Early Magnetic Resonance Imaging in Transient Ischemic Attack and Minor Stroke
Do it or Lose it

François Moreau, MD; Jayesh Modi, MD; Mohammed Almekhlafi, MD, FRCPC; Simer Bal, MD; Mayank Goyal, MD; Michael D. Hill, MD, FRCPC; Shelagh B. Coutts, MD, FRCPC

Background and Purpose—The use of magnetic resonance imaging (MRI) after transient ischemic attack (TIA) or minor stroke may be affected by the relative timing of imaging. We measured the impact of scanning an individual patient late versus early after TIA and minor stroke.

Methods—Two hundred sixty-three TIA or minor stroke (National Institute of Health Stroke Scale score ≤3) patients with a baseline MRI completed within 24 hours of symptom onset and a follow-up MRI at 90 days were included. Baseline and 90-day scans were assessed independently for the presence of any stroke lesions that could explain the presenting symptoms. The presence and pattern of any stroke lesions were compared at the 2 time points.

Results—The presence of a stroke (acute or chronic) in any location was more common on baseline MRI versus 90-day MRI (68% vs 56%; P=0.005). Thirty percent of subjects with negative scans at 90 days had a clearly identifiable stroke at baseline. When interpreted blinded to the baseline scan, the presumed relevant lesion on the 90-day MR scan was the correct lesion in only 53% patients. One-third (34%) of patients had a different lesion pattern on the baseline scan compared with the 90-day scan. Ninety percent (80/89) of these patients had more lesions on the baseline MRI and 10% (9/89) had new lesions on the 90-day MRI.

Conclusions—Delayed MRI after TIA or minor stroke reduces the diagnostic yield and results in missed understanding of the lesion pattern. MRI of minor stroke and TIA patients should occur early after symptom onset, and delayed imaging should be interpreted with caution. (Stroke. 2013;44:671-674.)
clinical and outcome information were prospectively collected for each patient. All patients were followed-up for up to 90 days and underwent a computed tomography of the brain and a computed tomography angiography of the head and neck vessel within 24 hours of symptom onset. A subset of patients underwent a brain MRI at baseline and at 90-day follow-up. The selection criteria to be included in this study were baseline MRI within 24 hours of symptom onset and follow-up MRI at ~90 days after the presenting event.

**Magnetic Resonance Imaging**

All MR images were acquired on a 3.0-T GE scanner. Baseline and follow-up MRI sequences included DWI (slice thickness, 3.5 mm; slice spacing, 0.0 mm), fluid-attenuated inversion recovery, T2, and MR angiography of the intracranial circulation. The 90-day follow-up MRI was jointly interpreted by a neuroradiologist and a stroke neurologist who were blind to the results of the baseline MRI. The raters, who were blind to the baseline MRI, had access to detailed clinical information of the event 90 days before and knew whether a recurrent clinical stroke had occurred after the baseline imaging. In addition, if a lesion qualifying for a chronic stroke on a 90-day MRI was found, then the rater was asked if this stroke was likely to be related to the clinical symptoms of the original event 3 months before. Once the 90-day MRI was interpreted, the baseline MRI was interpreted according to the same criteria. Because the MRI was completed within 24 hours, the lesion was considered related to the presenting symptoms if it showed restricted diffusion. If a stroke was identified on the 90-day MRI that was thought to be the cause of the original symptoms, then this lesion was rated as a true positive if there was a restricted diffusion lesion at the same location on the baseline MRI, and it was rated as a false positive if there was none.

Lesions were classified as acute/subacute or chronic, cortical stroke or subcortical stroke, in the right or left middle cerebral artery, in the right or left anterior cerebral artery, or in the brain stem/cerebellum. Acute/subacute classification required hyperintense signal on DWI with associated hypointensity or isointensity on apparent diffusion coefficient. If a DWI hyperintense lesion also was hyperintense on the apparent diffusion coefficient map, then it was classified as chronic and the DWI hyperintensity was attributed to T2 shine-through phenomenon. Cortical infarct required abnormal signal extending through the cortical ribbon up to the pial surface. Subcortical location was adjudicated otherwise. Chronic subcortical infarcts (without any involvement of the cortex) were required to show evidence of cavitation to differentiate from nonspecific white matter T2 or fluid-attenuated inversion recovery hyperintensities. There was no size threshold for lesions. MR angiography was reviewed for intracranial occlusions and stenosis. The MRI studies were classified according to distribution of lesions in the cortical or subcortical regions of 3 separate vascular territories: right internal carotid artery (right middle cerebral artery and anterior cerebral artery); left internal carotid artery (left middle cerebral artery and anterior cerebral artery); and posterior circulation (right posterior cerebral artery, left posterior cerebral artery, and brain stem/cerebellum). Categories were no definite stroke, single territory cortical stroke, multiple territory cortical strokes, single territory subcortical-only stroke, multiple territory subcortical-only strokes, and multiple strokes in 1 territory, including a cortical stroke. These categories were not mutually exclusive.

**Statistical Analysis**

Statistical analysis was completed with Stata (version 11). Standard descriptive statistics were used for continuous or binomial outcomes as appropriate. Proportions of any stroke lesion seen and of lesions that potentially explained the presenting symptoms were compared between the 90-day and the baseline MRIs. The proportion of patients who had a symptomatic lesion correctly identified on 90-day scan was assessed. Distribution of stroke lesions as described above was compared between the 90-day and baseline MRIs.

### Results

Two hundred sixty-three patients were included in this study. Baseline characteristics are shown in Table 1. Fifty-two percent (138/263) were TIsAs (completely resolved within 24 hours). Stroke at any age in any location was found on 56% (148/263) of the 90-day MRIs and on 68% (179/263) of the baseline MRIs (P=0.005). Thirty percent of the negative scans at 90 days had a clearly identifiable stroke on the baseline scan. All of these lesions were acute or subacute DWI lesions on the baseline scan showing nonspecific white matter hyperintensity or no abnormality on the 90-day scan (Table 2 and the Figure). For TIA patients, stroke of any age was found on 42% (58/138) of the 90-day MRIs and on 57% (78/138) of the baseline MRIs (P=0.008). For minor stroke, stroke of any age was found on 72% (90/125) of the 90-day MRIs and on 81% (101/125) of the baseline MRIs (P=0.05). MR angiography of the intracranial vessels was abnormal on 20% (51/263) of the 90-day MRIs and on 27% (70/263) of the baseline MRIs. In 18 of 19 patients, an occluded artery on baseline MR showed recanalization. Twenty percent (9/46) had clinical recurrent strokes to explain the new lesion, and 80% (37/46) had no identified clinical symptoms. Only 43% (20/46) of all new lesions were identified as a definite stroke lesion on review of the 90-day MRI. The others could be identified only by directly comparing both scans.

In patients with any stroke on 90-day MRI, 70% (104/148) had a least 1 stroke considered likely related to the presenting symptoms based on detailed clinical information. In 53% (78/148) of patients, the correct lesion was identified on the 90-day MRI (true positive). In 13% (13/104) of patients, the stroke lesion identified on the 90-day MRI was not the correct lesion when compared with the baseline MRI. In patients who were DWI-negative at baseline, 89% (105/118) were correctly

**Table 1. Baseline Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>N=263</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y, median (IQR)</td>
<td>69 (13.8)</td>
</tr>
<tr>
<td>Sex, men, n (%</td>
<td>161 (61.5)</td>
</tr>
<tr>
<td>TIA: resolved in 24 h, n (%)</td>
<td>137 (52.3)</td>
</tr>
<tr>
<td>Baseline NIHSS, median (IQR)</td>
<td>1 (2)</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>32 (12.2)</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>133 (50.8)</td>
</tr>
<tr>
<td>Atrial fibrillation, n (%)</td>
<td>19 (7.3)</td>
</tr>
<tr>
<td>Current smoker, n (%)</td>
<td>37 (14.1)</td>
</tr>
<tr>
<td>Symptom to baseline imaging, h, median (IQR)</td>
<td>14.9 (11.9)</td>
</tr>
<tr>
<td>Time to follow-up imaging, d, median (IQR)</td>
<td>88 (19)</td>
</tr>
</tbody>
</table>

| IQR indicates interquartile range; NIHSS, National Institute of Health Stroke Scale; and TIA, transient ischemic attack.

<table>
<thead>
<tr>
<th>Table 2. Comparison of 90-Day and Baseline Lesion Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 Days (N=263)</td>
</tr>
<tr>
<td>24 Hours (N=263)</td>
</tr>
<tr>
<td>Any stroke</td>
</tr>
<tr>
<td>Acute/subacute stroke</td>
</tr>
<tr>
<td>Chronic stroke</td>
</tr>
</tbody>
</table>
identified as having no culprit lesion on the 90-day MRI, and in 11% (13/118) of patients an incorrect lesion was identified on the 90-day MRI (false positive).

One-third (89/263) of patients had a different lesion distribution on the baseline MRI as compared with the 90-day MRI. Ninety percent (80/89) of these patients had more lesions on the baseline MRI and 10% (9/89) had new lesions on the 90-day MRI. The main difference observed was that patients with multiple DWI lesions on the baseline scan showed either no lesion or only a single lesion on the 90-day MRI (Table 3).

Table 3. Comparison of Stroke Lesion Distribution Between Baseline and 90-Day Magnetic Resonance Imaging Scans

<table>
<thead>
<tr>
<th>Distribution Category</th>
<th>Baseline MRI, n/N (%)</th>
<th>90-Day MRI, n/N (%)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No stroke</td>
<td>84/263 (32)</td>
<td>115/263 (44)</td>
<td>0.005</td>
</tr>
<tr>
<td>Single cortical stroke</td>
<td>24/263 (9)</td>
<td>40/263 (15)</td>
<td>0.030</td>
</tr>
<tr>
<td>Multiple territory cortical strokes</td>
<td>21/263 (8)</td>
<td>17/263 (6)</td>
<td>0.500</td>
</tr>
<tr>
<td>Single subcortical stroke (no cortical stroke)</td>
<td>41/263 (16)</td>
<td>44/263 (17)</td>
<td>0.700</td>
</tr>
<tr>
<td>Multiple territory subcortical strokes (no cortical stroke)</td>
<td>12/263 (5)</td>
<td>11/263 (4)</td>
<td>0.830</td>
</tr>
<tr>
<td>Multiple strokes in 1 territory, including 1 cortical</td>
<td>81/263 (31)</td>
<td>36/263 (14)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Any age (acute, subacute, or chronic) of stroke lesion is included in this comparison. MRI indicates magnetic resonance imaging.

**Discussion**

The timing of brain MRI after a TIA or minor stroke greatly affects its diagnostic use. Compared with an MRI completed within 24 hours of the symptom onset, an MRI completed 90 days later frequently misses the symptomatic lesion. The radiological diagnosis of stroke is frequently missed, and even if a stroke lesion can be identified, the distribution of lesions among vascular territories has changed as compared with the baseline scan. When there is an identifiable stroke lesion on late MRI, it is often difficult to definitively relate it to the original presenting symptoms.

DWI hyperintense lesions are common after TIA and minor stroke,9,15,16 but the hyperintensity on DWI is also known to decrease in intensity after 10 days17 and disappear altogether from 2 to 3 weeks after the original event.11,18 One group showed that DWI adds relevant information to T2 imaging alone in the investigation of TIA or minor stroke if completed as late as 2 to 3 weeks after the event.18 The main explanation for these discrepancies is the disappearance of DWI-positive lesions that evolve into nonspecific white matter fluid-attenuated inversion recovery hyperintensities and DWI reversal. DWI reversal is uncommon in large strokes19 but is much more frequent for the small DWI lesions encountered in TIA and minor stroke.20 When these lesions do persist, they frequently lead to a nonspecific, small, hyperintense signal in a subcortical area without evidence of cavitation. On a blind reading of a 90-day scan, which is equivalent to ordering a scan in a delayed
setting as an outpatient, these lesions cannot be identified as
the symptomatic lesion because they are not different from
nonspecific background T2 hyperintense lesions.

There is poor agreement even among experts on the clinical
diagnosis of TIA,22 and a DWI lesion resolves this issue by
confirming the diagnosis of ischemia. DWI lesions also have
prognostic value, particularly in TIA and minor stroke.3 The
correlation of the clinical diagnosis of the vascular territory
with the DWI abnormality is only moderate in TIA and minor
stroke.23 Lesion distribution patterns also may provide a clue
to the underlying cause. For example, multiple DWI lesions
in multiple vascular territories may indicate a cardiac or aor-
tic source for the event, and distribution of single carotid
lesions in combination with a severe ipsilateral carotid steno-
sis implicates that carotid stenosis as symptomatic.

A limitation to this study is the development of new lesions
(symptomatic or asymptomatic) between the first and the sec-
ond scan. Only 20 such lesions were clearly identified blindly
on the 90-day scan. These new lesions had the opposite effect
of increasing diagnostic yield of the delayed scan and represent
a failure of poststroke secondary preventive therapy. It is pos-
sible that some small lesions were missed because of slice thick-
ness, but we use 3.5-mm-thin slices with no interslice gap to
minimize this potential artifact. Our analysis represents a best-
case scenario in which the scans were read by a stroke neuro-
ologist and neuroradiologist together with access to detailed
clinical information. This provided high sensitivity for even
small stroke lesions. In real life, clinical information available
to a neuroradiologist may often be minimal, and MRI reports
are frequently limited to the assessment of acute or subacute
changes or obvious large chronic stroke lesions. We believe
that our interpretation of the 90-day scan likely has a higher
yield than a delayed interpretation completed in everyday prac-
tice, in which the clinical details are frequently missing.

In conclusion, early MRI scanning provides better sensitiv-
ity to identify stroke lesions and shows different lesion topog-
raphy than delayed MRI after TIA or minor stroke. The results
of this study support current guidelines1 and call for resource
allocation to provide access to early MRI in the setting of TIA
and minor stroke. This study also suggests that late MRI must
be interpreted with caution because the absence of abnormal-
ity does not guarantee the absence of pathology.

Sources of Funding

Dr Coutts received salary support from the Alberta Innovates-
Health Solutions and the Heart and Stroke Foundation of Canada’s
Distinguished Clinician Scientist award, supported in partnership with
the Canadian Institute of Health Research, Institute of Circulatory and
Respiratory Health, and AstraZeneca Canada Inc. Dr Hill re-
ceived salary support from Alberta Innovates-Health Solutions and
by the Heart and Stroke Foundation of Alberta/Northwest Territories/
Nunavut. This study was supported by Canadian Institute of Health
Research and a Pitzer Cardiovascular Research Award.

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Stroke. 2013;44:671-674; originally published online February 6, 2013;
doi: 10.1161/STROKEAHA.111.680033
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

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一過性脳虚血発作および軽度脳卒中における早期の磁気共鳴画像法
早期に行う意義

Early Magnetic Resonance Imaging in Transient Ischemic Attack and Minor Stroke
Do it or Lose it

Francois Moreau, MD1,2; Jayesh Modi, MD3; Mohammed Almekhlafi, MD, FRCP2,3,8; Simer Bal, MD2; Mayank Goyal, MD3,6; Michael D. Hill, MD, FRCP2,3,4,5,6; Shelagh B. Coutts, MD, FRCP2,3,6,7
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Abstract

背景および目的：一過性脳虚血発作（TIA）または軽度の脳卒中後の磁気共鳴画像法（MRI）の有用性は、画像診断の相対的なタイミングに左右される可能性がある。TIAおよび軽度の脳卒中後に、一定期間経過後に早期に実施した場合のスキャンの影響を個々の患者について評価した。

方法：発症後24時間以内に実施したベースラインMRIおよび90日後のフォローアップMRIを受けた患者で、TIAまたは軽度脳卒中[米国国立衛生研究所脳卒中スケール（National Institutes of Health Stroke Scale）のスコア≤3]を有する患者263例を登録した。発現する症状を説明し得るあらゆる脳卒中病変の存在について、ベースラインおよび90日後の画像を個別に評価した。脳卒中病変の存在およびパターンを2時点間で比較した。

結果：すべての発症部位において脳卒中（急性または慢性）の存在は、90日後MRIよりもベースラインMRIで多く認められた（68%対56%、p=0.005）。90日後の画像で陰性所見を示した観察者の30%は、ベースライン時、明らかに脳卒中と同定可能だった。ベースラインの画像を盲検化して90日後の画像の解釈を実施したところ、MR画像上で推定された関連病変が妥当であったのは患者の53%にすぎなかった。患者の3分の1（34%）において、病変パターンがベースライン画像と90日後の画像とは異なっていた。これらの患者的90%（80/89）では、病変数がベースラインMRIの方多く、10%（9/89）では、90日後MRIで新たな病変を認めた。

結論：TIAまたは軽度の脳卒中後には、一定期間が経過した後のMRIは、診断率を低下させ、病変パターンの誤解釈に繋がる。軽度の脳卒中およびTIAを有する患者のMRIは、発症後の早期に実施するべきであり、一定期間経過後の画像診断は慎重に解釈するべきである。

Stroke 2013; 44: 671-674

表3 ベースラインと90日後の磁気共鳴画像における脳卒中病変の分布の比較

<table>
<thead>
<tr>
<th>分布カテゴリー</th>
<th>ベースラインMRI, n/N (%)</th>
<th>90日後MRI, n/N (%)</th>
<th>p 値</th>
</tr>
</thead>
<tbody>
<tr>
<td>脳卒中なし</td>
<td>84/263 (32)</td>
<td>115/263 (44)</td>
<td>0.005</td>
</tr>
<tr>
<td>単発性皮質脳卒中</td>
<td>24/263 (9)</td>
<td>40/263 (15)</td>
<td>0.030</td>
</tr>
<tr>
<td>複数領域の皮質脳卒中</td>
<td>21/263 (8)</td>
<td>17/263 (6)</td>
<td>0.500</td>
</tr>
<tr>
<td>単発性皮質下脳卒中 (皮質脳卒中なし)</td>
<td>41/263 (16)</td>
<td>44/263 (17)</td>
<td>0.700</td>
</tr>
<tr>
<td>複数領域の皮質下脳卒中 (皮質脳卒中なし)</td>
<td>12/263 (5)</td>
<td>11/263 (4)</td>
<td>0.830</td>
</tr>
<tr>
<td>脳卒中1箇所を含む1領域中の多発性脳卒中</td>
<td>81/263 (31)</td>
<td>36/263 (14)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

脳卒中病変の保有期間（急性、亜急性、慢性）にかかわらず、比較に組み入れた。MRI：磁気共鳴画像法。