Comparison of Computed Tomographic and Magnetic Resonance Perfusion Measurements in Acute Ischemic Stroke
Back-to-Back Quantitative Analysis

Longting Lin, MMed; Andrew Bivard, PhD; Christopher R. Levi, MD; Mark W. Parsons, MD, PhD

Background and Purpose—Magnetic resonance perfusion (MRP) and computed tomographic perfusion (CTP) are being increasingly applied in acute stroke trials and clinical practice, yet the comparability of their perfusion values is not well validated. The aim of this study was to validate the comparability of CTP and MRP measures.

Methods—A 3-step approach was used. Step 1 was a derivation step, where we analyzed 45 patients with acute ischemic stroke who had both CTP and MRP performed within 2 hours of each other and within 9 hours of stroke onset. In this step, we derived the optimal perfusion map with the least difference between MRP and CTP. In step 2, the optimal map was validated on whole-brain perfusion data of 15 patients. Step 3 was to apply the optimal perfusion map to define cross-modality reperfusion from acute CTP to 24-hour MRP in 45 patients and, in turn, to assess how accurately this predicted 3-month clinical outcome.

Results—Among 8 different perfusion maps included in this study, time to peak of the residual function ($T_{\text{max}}$) was the only one with a nonsignificant difference between CTP and MRP in delineating perfusion defects. This was validated on whole-brain perfusion data, showing high concordance of $T_{\text{max}}$ between the 2 modalities (concordance correlation coefficient of Lin, $>0.91$); the best concordance was at 6 s. At $T_{\text{max}}>6$ s threshold, MRP and CTP reached substantial agreement in mismatch classification ($k>0.61$). Cross-modality reperfusion calculated by $T_{\text{max}}>6$ s strongly predicted good functional outcome at 3 months (area under the curve, 0.979; $P<0.05$).

Conclusions—MRP and CTP can be used interchangeably if one uses $T_{\text{max}}$ measurement. (Stroke. 2014;45:1727-1732.)

Key Words: perfusion imaging ■ reperfusion ■ stroke

Magnetic resonance perfusion (MRP) imaging has been used in several past and current clinical trials.1,2 The role of MRP is to triage patients for reperfusion treatment by quantifying the acute ischemic lesion and classifying mismatch pattern. More recently, computed tomographic perfusion (CTP) has been applied in a similar manner.3,4 In the interest of timely recruitment, several studies now include both MRP and CTP in their protocols.5,6 However, in terms of triaging patients, it is unclear whether the use of the same criteria is appropriate across the 2 imaging modalities.

In clinical practice, MRP and CTP are also being increasingly used not only to triage patients for reperfusion therapy but also to assess its success.7 In many centers, patients with stroke often receive CTP pretreatment because it is more rapidly accessible. Then after treatment, MRI (including MRP) is often the preferred option because it avoids additional radiation and provides maximum pathophysiologic information (eg, stroke mechanism). Thus, success of reperfusion therapy is assessed by comparing perfusion change across the 2 modalities. Such assessment of cross-modality reperfusion seems a common-sense approach for clinicians, but its accuracy has not been studied.

To triage patients for reperfusion therapy or to assess its success in the above manner, MRP and CTP are assumed to be interchangeable. We previously showed that MRP and CTP were comparable,8 but this was restricted to 1 single perfusion threshold with limited brain coverage data. The aim of the current study is to compare the 2 modalities comprehensively across a broad range of thresholds and on whole-brain data. Ultimately, we aimed to determine whether MRP and CTP measurement had strong enough agreement to be used interchangeably in triaging patients for acute reperfusion therapy and in assessing subsequent reperfusion.

Study Design
The study comprised 3 steps. Step 1 was a derivation step, where a wide range of perfusion parameters and thresholds were analyzed to identify the perfusion measure with the least volumetric difference

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between CTP and MRP. Steps 2 and 3 were validation steps on whole-brain data. Step 2 tested the agreement of acute CTP and acute MRP in detecting mismatch pattern to select patients for treatment. Step 3 tested the accuracy of reperfusion from acute CTP to 24-hour MRP in predicting clinical outcome.

Patients
For this study, we retrospectively included patients with acute hemispheric ischemic stroke presenting to John Hunter Hospital between 2005 and 2013 who were imaged within 9 hours of symptom onset and who had an acute symptomatic intracranial occlusion on CT angiography. The sites of occlusion were intracranial internal carotid artery, middle cerebral artery, posterior cerebral artery, or anterior cerebral artery. For the step 1 and 2 analyses, we used data from patients who had CTP and MRP performed within 2 hours of each other and both within 9 hours of stroke onset. For step 1, we restricted patient data to those presenting between 2005 and 2010, when limited-slice CTP was performed. For step 2 analysis, we restricted patient data to those presenting between 2010 and 2013, when whole-brain CTP was performed (in addition to MRP within 2 hours of CTP and both within 9 hours of stroke onset). For the step 3 analysis, we used patients imaged with whole-brain CTP within 9 hours of stroke onset between 2010 and 2013, but in addition, they had to have had follow-up MRP performed at 24 to 48 hours after CTP. The data collection and analysis were approved by the institutional ethics committee.

Perfusion Image Acquisition
CTP images were acquired on 2 scanners. The first was 16-slice Philips scanner (Philips Mx8000; Philips, Cleveland, OH). To obtain reasonable brain coverage, 2 adjacent series were performed, each with slice coverage of 24 mm. The second scanner was a 320-slice Toshiba (Toshiba Aquilion ONE; Toshiba, Tokyo, Japan). This scanner has an axial coverage of 160 mm, obtaining whole-brain coverage with a single acquisition. MRP was performed on a 1.5-Tesla scanner (Siemens Avanto, Erlangen, Germany) with a dynamic susceptibility contrast technique and gradient-echo echo-planar imaging technique. Additional image acquisition details are provided in the online-only Data Supplement.

Perfusion Image Postprocessing
CTP and MRP data were processed by the same commercial software MIStar (Apollo Medical Imaging Technology, Melbourne, Victoria, Australia). With this software, various perfusion measures can be generated by deconvolution models. The measures include cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), time to peak of the residual function (T_{\text{res, max}}), and delay time to peak of the residual function (DT).

In this study, for each imaging modality, 2 common deconvolution models were applied. Those were delay- and dispersion-corrected singular value decomposition (SVD)

\[ T_{\text{max}} = \frac{T_{\text{res, max}}}{M+1} \]

and standard SVD. From delay- and dispersion-corrected SVD, we generated 4 perfusion maps labeled as CBF1, CBV1, MTT1, and DT; from standard SVD, we generated another set of 4 parametric maps labeled as CBF2, CBV2, MTT2, and T_{\text{max}} (Figure I in the online-only Data Supplement).

Imaging and Statistical Analysis

Step 1: Comparison of MRP and CTP on 2 Perfusion-Measurement Levels
By setting perfusion thresholds, regions with hypoperfusion were delineated on acute CTP and acute MRP separately. Hypoperfusion refers to the ischemic area with low CBF/CBV and prolonged MTT/DT/T_{\text{max}}. To include most of the definitions for ischemia, a wide range of thresholds was covered in this study (Figure I in the online-only Data Supplement). For CBF1, CBF2, CBV1, and CBV2, the threshold ranged from 95% to 5%, with 5% decrements; for MTT1 and MTT2, the threshold range was from 105% to 195%, with 5% increment; for DT and T_{\text{max}}, it was from 0.5 to 9.5 s, with increment of 0.5 s. The threshold levels were defined relative to the mean tissue perfusion value of the unaffected hemisphere.

Then, difference of the 2 imaging modalities (MRP–CTP) was calculated in terms of hypoperfusion volume measured by the same threshold setting. To compare the result of the 2 imaging modalities accurately, MRP was coregistered to CTP with a 3-dimensional orientation to adjust for anatomic variation between the 2 modalities. One slice (12-mm thickness, at the level of the largest perfusion defect) was chosen to calculate the volumetric difference between the CTP and MRP lesions.

For statistical analysis, a multilevel random-effects model was used. In the model, the volumetric difference was treated as the dependent variable; the perfusion map was set as the level 1 random effect and the threshold as the level 2 random effect. The model was estimated by maximum-likelihood estimation.

Step 2: Intermodality Agreement
In this step, agreement of acute MRP and CTP was validated on whole-brain data. The cross-modality agreement included 2 aspects: (1) measuring the acute perfusion lesion and (2) classifying mismatch pattern. To calculate ischemic lesion volume, the perfusion measure with the least cross-modality difference (from step 1) was applied. To classify mismatch pattern, 2 criteria were used. The first was the EXtending the time for Thrombolysis in Emergency Neurological Deficits (EXTEND) trial criteria\(^a\): mismatch ratio >1.2, mismatch volume >10 mL, and infarct core <70 mL; the second was the Diffusion and Perfusion Imaging Evaluation for Understanding Stroke Evolution Study 2 (DEFUSE 2) trial criteria\(^b\): mismatch ratio >1.8, mismatch volume >15 mL, infarct core <70 mL, and T_{\text{max}} 10 s <100 mL. Mismatch ratio = ischemic lesion volume/infarct core volume; mismatch volume = ischemic lesion volume–infarct core volume; infarct core was defined by CBF <30% of the contralateral hemisphere on CTP\(^c\) and by the diffusion-weighted imaging lesion on MRI.\(^d\) Statistically, agreement of MRP and CTP in measuring the acute perfusion lesion was quantified by concordance correlation coefficient (CCC) of Lin. In terms of classifying patients with mismatch pattern, the agreement was quantified by \(k\) coefficient.

Step 3: Cross-Modality Reperfusion Index
Reperfusion was assessed by the change of perfusion status from acute CTP to 24-hour MRP. To quantify the cross-modality reperfusion, a reperfusion index was introduced: reperfusion index = (acute CTP_{\text{vol}}–24-hour MRP_{\text{vol}})/acute CTP_{\text{vol}}. CTP_{\text{vol}} and MRP_{\text{vol}} were the perfusion volumes calculated by the optimal cross-modality measurement derived from step 1 (ie, the measurement with the least difference between CTP and MRP).

The cross-modality reperfusion index was then used as the independent variable in logistic regression to predict good clinical outcome at 90 days (modified Rankin Scale, 0–2). Afterward, receiver operating characteristic analysis was performed to examine how well cross-modality reperfusion predicted clinical outcome. All statistical analyses were done using STATA 11.0, and a significance level of 0.05 was set.

Results
Patients
For step 1, 57 patients were eligible. However, 7 cases were excluded because of severe motion artifact of perfusion images, and 5 cases were excluded because of vessel recanalization between CT and MR. For step 2, 22 patients were included, of which 7 patients were excluded for the above reasons. For step 3, 47 patients were eligible, but 2 were excluded because of substantial motion artifact of perfusion images.

In summary, image data of 45 patients were used in step 1, 15 patients were used in step 2, and 45 cases were used in step 3. Demographics of patients are shown in Table 1.
Step 1: Deriving the Map With the Least Difference Between CTP and MRP

For each imaging modality, 6840 perfusion regions were derived. Results of the random-effects model showed that there was a significant variance between perfusion maps (mean difference of MRP and CTP=1.11 mL, SD among perfusion maps=3.84 mL with 95% confidence interval, 2.34–6.28). However, within each parameter, the variance between thresholds was small (SD among thresholds=0.24 mL, with 95% confidence interval, 0.26–1.07). Thus, the relationship of CTP and MRP varied significantly between perfusion parameters but was consistent among thresholds within each parameter.

We then further assessed the exact difference between CTP and MRP for each respective perfusion map (Table 2). For CBF and CBV, MRP volume was significantly smaller than the respective CTP volume (P<0.01); for MTT and DT, MRP volume was significantly bigger than its CTP comparator (P<0.01). The only perfusion map with no significant volume difference between the 2 modalities was T max (P=0.133). T max was, therefore, identified as the perfusion parameter to take forward to the next 2 steps.

Step 2: Intermodality Agreement of Measuring Ischemic Lesion With T max

From T max>3 definitions were chosen to define the ischemic lesion: T max>2 s, T max>4 s, and T max>6 s.16–18 For each threshold, whole-brain lesion volume was extremely close between MRP and CTP (Figures 1 and 2; Table I in the online-only Data Supplement). The definition with best cross-modality concordance was T max>6 s, with CCC of 0.93 (P<0.01). Setting the threshold of T max>6 s, CTP resulted in a mean acute perfusion lesion volume of 102.61±78.3 mL and MRP of 102.91±75.81 mL (P>0.05).

T max>6 s was then used as the definition for the extent of the ischemic lesion for both imaging modalities to classify mismatch. In selection of patients with mismatch, CTP and MRP reached substantial agreement (κ=0.61).19 With the EXTEND criteria, 3 of 15 patients differed in classification across modality (κ=0.613; P<0.01); with DEFUSE, there were 2 of 15 misclassified (κ=0.746; P<0.01). More details could be found in Table II in the online-only Data Supplement.

Step 3: Cross-Modality Reperfusion Index With T max Measurement

Increasing cross-modality reperfusion from acute CTP to 24-hour MRP at the T max>6 s threshold was associated with improving clinical outcome (Figure 3A; Table III in the online-only Data Supplement). With each 1% increase in reperfusion, the odds of good clinical outcome (modified Rankin Scale, 0–2) increased by 1.1 (95% confidence interval, 1.04–1.16; P<0.05). More importantly, receiver operating characteristic results (Figure 3B) suggested that the prediction of good clinical outcome by reperfusion was highly sensitive and specific with an area under the curve value of 0.98 (95% confidence interval, 0.95–1). A cross-modality T max reperfusion index >77% predicted a good clinical outcome with 94.12% sensitivity and 93.33% specificity.

**Discussion**

Overall, the difference in acute perfusion lesions between MRP and CTP modalities was not dramatic. However, we did observe some variance across different perfusion maps. Among the 8 different perfusion maps assessed in this study, T max was clearly the best performer, with minimal difference between MRP and CTP.

The finding adds evidence to current data that T max has superior performance to other perfusion maps in stroke. Previous MRP studies16,17 showed that T max=4 to 6 s was the most accurate definition of the acute perfusion lesion. The MRP–T max definition was also validated by showing the highest correlation to the ischemic reference on positron emission tomography (CBF <20 mL/100 g per minute), and notably T max was more accurate than MRP–CBF.20 The current study found that T max=4 to 6 s measurement had good agreement between MRP and CTP.

**Table 1. Patient Demographics**

<table>
<thead>
<tr>
<th></th>
<th>Patients in Step 1 Analysis</th>
<th>Patients in Step 2 Analysis</th>
<th>Patients in Step 3 Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median</td>
<td>IQR</td>
<td>Median</td>
</tr>
<tr>
<td>Age, y</td>
<td>75</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>Baseline NIHSS</td>
<td>17</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Time to CTP, h</td>
<td>3.13</td>
<td>0.4</td>
<td>3.33</td>
</tr>
<tr>
<td>Time to MRP, h</td>
<td>3.67</td>
<td>0.77</td>
<td>4.33</td>
</tr>
<tr>
<td>CTP to MRP, h</td>
<td>0.5</td>
<td>0.17</td>
<td>1.23</td>
</tr>
</tbody>
</table>

CTP indicates computed tomographic perfusion; IQR, interquartile range; MRP, magnetic resonance perfusion; and NIHSS, National Institutes of Health Stroke Scale.

**Table 2. Difference of Hypoperfusion Regions Between MRP and CTP on Each Map**

<table>
<thead>
<tr>
<th>Perfusion Maps</th>
<th>MRP–CTP Difference, mL</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBF1</td>
<td>−2.22</td>
<td>−2.82 to −1.66</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CBF2</td>
<td>−2.30</td>
<td>−3.05 to −1.60</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CBV1</td>
<td>−1.75</td>
<td>−2.18 to −1.34</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CBV2</td>
<td>−2.11</td>
<td>−2.51 to −1.70</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MTT1</td>
<td>7.80</td>
<td>7.03 to 8.65</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>MTT2</td>
<td>6.41</td>
<td>5.60 to 7.27</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>DT</td>
<td>2.81</td>
<td>2.33 to 3.28</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>T max</td>
<td>0.67</td>
<td>−0.20 to 1.54</td>
<td>0.133*</td>
</tr>
</tbody>
</table>

*Difference of MRP and CTP is nonsignificant on T max map.

CBF indicates cerebral blood flow; CBV, cerebral blood volume; CTP, computed tomographic perfusion; DT, delay time to peak of the residual function; MRP, magnetic resonance perfusion; MTT, mean transit time; and T max, time to peak of the residual function.
and CTP (CCC >0.91) and was superior to other perfusion maps and thresholds. This finding allows more confidence in generalizing the ischemic definition from MRP to CTP and is a step forward in the quest standardizing perfusion lesion assessment in acute stroke.

Our results have major significance for the application of perfusion imaging in current and future acute stroke trials, particularly in multicenter trials, where both modalities are used for patient triage.⁵,⁶ There has been concern in past trials that there existed inconsistency in patient selection across the 2 modalities.⁵ In the current study, we have shown that there is a strong agreement (CCC >0.61) between MRP and CTP in patient selection based on mismatch pattern, provided our validated ischemic lesion thresholds are used. These are \( T_{\text{max}}>6 \) s/CBF <30% for penumbra/core mismatch on CTP and \( T_{\text{max}}>6 \) s/diffusion-weighted imaging lesion for the mismatch on MRP. This will maximize the likelihood that the same treatment decision is made by MRP and by CTP.

For the first time, our study has validated the cross-modality assessment of reperfusion. Reperfusion is a potent predictor of early recovery and later clinical outcomes after stroke²¹ and also a powerful biological marker of acute treatment efficacy.²⁴,⁶Growing evidence²²,²³ suggests that reperfusion is a stronger predictor of patient outcome than recanalization. Past validation of reperfusion has been limited to the use of single imaging modality. That is, it was calculated either by acute CTP and follow-up CTP or by acute MRP and follow-up MRP. This omits a common clinical scenario, whereby reperfusion success is examined after acute reperfusion therapy (particularly intravenous tissue-type plasminogen activator), using pretreatment CTP, and post-treatment MRP is performed to minimize radiation dose. We found that cross-modality reperfusion, with \( T_{\text{max}}>6 \) s measurement, had extremely high sensitivity and specificity in predicting good 3-month outcome. This agrees with a recent CTP-only study²³ that \( T_{\text{max}} \) measurement of reperfusion, when compared with other perfusion measurements, best predicted clinical outcome after stroke.

In summary, MRP and CTP are interchangeable if \( T_{\text{max}} \) is used as the perfusion threshold. We use the term interchangeable because MRP and CTP reached a high degree of agreement (CCC >0.9 or \( \kappa >0.61 \)). This does not mean that they are in perfect concordance because their technical differences

Figure 1. Concordance of the acute ischemic lesion between magnetic resonance perfusion (MRP) and computed tomographic perfusion (CTP). A, Distribution of whole-brain lesion volume measured by time to peak of the residual function (\( T_{\text{max}} >2 \) s, >4 s, and >6 s separately. B, Concordance of MRP and CTP with \( T_{\text{max}}>2 \) s measurement (CCC=0.89; slope of reduced major axis, 0.97). C, Concordance of MRP and CTP with \( T_{\text{max}}>4 \) s measurement (CCC=0.91; slope of reduced major axis, 0.97). D, Concordance of MRP and CTP with \( T_{\text{max}}>6 \) s measurement (CCC=0.93; slope of reduced major axis, 1.03). For all measurements, lesion distribution is similar between MRP and CTP, and slope of reduced major axis is close to 1 (line of perfect concordance).
are unavoidable. Furthermore, the interchangeability of $T_{\text{max}}$ measurement on MRP and CTP is contingent on the following 2 conditions being met. First, the same software is used to process MRP and CTP. This does not necessarily mean that it must be the software used in this study (MIStar). In our previous study, an in-house software also resulted in a good cross-modality agreement on $T_{\text{max}}>6$ s. Second, the $T_{\text{max}}$ map should be generated by standard SVD. Although delay-corrected SVD has been reported to generate accurate perfusion values to define infarct core and penumbra, the correction might lead to different results on MRP versus CTP. In our study, and in previous reports, $T_{\text{max}}$ values changed significantly on CTP, but not on MRP, with delay correction. The differential effect of delay correlation on the 2 imaging modalities explains why delay time (delayed $T_{\text{max}}$) had slightly worse cross-modality agreement in this study than did non-delay corrected $T_{\text{max}}$.

This is not the first study comparing MRP and concurrent CTP. However, previous studies were limited with only 1-threshold comparison and on limited slice coverage. Comparatively, our current study has 2 major advantages. First, in the derivation step, we systematically compared the 2 imaging modalities with multilevel perfusion information, including 19 threshold levels and 8 parameter levels. Second, we further validated our findings in a new data set using whole-brain perfusion information of both CTP and MRP. This is the first time such comparison has been done on a whole-brain spatial level.

There are limitations in this study. First, MRP and CTP are assumed to be concurrent, but there was a short interval time between the 2. Changes might have happened between modalities. We excluded patients with any evidence of vessel recanalization between modalities, but we might have included some with partial reperfusion or infarct growth between modalities. Notably, these changes would underestimate the agreement between MRP and CTP. Second, we were limited by relatively small patient numbers with whole-brain CTP data because the technology is relatively new. The small sample size in step 2 may, of course, have limited our ability to find better agreement between the modalities. Third, patients with stroke had exclusively hemispheric ischemia with relatively large lesion volumes. Additional study is needed in a broader range of patients with stroke.

**Conclusions**

This study provides evidence for researchers and clinicians that MRP and CTP can be used interchangeably if one uses...
Sources of Funding

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Disclosures

Dr Parsons has research support from National Health and Medical Research Council (NHMRC) Partnership Project Grant, ID: 1013719.

References


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http://stroke.ahajournals.org/content/45/6/1727

Data Supplement (unedited) at:
http://stroke.ahajournals.org/content/suppl/2014/05/13/STROKEAHA.114.005419.DC1

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Supplemental Methods

Patient

Patient data were retrospectively analysed in four steps. Firstly, we identified from the stroke patient database of John Hunter Hospital from 2005 to 2013, and included patients with multi-modal CT (NCCT+CTA+CTP) done within 9 hour of stroke onset. All patients had an acute neurological deficit consistent with ischaemic stroke, and received intravenous t-PA if they were clinically eligible (otherwise they received standard care). From this group we then selected patients with an acute symptomatic intracranial occlusion on CTA. The sites of occlusion were intracranial internal carotid artery (ICA), middle cerebral artery (MCA), posterior cerebral artery (PCA) or anterior cerebral artery (ACA). From this group, for the analysis of cross-modality agreement, we selected patients who had acute MR (DWI+MRP+MRA) done within two hours of CTP. Patients with evidence of any recanalization between acute CTA and acute MRA were excluded from this analysis. For the analysis of cross-modality reperfusion, we selected patients who had MR performed 24-48 hours after CTP.

CTP acquisition

For patients admitted before 2010, CTP images were acquired on 16-slice Philips scanner (Philips Mx8000; Philips, Cleveland, OH, USA). The image scanning commenced 4 seconds after intravenous injection (40 ml, injected at 5ml/s) of non-ionic iodinated contrast (Ultravist 370; Bayer HealthCare, Berlin, Germany). It lasted for 60 seconds, with acquisition of one image per second per slice. The acquisition parameters were 90 kV, 170 mA, Field of View (FOV) 210×210mm, and Matrix 512×512. The 60-second series had brain coverage of 24mm, which consisted two adjacent 12mm axial slices.

For patients admitted from 2010 to 2013, CTP images were derived from 320-slice Toshiba scanner (Toshiba Aquilion ONE; Toshiba, Tokyo, Japan). The scanner had an axial coverage of 160mm, generating 320 slices with the thickness of 0.5mm by one gantry rotation. Image scanning started 7 seconds after intravenous injection (40 ml, injected at 6ml/s) of non-ionic iodinated contrast (Ultravist 370; Bayer HealthCare, Berlin, Germany). It lasted for 60 seconds, acquiring 19 images per slice. The whole acquisition process was divided into three phases: phase one, 1 image was generated (80kV, 310mA) as a mask for all subsequent volumes; phase two, 13 images were generated at rate of one image per second (80kV, 150/300mA); phase three, 5 images were generated at rate of one image per five seconds (80kV, 150mA). For all three phases, FOV was 220×220mm, and Maxtrix was 512×512.

MRP acquisition

MRP was performed on a 1.5-Tesla scanner (Siemens Avanto, Erlangen, Germany). It was using dynamic susceptibility contrast technique and gradient-echo echo-planar imaging technique (GE-EPI). Following a bolus of gadolinium contrast (Magnevist; Bayer HealthCare, Berlin, Germany) into the antecubital vein (0.2mmol/kg, injected at speed of 5ml/s), perfusion images were obtained with acquisition parameters as follows: TR 1400 ms, TE 30 ms, Flip 90, FOV 230×230mm, and Matrix 128×128. The scanning lasted for 60 seconds, resulting in 40 images per slice. A total 19 slices were obtained with the thickness of 5mm, and with a slice gap of 1.5mm.
**Image post-processing**

MRP and CTP data were processed by the same commercial software MIStar (Apollo Medical Imaging Technology, Melbourne, VIC., Australia). Details of MIStar can be found in the following links [http://www.apollomit.com/](http://www.apollomit.com/). In summary, the software runs on all sorts of consoles from different manufacturers, and provides a broad choice of processing algorithm.

In this study, same post-processing protocol was used for MRP and CTP to improve the comparability of the two modalities. To be more specific: (1) the same deconvolution model was set to generate perfusion maps; (2) the anterior cerebral artery was selected as the arterial input function (AIF) for both modalities; and (3) the same approaches were applied to remove noise from perfusion maps. Regarding noise removal two approaches were taken; firstly, the software automatically detected voxels without clear contrast peak and these voxels were allocated with zero perfusion value of CBF and maximum perfusion value of MTT/Tmax/DT; secondly, Gaussian smoothing was applied manually (sigma=0.5, kernel size =3×3).

Noticeably, there are still technical differences between the two modalities that cannot be altered, such as the process of converting the time-intensity curve to a time-contrast curve. In this process, different mathematical models were applied, since CT detects tissue density which has a linear relationship with contrast concentration, whereas MR signal-intensity relationship with contrast concentration is nonlinear.

**Supplemental Figures**

Supplementary Figure I. Data structure of perfusion modality. Each imaging modality is post-processed by two mathematical models, delayed SVD (dSVD) and standard SVD (sSVD), resulting in 8 perfusion maps. For each map, 19 thresholds are set to derive corresponding perfusion defect regions. Comparison of MRP and CTP is based on perfusion region of the same threshold of the same map.
**Supplemental Tables**

### Supplementary Table I. Agreement of MRP and CTP on measuring whole-brain lesion with Tmax

<table>
<thead>
<tr>
<th>Tmax</th>
<th>MRP volume (ml) Mean ± SD</th>
<th>CTP volume (ml) Mean ± SD</th>
<th>Concordance correlation coefficient (CCC) Estimation</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2s</td>
<td>175.58 ± 112</td>
<td>171.09 ± 108.61</td>
<td>0.89</td>
<td>0.78 1.00</td>
</tr>
<tr>
<td>&gt;4s</td>
<td>136.69 ± 95.29</td>
<td>131.91 ± 92.37</td>
<td>0.91</td>
<td>0.82 1.00</td>
</tr>
<tr>
<td>&gt;6s</td>
<td>102.91 ± 75.81</td>
<td>102.61 ± 78.3</td>
<td>0.93</td>
<td>0.86 1.00</td>
</tr>
</tbody>
</table>

### Supplementary Table II. Patient classification by mismatch pattern

<table>
<thead>
<tr>
<th>CTP classification</th>
<th>MR classification</th>
<th>Mismatch pattern (-)</th>
<th>Mismatch pattern (+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTEND criteria</td>
<td>Mismatch pattern (-)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mismatch pattern (+)</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>DEFFUSE-2 criteria</td>
<td>Mismatch pattern (-)</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mismatch pattern (+)</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

### Supplementary Table III. Cross-modality reperfusion and clinical outcome

<table>
<thead>
<tr>
<th>Modified Rankin Score (mRS)</th>
<th>Patient number (N)</th>
<th>Reperfusion index (Median ±IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11</td>
<td>100% ± 9.82%</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>100% ± 1.89%</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>95.27% ± 26.9%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>71.29% ± 41.23%</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>28.58% ± 20.75%</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>26.86% ± 11.45%</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>0% ± 7.36%</td>
</tr>
</tbody>
</table>