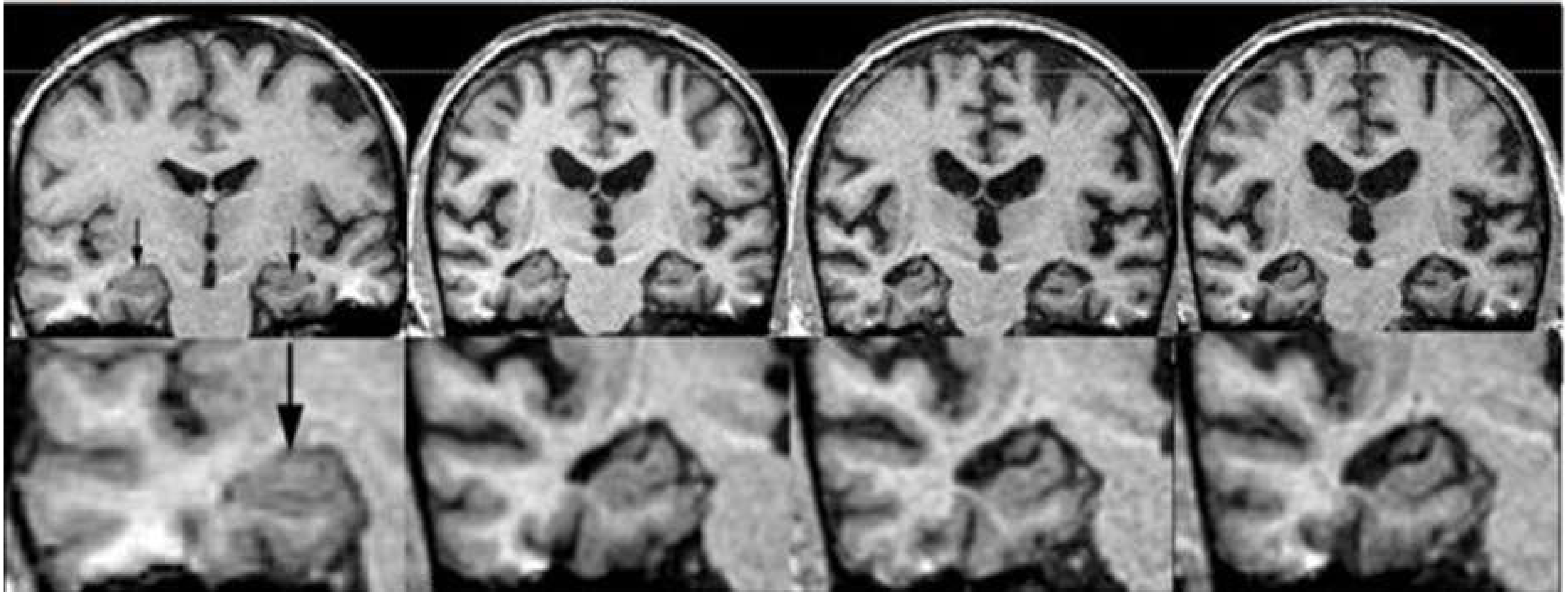
V. CLINICAL APPLICATIONS OF 7T MRI IN NEURODEGENERATIVE DISEASES

A PUBLIC HEALTH PROBLEM

- 40% Institutionalized
- 1.3 cases of Alzheimer's disease (AD) in 2020 in France
- Total health care cost (all care, medical and other) : 5 Billion Euros/year
    - 53% hospital care / 47% outpatient care
    - 13% in specialized drug cost / 7% imaging cost

A FEW NUMBERS

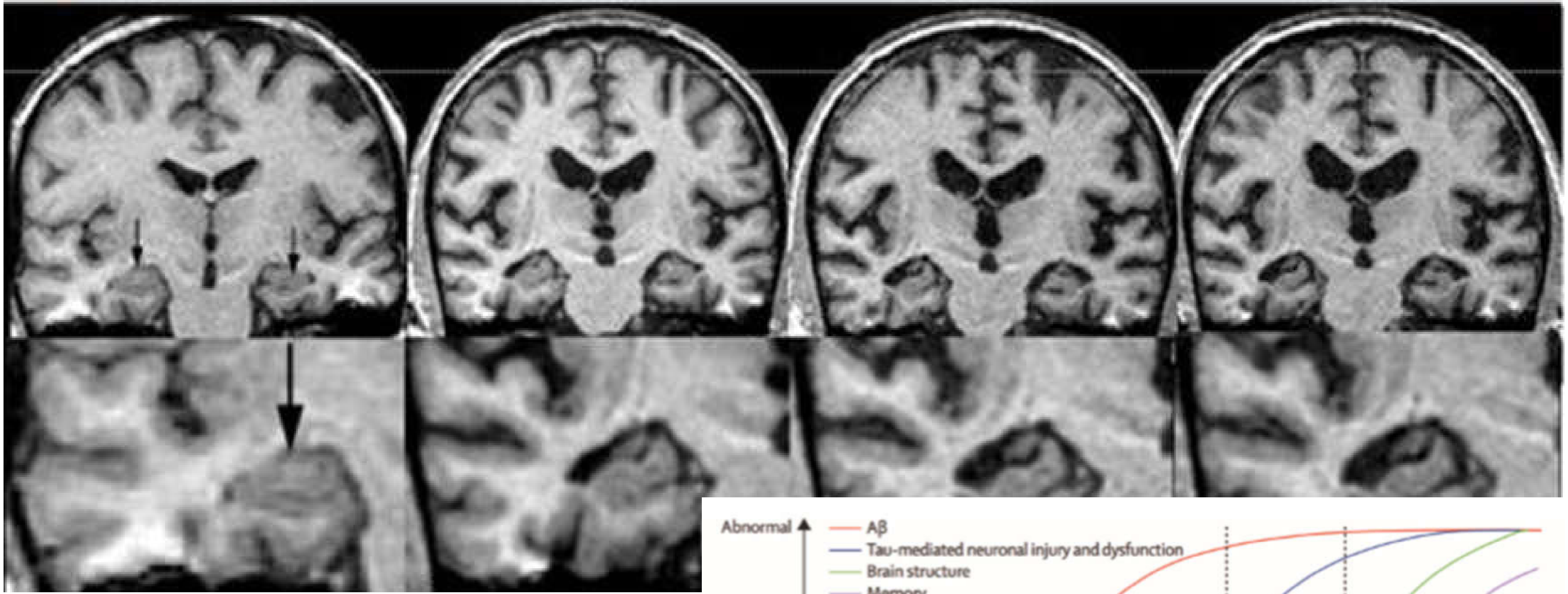
Ad patients in france | **New cases/year** | **2/3 are woman** | **Over 1000 Euros in health care costs for patients / families**



Normal aging | Mild MCI | AD Mild | AD Moderate

10% | 25% | 40%

Decrease in hippocampal volume in AD

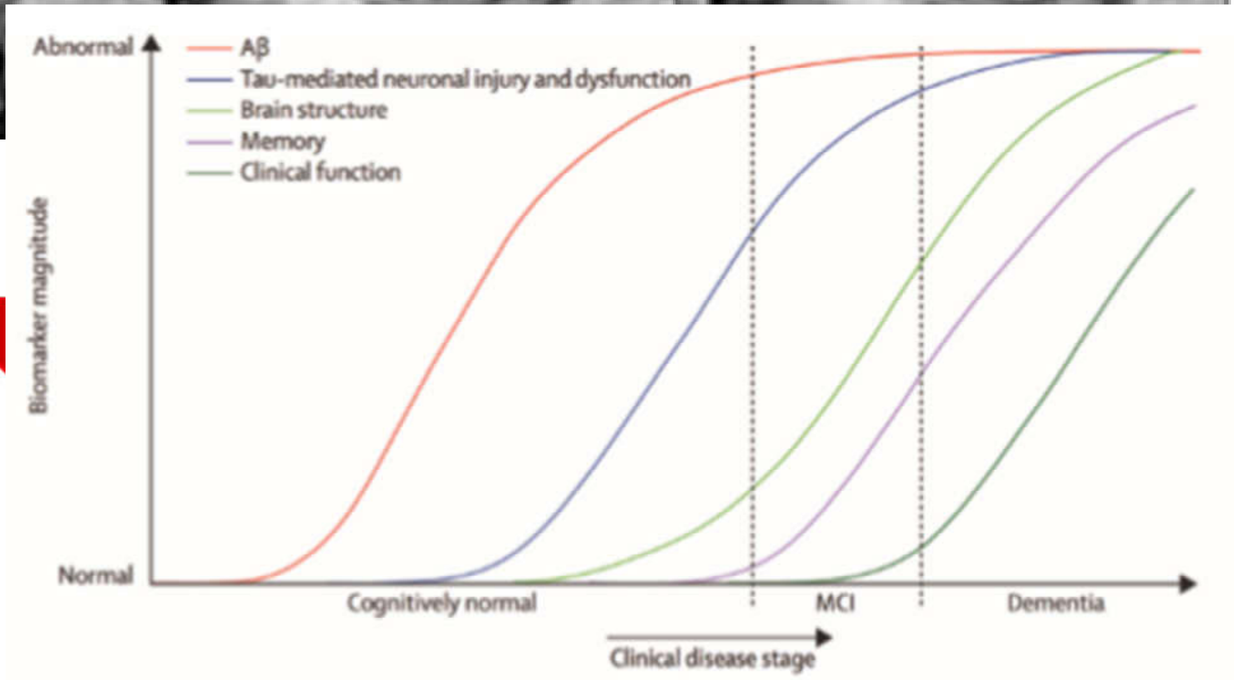


Normal aging

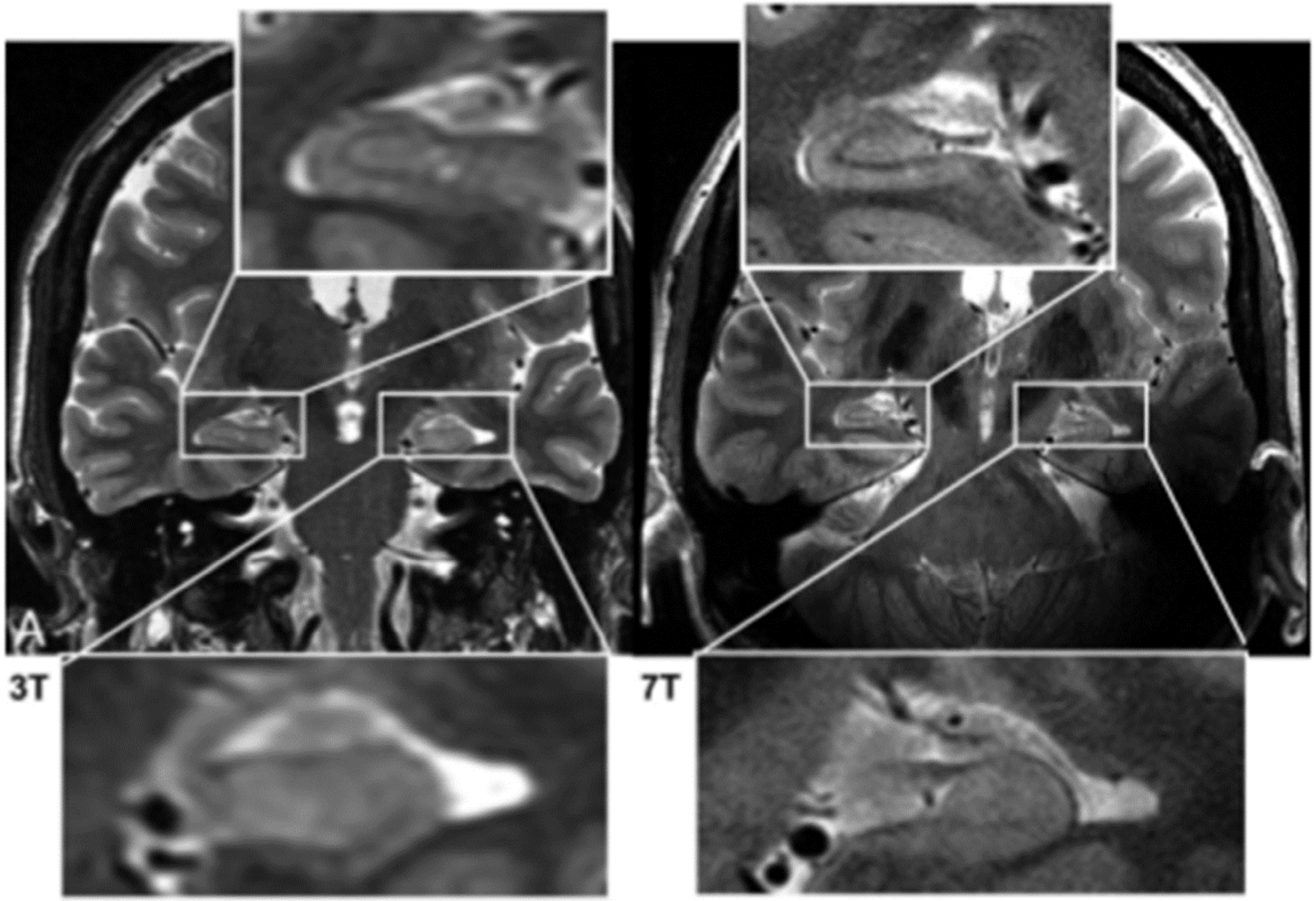
Mild MCI

Decrease in hippocampal volume in AD

10%

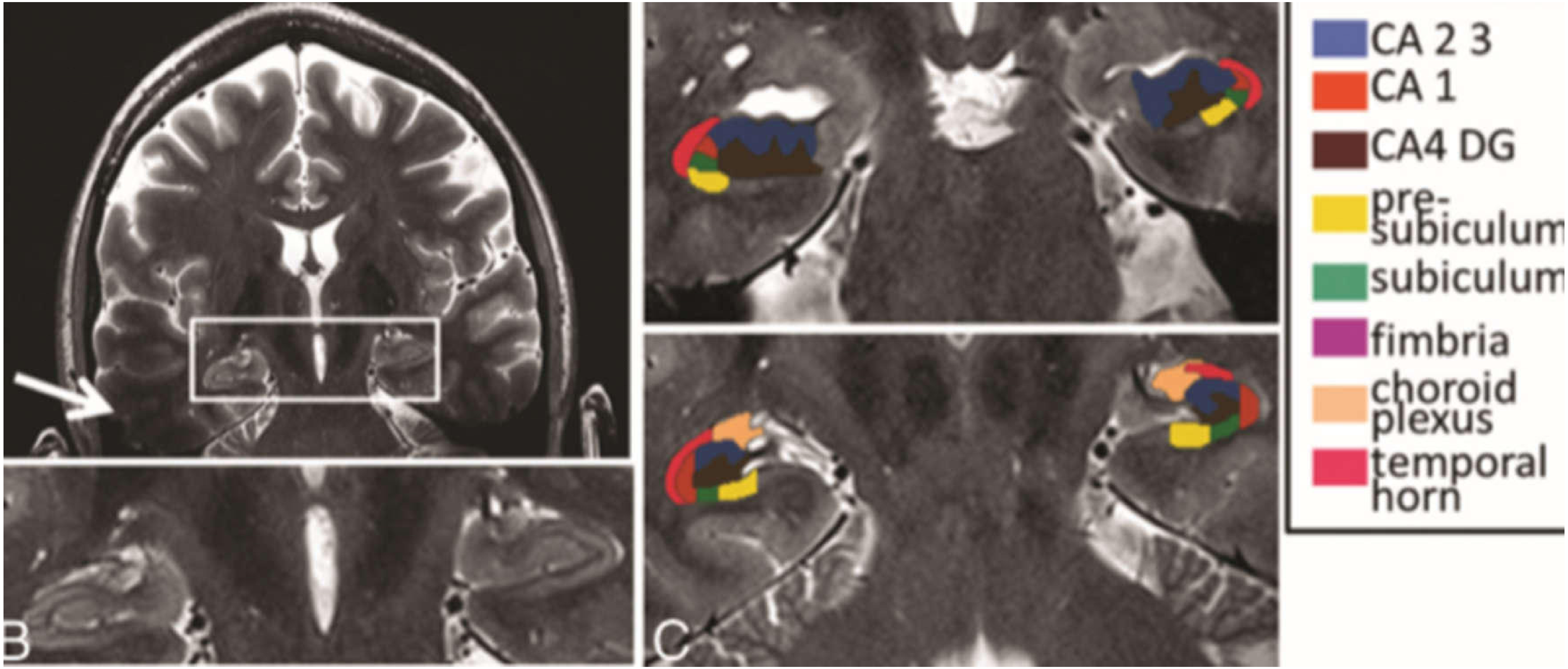


NEURODEGENERATIVE



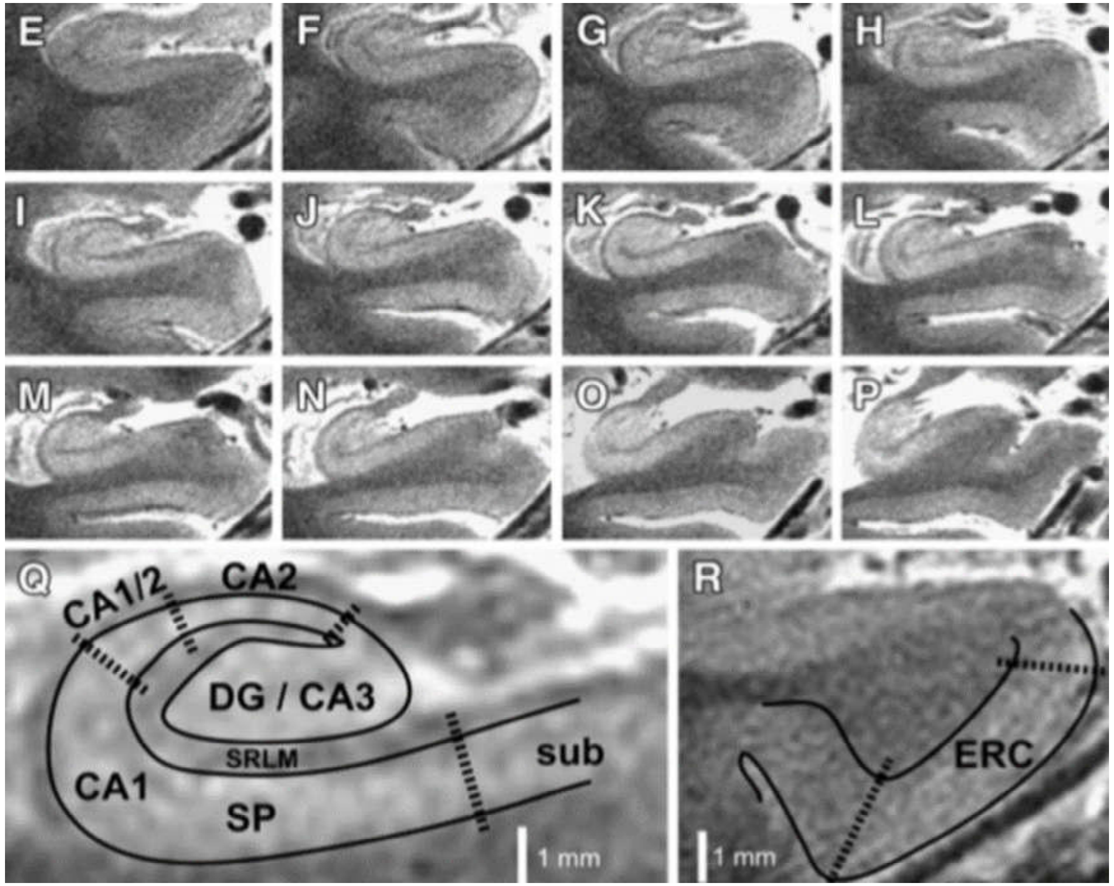
Hippocampal atrophy

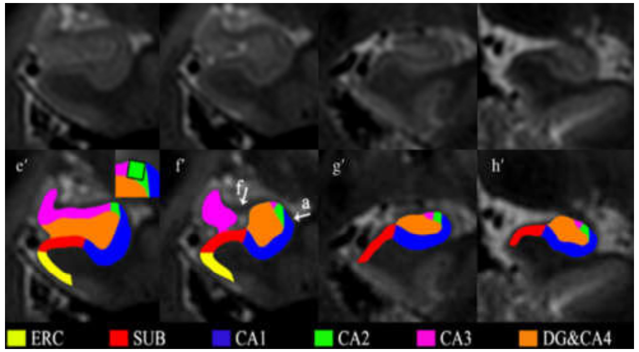
NEURODEGENERATIVE

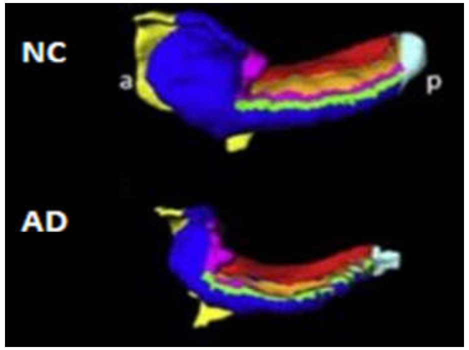


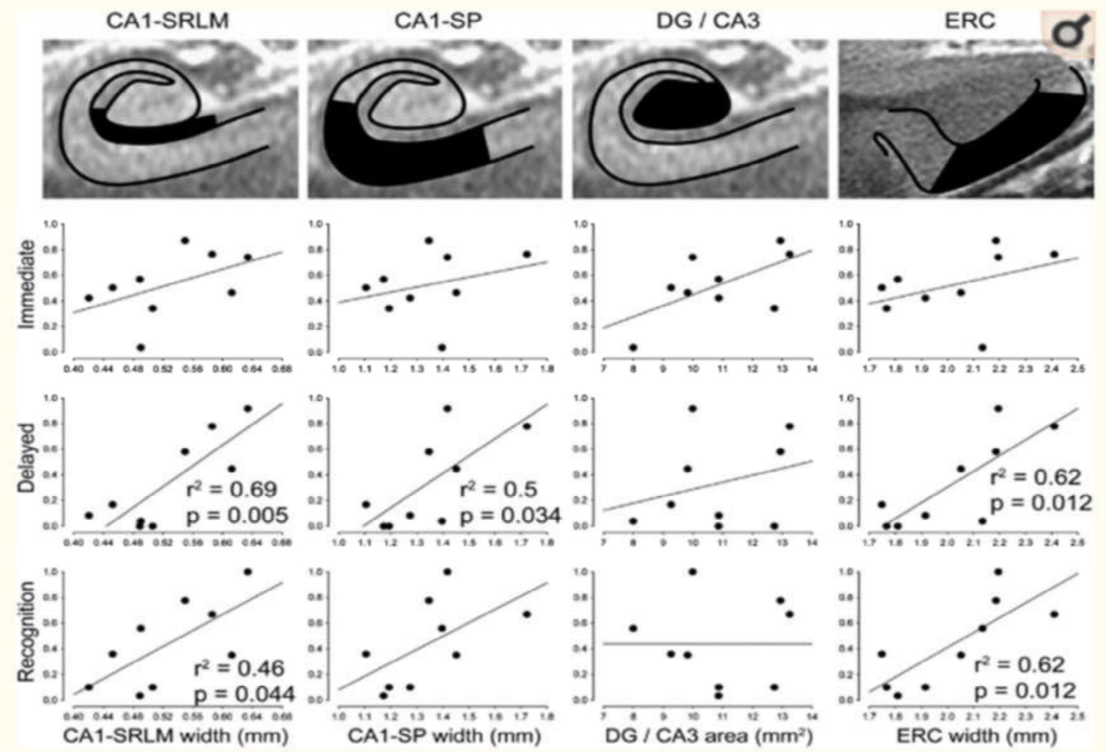
Hippocampal atrophy

NEURODEGENERATIVE





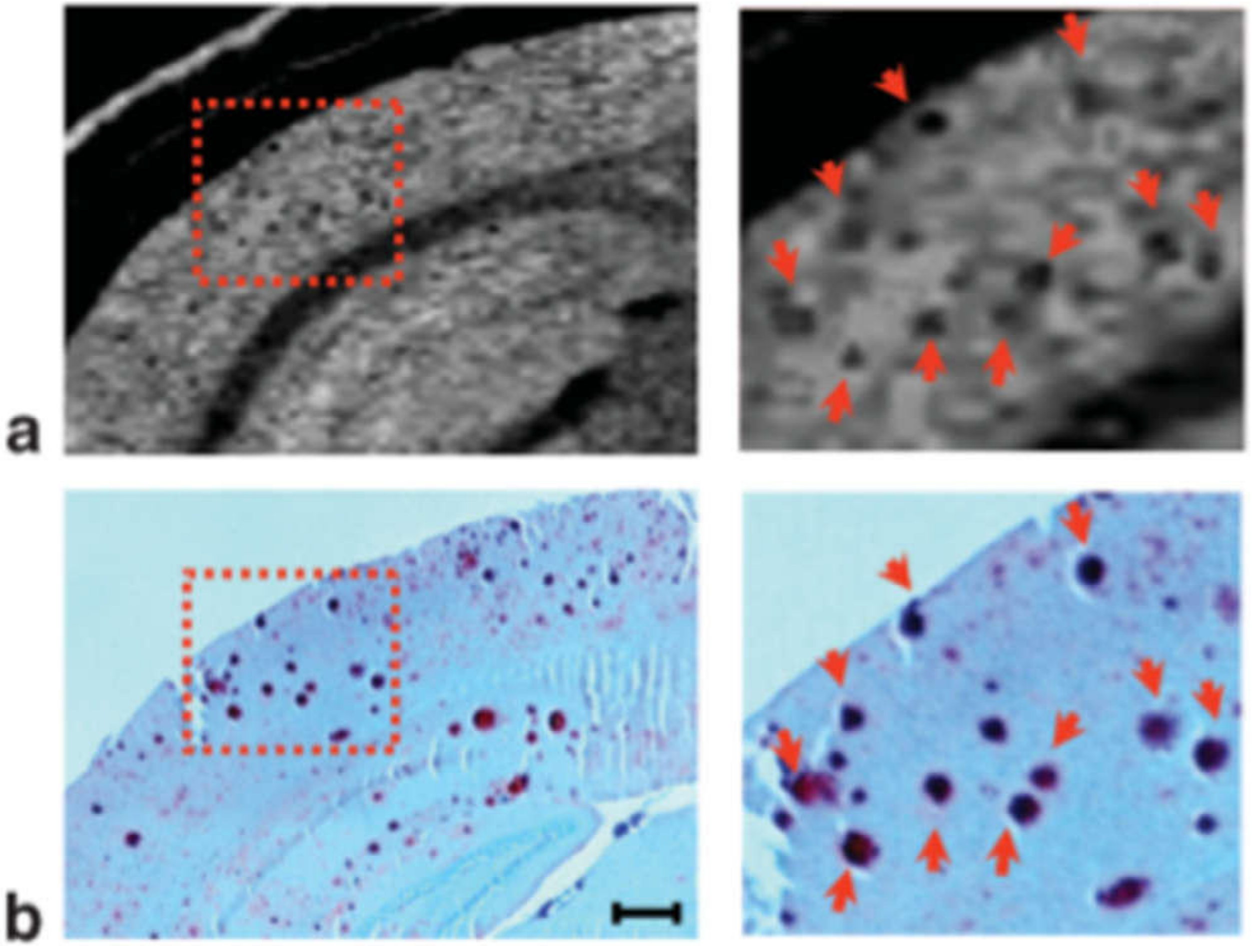




Improved definition of hippocampal sub-zones
Definition of patterns of hippocampal atrophy

NEURODEGENERATIVE

Imaging amyloid plaques



NEURODEGENERATIVE

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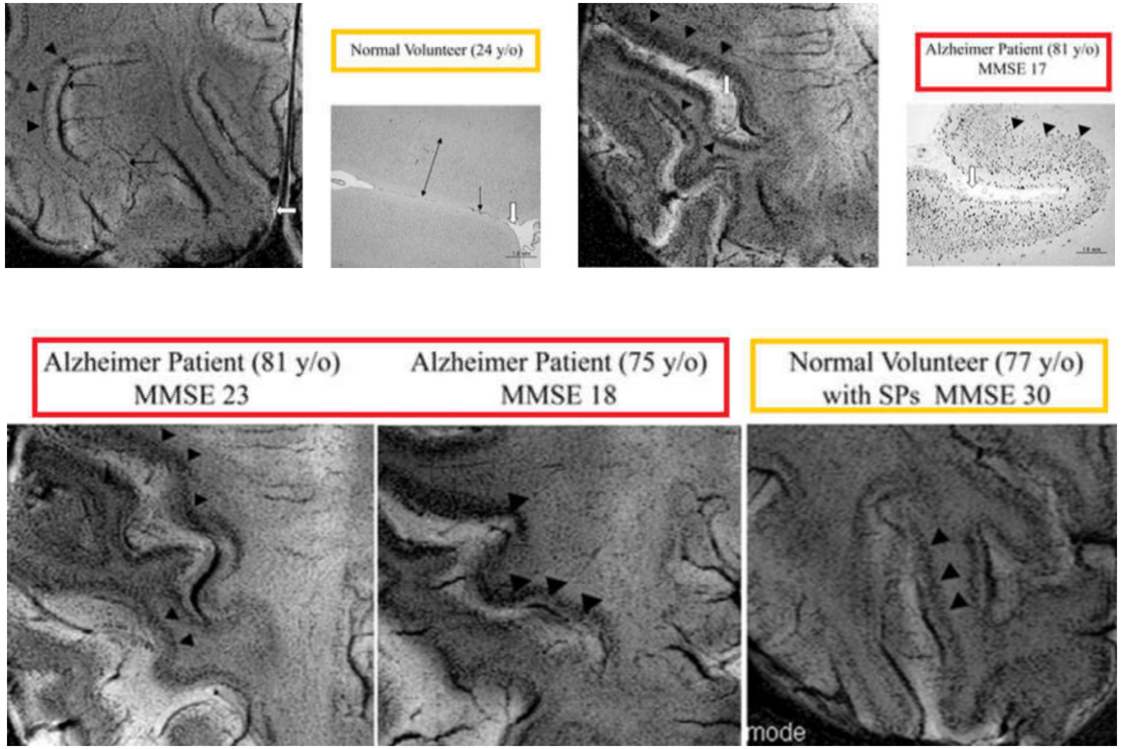
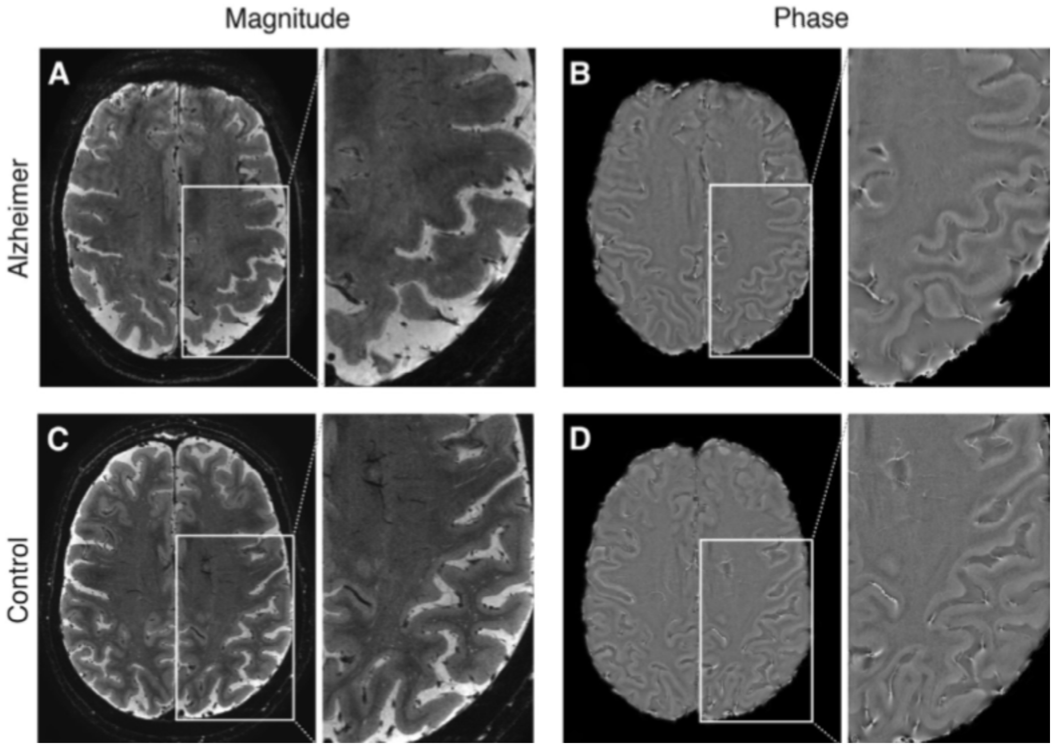


Magnetic resonance microscopy



Phase contrast MR imaging

PERSPECTIVES

Other fields of neuroradiology :

→ Drug-resistant partial complex seizures : identification of cortical dysplasia not detectable at lower field (Guye et al 2019).

→ Parkinson's disease (neuromelanin at T2*)

→ Better characterization of smaller anatomical structures : cochlea, olfactory system, etc.

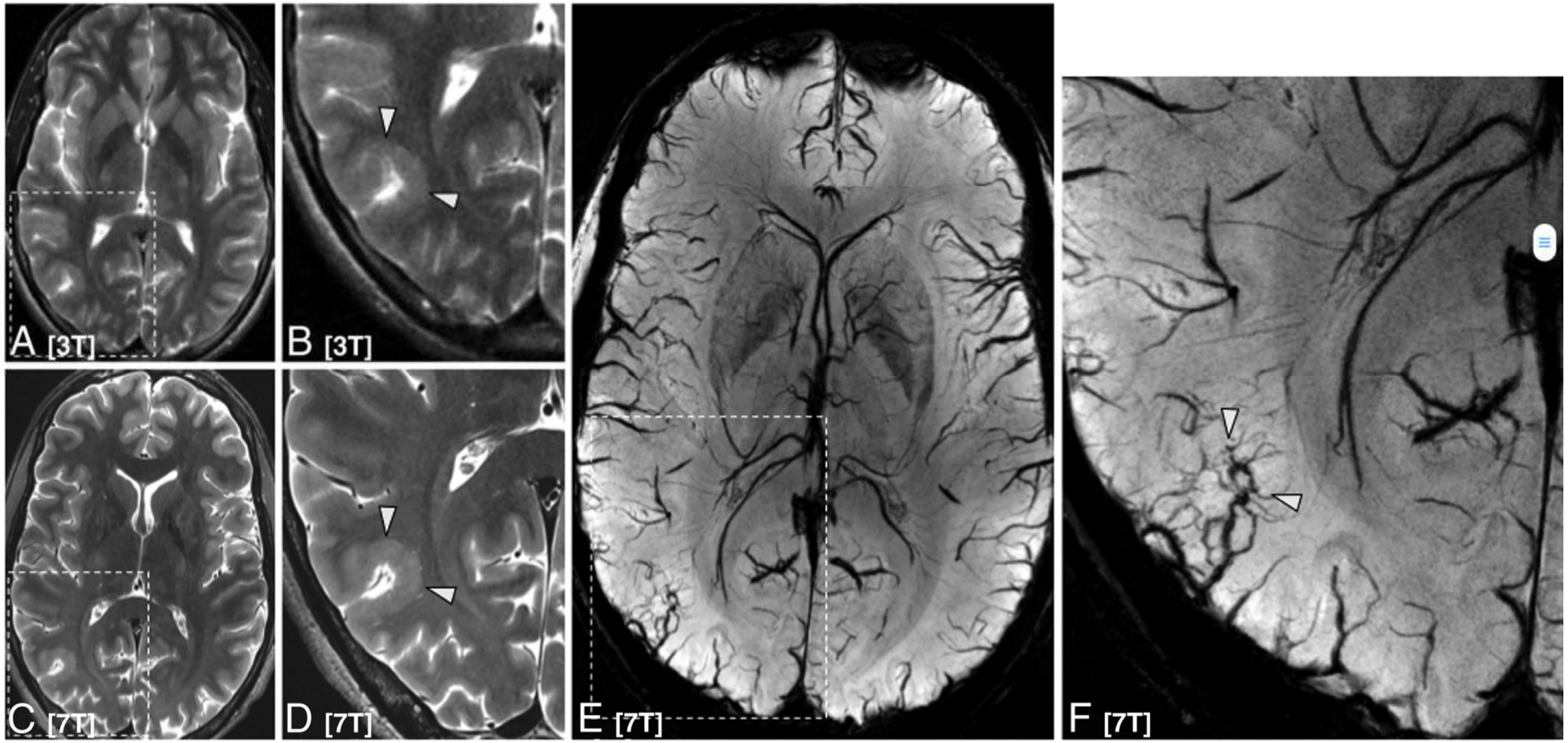
→ Brain tumors : glioblastoma infiltration

→ Trigeminal neuralgia : somatosensory pathophysiology

→ Haut de France regional project ARIANES

→ Increase in 7T imaging for large scale population studies

FOCAL SEIZURE



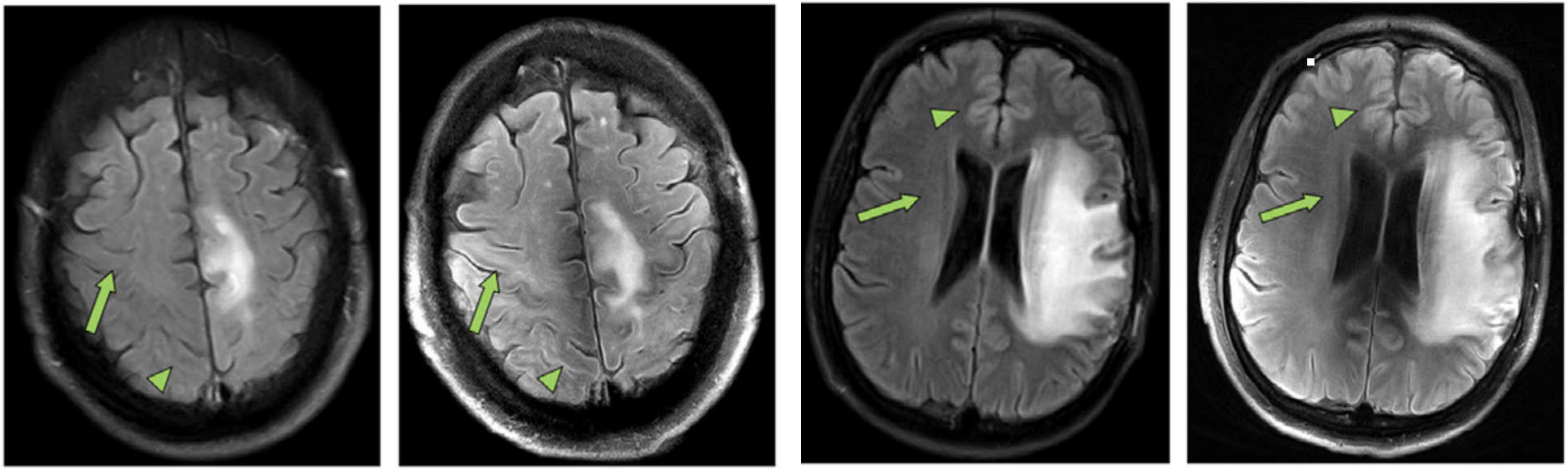
Feldman et al, 2019

Subtle right-sided epileptogenic parieto-occipital polymicrogyria faintly seen on axial T2 imaging 3T (A, B) and 7T (C, D).

SWI 7T demonstrates a cluster of venous structures associated with the polymicrogyria (E, F)

Enhanced detection of abnormalities contributed directly to better surgical interventions

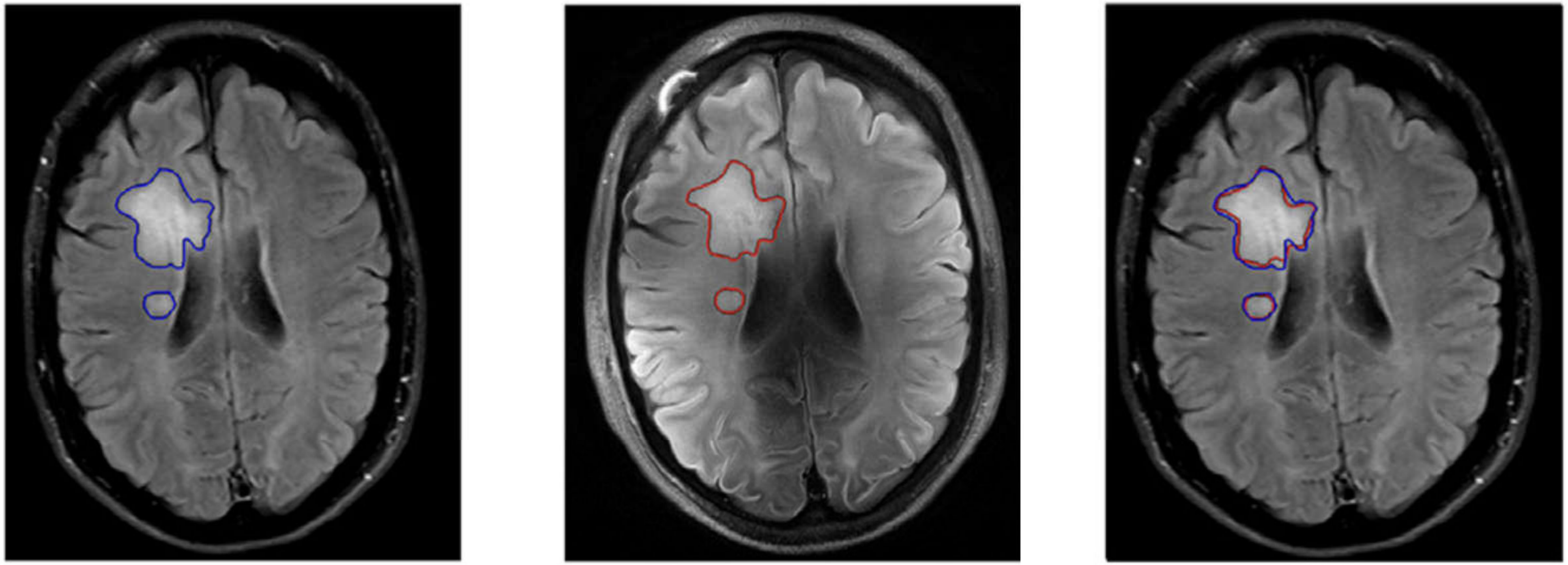
GLIOBLASTOMA



Regnery et al, 2019

Increased visibility of major white matter tracts (green arrows) and boundaries between grey matter and white matter (green arrowheads) in the 7T FLAIR, important to evaluate infiltration.

GLIOBLASTOMA



3 Tesla | 7 Tesla | Superimposed

Regnery et al, 2019

Enhanced visualization of tumor infiltration, particularly along white matter tracts :

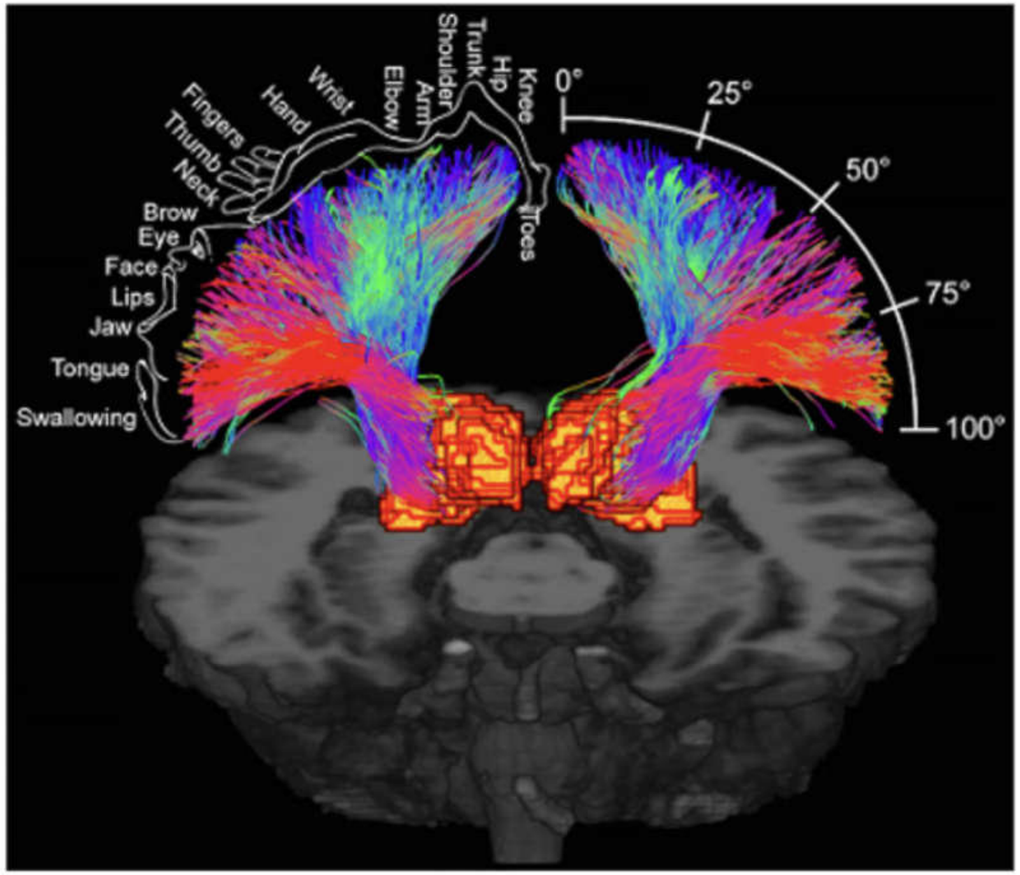
→ important to determine volumes to treat by radiotherapy.

→ lower gross tumor volume in 7T FLAIR

→ possible advantages : improved sparing of organs at risk and enhanced dose coverage of the target volumes.

TRIGEMINAL NEURALGIA

Diffusion tensor imaging (DTI) to detect altered microstructure of thalamic-somatosensory tract anatomy in trigeminal neuralgia



Rutland et al, 2019

7T DTI-based tractography of the thalamic-somatosensory tracts with homunculus

TRIGEMINAL NEURALGIA

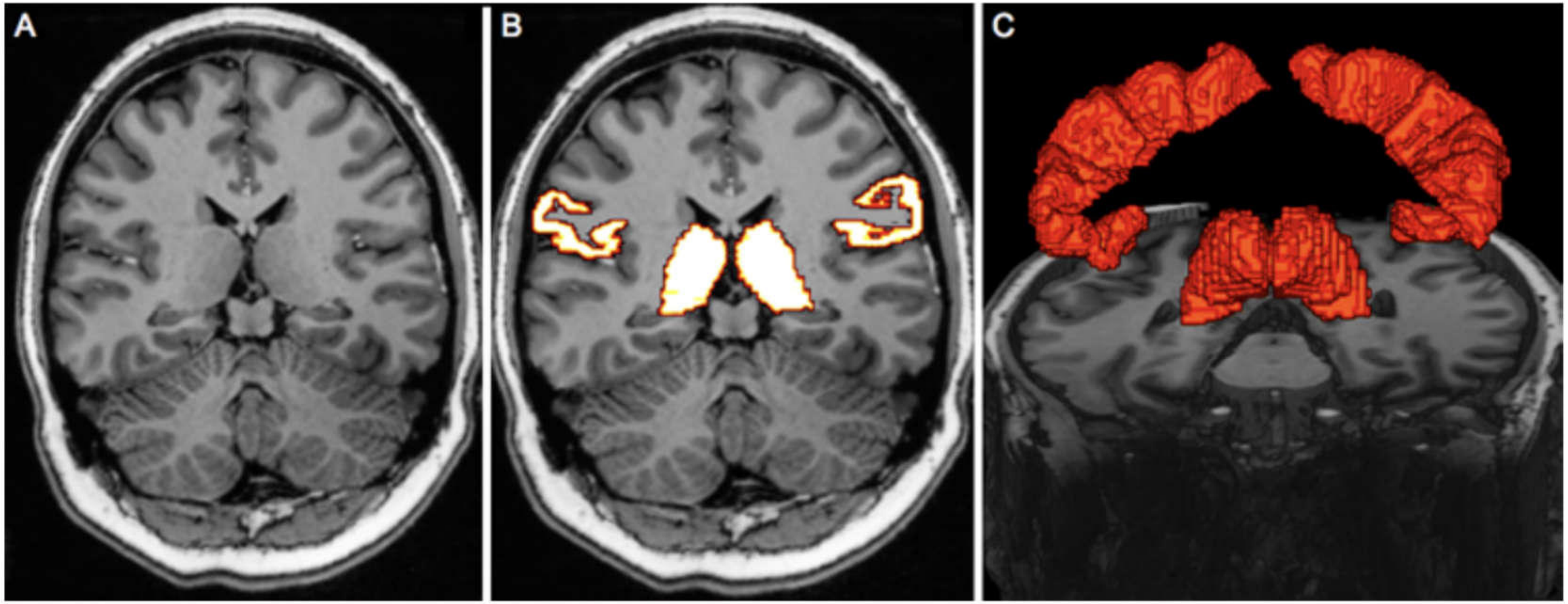


FIG. 1. ROI selection. **A:** Coronal T1-weighted image used for the whole-brain segmentation. **B:** Thalamic cortex and S1 segmentation results on coronal T1-weighted image. **C:** A 3D rendering of thalamic and primary visual cortices. Figure is available in color online only.

Rutland et al, 2019

TRIGEMINAL NEURALGIA

TABLE 2. Thalamic-somatosensory tract microstructural properties in patients with TN compared with matched healthy controls

Property	Affected Side, Mean (SD)			Unaffected Side, Mean (SD)		
	Control	TN	p Value	Control	TN	p Value
FA	0.474 (0.02)	0.43 (0.04)	**0.01**	0.461 (0.02)	0.444 (0.04)	0.60
MD	6.15×10^{-4} (1.72×10^{-5})	6.58×10^{-4} (5.10×10^{-5})	**0.02**	6.25×10^{-4} (1.31×10^{-5})	6.44×10^{-4} (3.71×10^{-5})	0.06
AD	9.56×10^{-4} (2.65×10^{-5})	9.93×10^{-4} (6.10×10^{-5})	0.13	9.64×10^{-4} (1.94×10^{-5})	9.84×10^{-4} (5.80×10^{-5})	0.60
RD	4.44×10^{-4} (1.88×10^{-5})	4.91×10^{-4} (5.70×10^{-5})	**0.01**	4.61×10^{-4} (1.89×10^{-5})	4.79×10^{-4} (4.67×10^{-5})	0.19

Boldface type indicates statistical significance. Diffusivity units are expressed in mm^2/second.

Fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD) : properties that mesure white matter fibers quality

→ microstructural alteration at the thalamus level and S1
→ compensatory mechanism to reduce pain sensation
→ further understanding of the neurobiological substrates of TN and remission from chronic pain.

VI. REGIONAL PROJECT " ARIANES "

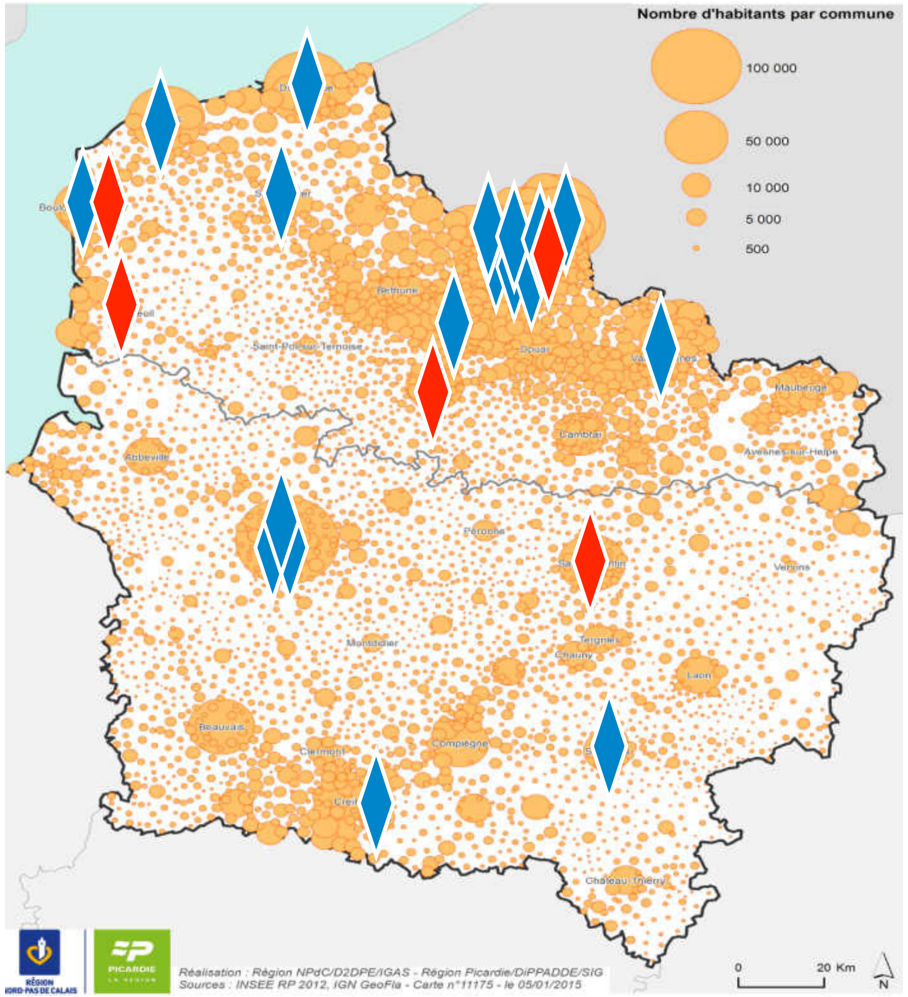
STATE OF PLAY

Existing in imaging

A potential grid of 100+
MRI and 150 CT Scan
18 3 Tesla MRI
and 5 in installation

Healthcare institutions

2 CHU of Lille and Amien
50 hospitals (CH)
80 private clinics

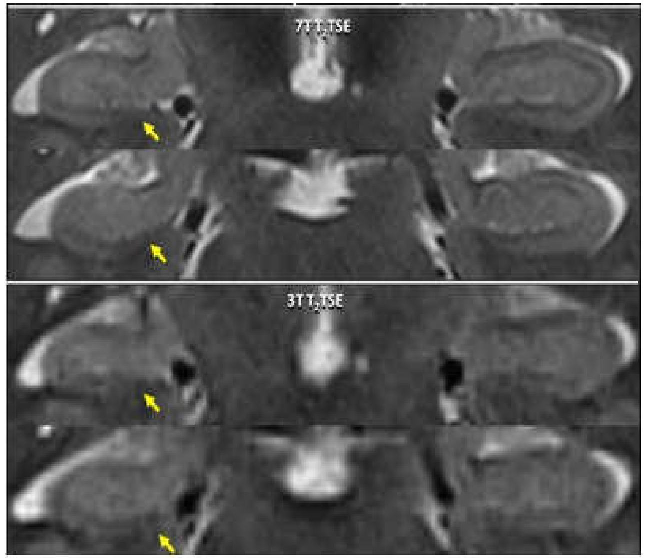


3T / 7T MRI - AI NETWORK

Identify new 7T MRI biomarkers for a better understanding
of the pathophysiology of neurological and psychiatric diseases

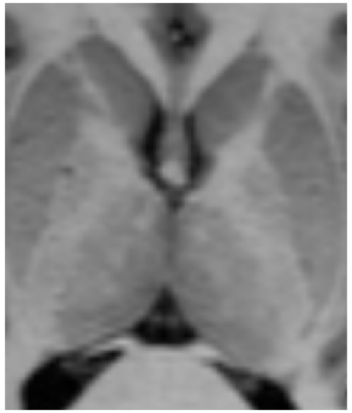
Use of 7T biomarkers
on cohorts of patients
in clinical routine using
3T MRIs from the region

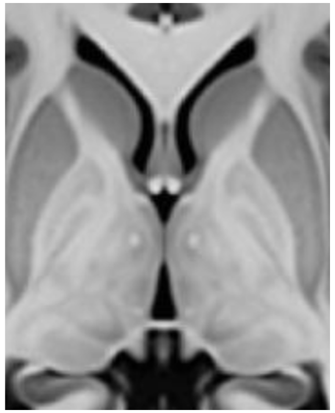
AI →



Epilepsy : hippocampal asymmetry

3T

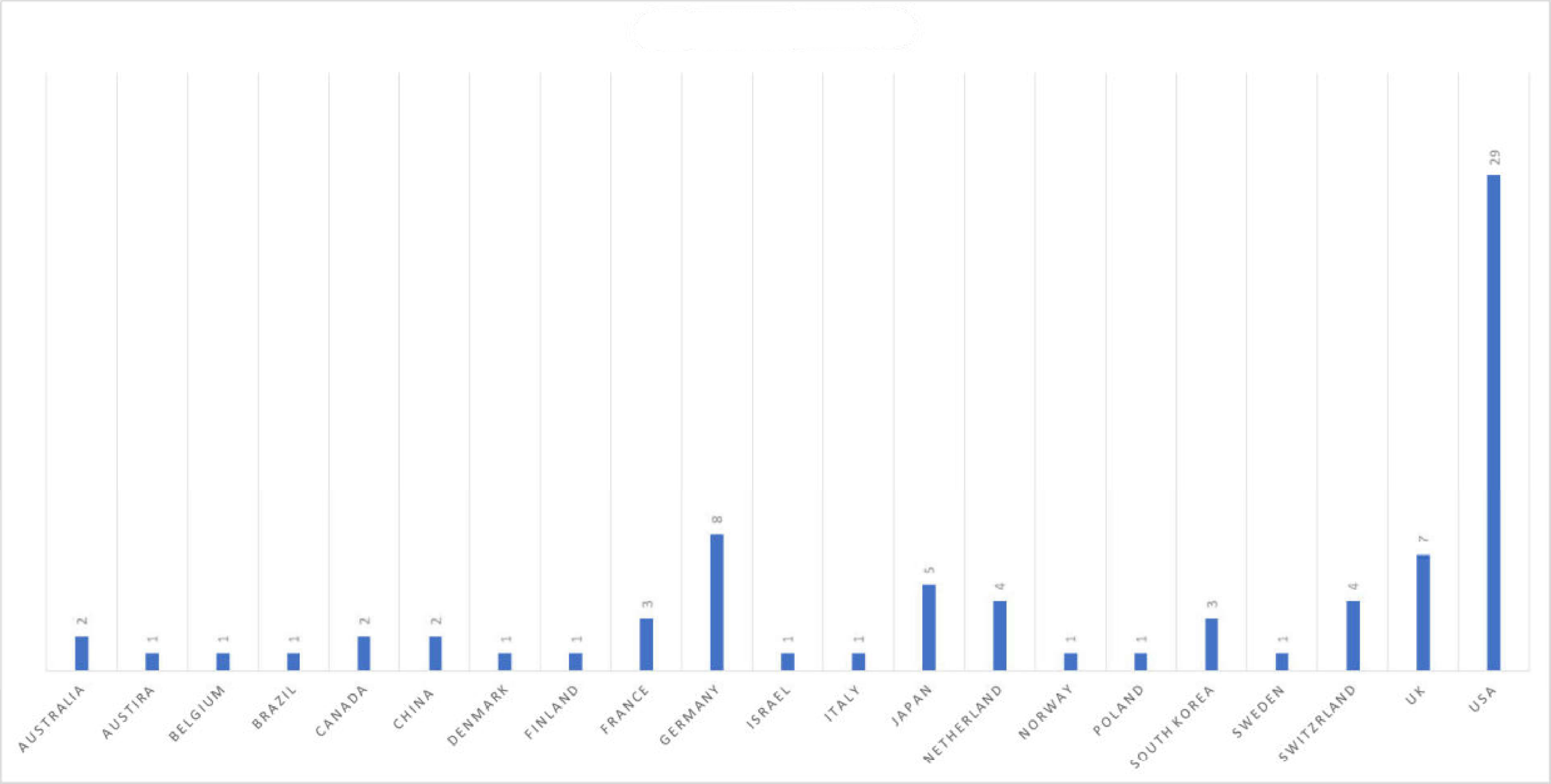




7T

Courtesy of Pr. M. Gueye, CRMBM-CEMEREM, Marseille

7T MRI WORLDWIDE : > 80



Country	City	MRI type	University/Organization Name
Australia	Brisbane	7T	Universito of Queensland (Centre for Advanced Imaging)
Australia	Melbourne	7T	University of Melbourne (Royal Melbourne Hospital)
Austria	Vienna	7T	High Field Magnetic Resonance Center
Belgium	Liège	7T	Centre Hospitalier Universitaire (CHU) de Liège
Brazil	São Paulo	7T	University of Sao Paulo (USP - Autopsy Room Imaging Platform)
Canada	London, Onta	7T	Western University of London (Centre for Functional and Metabolic Mappingà
Canada	Montréal	7T	Université McGill
China	Beijing	7T	Chinese Academy of Sciences (State Key Laboratory of Brain and Cognitive Science, Institute of Biophysics)
Denmark	Copenhagen	7T	Danish Research Centre for Magnetic Resonance
Finland	Helsinki	7T	Aalto University
France	Marseille	7T	Centre de Résonance Magnétique Biologique et Médicale
France	Paris-Saclay	11.7T	Atomic Energy Commission (CEA - Neurospin Saclay)
France	Poitiers	7T	Centre Hospitalier Universitaire (CHU) de Poitiers
Germany	Berlin	7T	Helmholtz Association (Max Delbrück Center for Molecular Medicine)
Germany	Bonn	7T	German Center for Neurodegenerative Diseases (DZNE)
Germany	Erlangen	7T	Radiology of the University Hospital Erlangen
Germany	Essen	7T	Erwin L. Hahn Institute for Magnetic Resonance Imaging
Germany	Heidelberg	7T	German Anticancer Research Center (DKFZ - Division of Medical Physics in Radiology)
Germany	Jülich	9.4T	Forschungszentrum Jülich
Germany	Jülich	7T	Forschungszentrum Jülich
Germany	Leipzig	7T	Max Planck Institute for Human Cognitive and Brain Sciences
Germany	Magdenburg	7T	University Otto von Guericke
Germany	Tubingën	9.4T	Max Planck Institute for Biological Cybernetics
Israel	Rehovot	7T	Weizmann Institute of Science
Italy	Pisa	7T	University of Pisa, Fondazione Imago 7
Japan	Iwate	7T	Iwate Medical University (Institue of Biomedical Sciences)
Japan	Kyoto	7T	Kyoto University
Japan	Niigata	7T	University of Niigata (Center for Integrated Human Brain Science)
Japan	Okazaki	7T	National Institute for Physiological Sciences (NIPS)
Japan	Osaka	7T	National Institute of Information and Communications Technology (Center for Information and Neural Networks)

Netherlands	Amsterdam	7T	Spinoza Centre for Neuroimaging
Netherlands	Leiden	7T	Leiden University Medical Center (LUM : Department of Radiology, C.J. Gorter Center for High Field Magnetic Resonanc)
Netherlands	Maastrich	7T	Maastrist University (Scannexus)
Netherlands	Maastrich	9.4T	Maastrist University (Scannexus)
Netherlands	Utrecht	7T	University of Utrecht (Image Sciences Institute, University Medical Center)
USA	New York	7T	Mount Sinai School of Medicine (Translational and Molecular Imaging Institute)
Norway	Trondheim	7T	Norwegien University of Science and Technology (NTNU)
Poland	Lublin	7T	Medical University of Lublin
South Kore	Daejeon	7T	Korea Basic Science Institute
South Kore	Incheon	7T	Gachon University of Medicine and Science (Neuroscience Research Institute)
South Kore	Suwon	7T	Sungkyunkwan University (IBS Center for Neuroscience Imaging Research)
Sweden	Lund	7T	Lund University (Bioimaging Center)
Switzerland	Lausanne	7T	Ecole Polytechnique Fédérale de Lausanne (CIBM : Center for Biomedical Imaging)
Switzerland	Zürich	7T	ETH Zurich (Institute of Chemical and Bioengineering)
UK	Cambridge	7T	Cambridge (Wolfson Brain Imaging Centre)
UK	Cardiff	7T	Cardiff University (CUBRIC : Cadriff University Brain Research Imaging Centre)
UK	Glasgow	7T	University of Glasgow (ICE)
UK	London	7T	King's College of London
UK	Nottingham	7t	Sir Peter Mansfield Magnetic Resonance Centre
UK	Oxford	7T	Oxford Centre for Functional MRI of the Brain
USA	Auburn	7T	Auburn University
USA	Austin	7T	Cancer Prevention & Research Institute of Texas
USA	Baltimore	7T	Kennedy Krieger Institute
USA	Bethesda	7T	NIH
USA	Bethesda	7T	NIH
USA	Bethesda	11.7T	NIH
USA	Boston	7T	Harvard (Brigham and Women's Hospital)
USA	Boston	7T	Massachusetts General Hospital
USA	Chapel Hill	7T	University of North Carolina (UNC – Biomedical Research Imaging Center)
USA	Chicago	9.4T	UIC Center for Magnetic Resonance Research
USA	Cleveland	7T	Cleveland Clinic Foundation
USA	Columbus	8T	The Ohio State University
USA	Coralville	7T	University of Iowa Health Care
USA	Dallas	7T	UT Southwestern Imaging Center
USA	Los Angele	7T	University of Southern California Health Sciences Campus
USA	Milwaukee	7T	Medical College of Wisconsin Center for Imaging Research
USA	Minneapolis	7T	Center for Magnetic Resonance Research
USA	Minneapolis	7T	Center for Magnetic Resonance Research
USA	Minneapolis	9.4T	Center for Magnetic Resonance Research
USA	Minneapolis	10.5T	Center for Magnetic Resonance Research
USA	Minneapolis	7T	Mayo Clinic
USA	Nashville	7T	Vanderbilt University Institute of Imaging Science
USA	New Haven	7T	Columbia University
USA	New Haven	7T	Yale University (MRRC – Magnetic Resonance Research Center)
USA	New York	7T	New York University (Department of Radiology, Center for Biomedical Imaging)
USA	Philadelphia	7T	University of Pennsylvania (Center for Magnetic Resonance and Optical Imaging)
USA	Pittsburg	7T	University of Pittsburgh (Magnetic Resonance Research Center)
USA	Portland	7T	Oregon Health Sciences University (Advanced Imaging Research Center)
USA	Rochester	7T	Mayo Clinic
USA	San Francis	7T	San Francisco Valley Medical Center
USA	San Francis	7T	University of California, San Francisco (UCSF – Department of Radiology & Biomedical Imaging)
USA	Stanford	7T	Stanford Medical School

NEW IN 2020

Switzerland :

→ Bern, Inselspital
→ Zurich, Universitätsklinik Balgrist

China :

→ Zhejiang, Zhejiang University Interdisciplinary Institute of Neuroscience and Technology (ZIINT)

UK :

→ London, Wellcome Centre for Human Neuroimaging (WCHN)

TO BE INSTALLED IN 2021

China :

→ Beijing, Beijing Tiantan Hospital
→ Shanga, Fudan University
→ Guangzhou, Zhonghan University
→ Chenzhou, PLA Southwest
→ Changsha, Hunan Xiangya

US :

→ Berkeley, University of California

THANK YOU

APPLICATIONS OF 7T MRI IN NEURORADIOLOGY