Brain MRI in an Emergency Department: Clinical Implementation and Experience in the First Year

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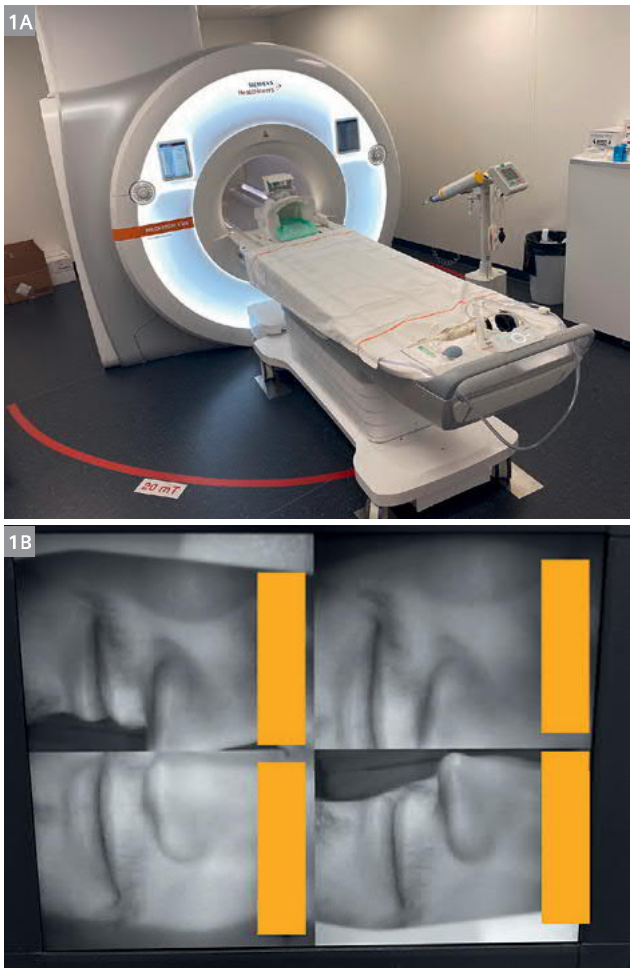
Introduction

While computed tomography (CT) is generally used as a first-line investigation method in emergency departments, magnetic resonance imaging (MRI) is the reference method to accurately detect and characterize cerebral involvement and investigate subtle pathophysiological alterations in most brain diseases, including stroke, seizure, brain tumors, and infections.

Magnetic resonance (MR) investigation for patients referred to emergency departments remains challenging, as scanners are not always available 24/7 and patients are often unstable. Also, as longer acquisition times are needed compared to CT imaging, a strict selection of indications that could benefit from MRI without unnecessarily prolonging the patient workup is mandatory in order to optimize time-to-treatment.

A 3T MAGNETOM Vida scanner (Siemens Healthcare, Erlangen, Germany) was installed in the Emergency Radiological Unit of the Department of Diagnostic and Interventional Radiology of the University Hospital of Lausanne at the end of December 2017 (Fig. 1). To date, this is the first MR scanner located directly within an emergency department in Switzerland. We present brain MR workflow implementation and current brain MR guidelines in the emergency setting. We also report on the activity during the first year of use and results after the first 1,000 brain MR cases.



1 **3T MAGNETOM Vida scanner and cameras**
The 3T MAGNETOM Vida scanner **(1A)** was installed in the Emergency Radiological Unit and was equipped with three cameras: one at the top of the bore and four mounted into the bore **(1B)** to allow monitoring of patients' face and motion on screens in the control room.

MR workflow implementation

MR activity started on January 1, 2018, with 12-hour daily availability until the end of March, followed by 24/7 availability from April 2018. On May 1, 2018 (week 18), we also started using MRI in the 24/7 acute stroke workflow. Emergency department collaborators, including nurses and physicians, were given MR safety information and guidelines on implementing brain MRI both for daily emergency practice as well as for the acute stroke workflow. We also developed a harmonized multi-disciplinary list of indications.

From the beginning, our MR activity was not limited to brain imaging, but also included body imaging for urgent indications for which MRI remains the reference standard, such as the search for bile duct stones.

MR safety

The use of MRI in an emergency setting is a challenge for patient safety and management, so it was necessary to prepare the Emergency Department and Neurology teams. From December 2017 to March 2018, 100 nurses and physicians were given 20 teaching sessions that covered MR setup, safety rules in the MR environment, and MR safety checklists (one for employees, one for patients).

Teaching also included stroke-like workflow simulations, with a volunteer simulating a stroke complicated by an acute seizure that occurred in the MR scanner. Each simulation involved a neuroradiologist, a neurologist, a physician from the Emergency Department, two MR technologists, and two nurses, all blinded for volunteer behavior. Each step was timed, and the availability of materials and respect of MR safety rules were checked by a separate team consisting of one neuroradiologist, one MR technologist, one neurologist, and one physician from the Emergency Department. A debriefing meeting for all participants followed. A second simulation was then conducted to ensure that performance had improved, before making MR available for acute stroke 24/7.

To ensure patient safety during MRI acquisition, EKG, arterial blood pressure, respiratory rate, and oxygen saturation index were continuously monitored on repetition screens in the control room. Furthermore, position, and patients' faces were monitored via dedicated cameras inside the tunnel (Fig. 1).

MR indications and contraindications

A complete switch from CT imaging to MRI is not feasible in an Emergency Department due to the difference in acquisition time, as well as frequent hemodynamic instability and restlessness of admitted patients. It is therefore crucial to determine indications and contraindications in patients that could benefit from a brain MRI.

After multi-disciplinary meetings with the responsible physicians at the Emergency Department (emergency and intensive care physicians, anesthesiologists, neurologists, neurosurgeons), we defined a list of indications for access to MRI within reasonable delay times (Table 1). We also set MR contraindications, including high level of restlessness, hemodynamic or respiratory instability, vomiting, severe claustrophobia, and implanted devices (pacemaker, neurostimulator, cochlear implant, or any fixed head or neck device).

Brain MRI indications and delay	
MRI within 30 min	**MRI within 3 h**
Acute stroke ≤8h with potential IVT or EVT Acute stroke >8h with potential late EVT	Acute coma Meningo-encephalitis Pituitary apoplexia before emergency surgery Brain tumor before emergency decompressive surgery
MRI within 6 h	**No indication for MRI within 6 h**
TIA or acute stroke without IVT or EVT Isolated acute vertigo without any peripheral cause Seizure and refractory status epilepticus Multiple sclerosis and RBON Intracranial hypotension	Any MRI contraindication (CT) Meningitis without focal deficit (CT) Initial workup of an extracerebral tumor without symptoms Acute hemorrhage (angio-CT) Isolated acute headache (angio-CT) Acute brain trauma (CT) Brain tumor with no need for emergency surgery

Table 1: Summary indications for emergency brain MRI and delay.
Abbreviations:
EVT: endovascular thrombectomy
IVT: intravenous thrombolysis
RBON: retrobulbar optical neuritis
TIA: transient ischemic attack

Some patients may have implanted devices but are not able to communicate in emergency situations, for example because of aphasia or cognition problems, so it was decided to perform a chest X-ray before MRI for any unresponsive patient admitted to the Emergency Department without recent documentation in our picture archiving and communication system. This is important especially for patients referred within the context of the acute stroke workflow. The initial evaluation by neurologists includes filling in the patient's safety checklist to decide between CT and MR imaging.

MR protocols

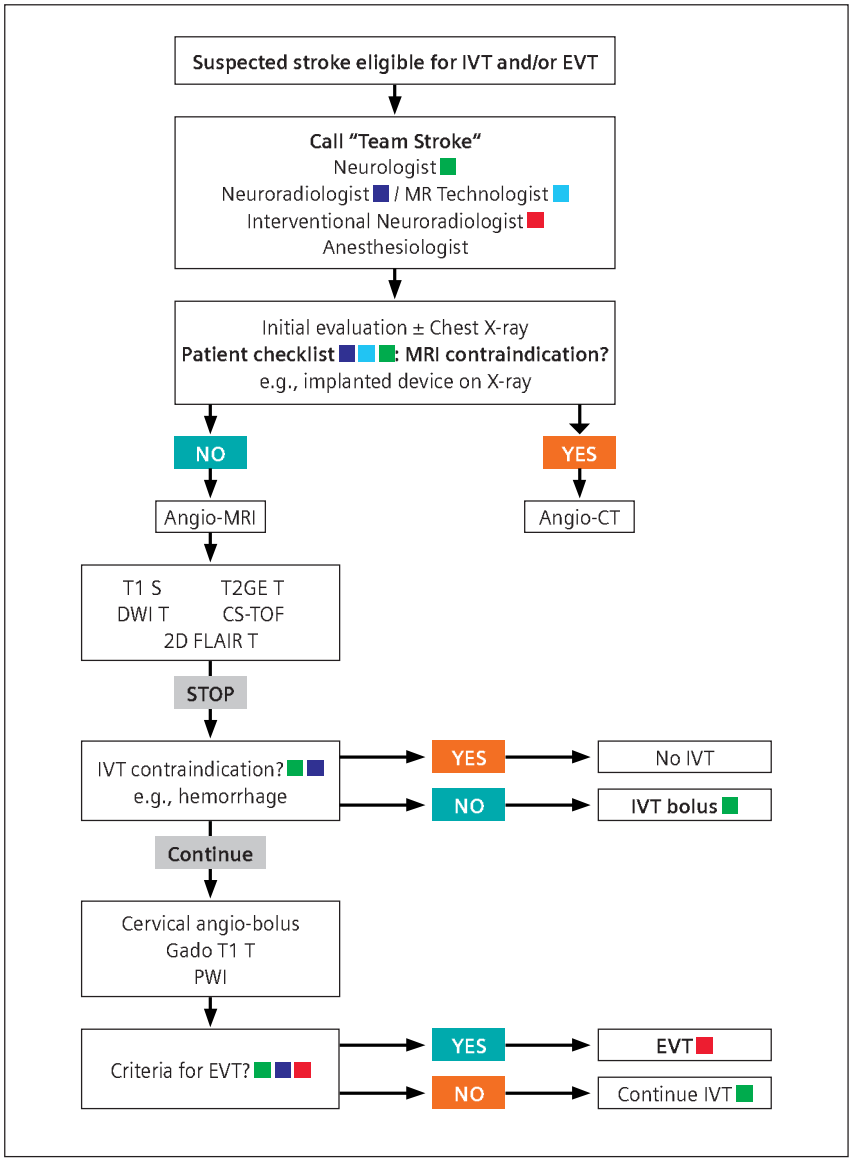
For most emergency cases, MRI is performed with a 64-channel array coil using standard MR protocols, as set up for outpatients; but MR acquisitions in cases of suspected stroke deserve special attention.

Although the choice of CT imaging or MRI does not influence the outcome of patients with acute stroke due to large vessel occlusion [1], MRI is superior to CT imaging for the diagnosis of small ischemic lesions and stroke mimickers [2–4]. However, the use of MRI delays patient management due to longer patient positioning and acquisition time [1], so MR protocols must be optimized. Fast MR sequences reduce acquisition time and the potential impact of patient motion. It is, however, important not to inconsistently reduce the number of MR sequences, and consequently image quality, in order to take advantage of using MRI rather than CT imaging. Given that "time is brain" in a suspected acute stroke, the implementation of MRI needs cautious protocol optimization in order to reduce the "time to therapy". Therapy being intravenous thrombolysis (IVT) and/or endovascular thrombectomy (EVT).

Starting with MR protocols previously used in our institution, we optimized our MR stroke protocol by adapting the number and duration of sequences while keeping optimal spatial resolution (Table 2). The choice following multi-disciplinary discussions was for the "short protocol with 3 mm thick slices and CS-TOF", which represents the best compromise between high image quality, resolution and sequence duration. This protocol was designed for all MRIs performed for suspected acute stroke that could potentially benefit from IVT and/or EVT. Neither the ultra-short protocol nor the short protocol with 5 mm thick slices were chosen because arterial intracranial TOF is necessary for EVT planification, and because thin slices are more suitable for the detection of small infarcts, respectively. Figure 2 summarizes the current workflow for any suspected acute stroke case that may benefit from IVT and EVT.

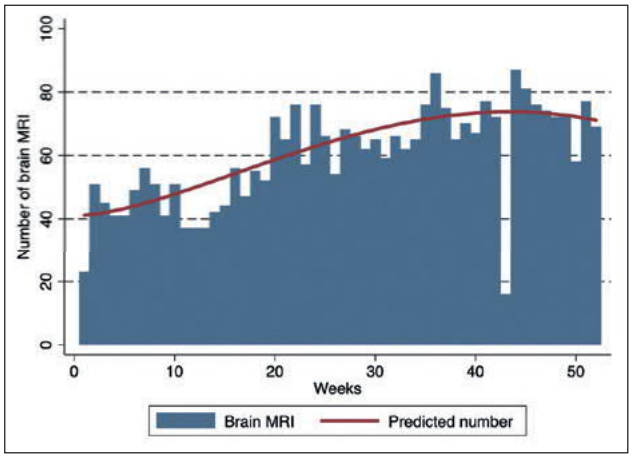
Sequences	Full protocol	Protocol without suspicion of cervical dissection	Short protocol 3 mm thick slices with CS-TOF	Short protocol 5 mm thick slices with CS-TOF	Ultra-short protocol 3 mm thick slices without TOF
T1_fl2d_sag	1'10	1'10	1'10	0'53	1'10
ep2d_diff_AVC*	1'54	1'54	1'54	1'46	1'54
T2_tse_FLAIR_tra	2'24	2'24	2'24	1'47	2'24
T2_gre_tra_hemo	2'08	2'08	2'08	1'24	2'08
Tof_fl3d_tra_art	6'12	6'12	—	—	—
CS_Tof_fl3d_tra_art	—	—	3'06	3'06	—
T1_space_cor_spair	4'53	—	—	—	—
Angio_fl3d_cor_pre	0'23	0'23	0'23	0'23	0'23
Care_bolus_cor	1'30	1'30	1'30	1'30	1'30
Angio_fl3d_cor_post	0'23	0'23	0'23	0'23	0'23
T1_fl2d_tra	1'05	1'05	1'05	1'05	1'05
ep2d_perf_p3HR	1'45	1'45	1'45	1'45	1'45
Total duration	**23'47**	**18'54**	**15'48**	**14'02**	**12'42**

Table 2: Optimization of brain MRI protocols for acute stroke evaluation.
Abbreviations: CS, Compressed Sensing; FLAIR, fluid attenuated inversion recovery; TOF, time-of-flight.
* Diffusion-weighted imaging is acquired using Simultaneous Multi-Slice acceleration technology.

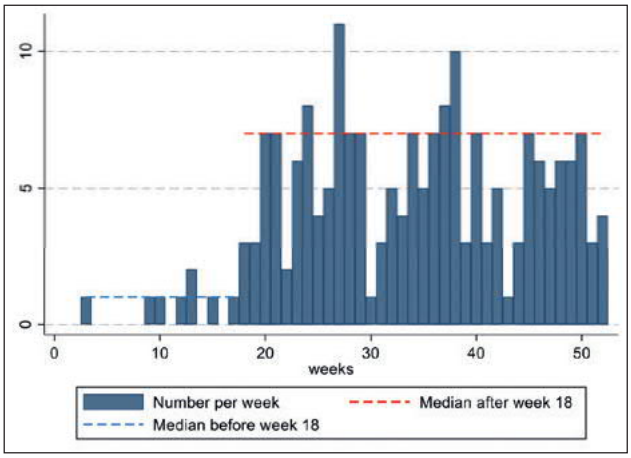


2 **Acute stroke workflow**
Abbreviations:
CS: compressed sensing
DWI: diffusion-weighted imaging
EVT: endovascular thrombectomy
IVT: intravenous thrombolysis
PWI: perfusion weighted imaging
TOF: time-of-flight

Color points represent practitioners involved in the step:
- green for neurologist
- navy blue for neuroradiologist
- cyan for MR technologist
- red for interventional neuroradiologist
- Multiple points are displayed when a multidisciplinary decision is needed.



3 Emergency MRI activity over the first year.



4 Number of brain MRI scans recorded in the Acute Stroke Registry and Analysis of Lausanne.

Experience in the first year

Activity in the first year

Overall, 4,127 MRI exams were performed during the first year. Of these, 3,107 (75%) were brain MRIs. The weekly median number of brain MRIs was 66 (Interquartile range: 55–75, min-max range 16–87). This increased during the first few months from 45 (Interquartile range: 41–51, min-max range 23–56) before week 18, to 70 in the following months (Interquartile range: 65-76, min-max range 16–87). A plateau of 74 was reached at week 35 (i.e. last week of August, median number of brain MRI: 74 per week, interquartile range: 70–77, min-max range 16–87, Fig. 3). This corresponds to a prediction of up to 5,000 MRI scans per year with 24/7 MR scanner availability.

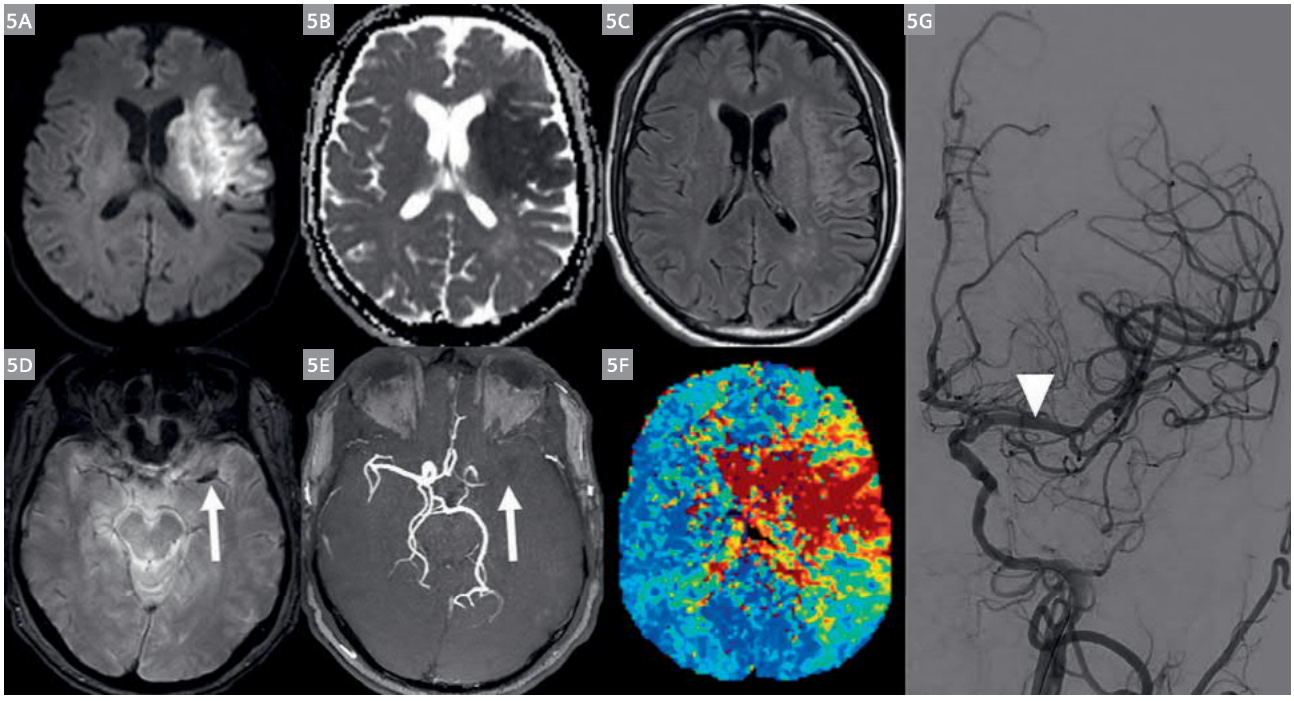
According to the Acute Stroke Registry and Analysis of Lausanne (ASTRAL), the number of patients who underwent a brain MRI at the acute phase of a stroke increased from a median of 1 case per week before week 18 (when the 24/7 acute stroke MRI workflow began) to 7 patients per week thereafter (Fig. 4).

The first 1,000 brain MR examinations: indications, protocols, and results

During the first five months, a total of 1,397 MR examinations were performed, including 1,000 brain MRIs. Of those 1,000 patients, 461 were female and 539 were male, with a median age of 57.2 years (95% interval 42–75 years; range 0–95 years).

Out of these first 1,000 brain MR examinations, 564 were for suspected stroke, 111 for other suspected vascular disease, 51 for seizure, 49 for suspected infection, 177 for known or suspected tumors, 31 for new psychological symptoms, and 17 miscellaneous. A total of 676 included the arterial TOF sequence, and 356 included both the arterial TOF and the cervical angio-bolus sequences.

Overall, 380 brain MRI scans (38%) were determined to be normal. The pathological results were stroke (Fig. 5) in 253 patients (25.3%), other vascular diseases (e.g., aneurysm, venous thrombosis) in 85, acute infection in 60, cerebral tumors in 173, and other miscellaneous diagnoses in 47 patients. MRI acquisition had to be stopped due to intractable nervousness in just two cases. We recorded no major adverse events due to MRI, or side effects after intravenous gadolinium contrast media injection.



5 Acute stroke on MRI
An early acute stroke of the left middle cerebral artery (MCA) is seen as a bright area on the diffusion-weighted image **(5A)**; as an area with low ADC value **(5B)**; and as a faint hyperintense area on FLAIR **(5C)**. The thrombus located within the left MCA appears dark on the T2 gradient echo image **(5D**, arrow) and CS-TOF confirmed vessel occlusion **(5E)**. On perfusion-weighted images, the T_{max} map **(5F)** shows a large area of penumbra surrounding the infarct. The patient consequently underwent intravenous thrombolysis followed by endovascular thrombectomy, with subsequent complete recanalization of the left MCA as seen on end-procedure digital subtraction angiography **(5G**, arrow head).

Discussion

The clinical integration of an MR scanner into an emergency department is feasible. It requires prior teaching of adequate safety rules, multidisciplinary meetings to define the exact indications, and optimization of MR acquisition protocols. When these preliminary conditions are fulfilled, as was achieved in our institution, MRI use could quickly increase up to 5,000 cases per year.

While stroke is the top diagnosis in pathological examinations, we found that 38% of patients admitted to the emergency department with an indication for brain MRI had a normal result. Although the impact on the time of patient discharge from hospital has not yet been assessed, the use of MR in an emergency department could shorten the duration of hospitalization for patients with a normal brain or other MRI.

The true conversion rate from CT imaging to MR examinations should also be evaluated in our institution and in others. Unlike other countries and cities in Switzerland, our department has centralized management of all radiological emergency prescriptions, and a single general radiologist who decides on the imaging modality based on our guidelines. MR activity and conversion from CT imaging to MRI might therefore differ if modalities are managed by multiple practitioners, as is the case in Germany.

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