Association Between Time to Reperfusion and Outcome
Is Primarily Driven by the Time From Imaging to Reperfusion

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Background and Purpose—A progressive decline in the odds of favorable outcome as time to reperfusion increases is well known. However, the impact of specific workflow intervals is not clear.

Methods—We studied the mechanical thrombectomy group (n=103) of the prospective, randomized REVASCAT (Randomized Trial of Revascularization With Solitaire FR Device Versus Best Medical Therapy in the Treatment of Acute Stroke due to Anterior Circulation Large Vessel Occlusion Presenting Within Eight Hours of Symptom Onset) trial. We defined 3 workflow metrics: time from symptom onset to reperfusion (OTR), time from symptom onset to computed tomography, and time from computed tomography (CT) to reperfusion. Clinical characteristics, core laboratory-evaluated Alberta Stroke Program Early CT Scores (ASPECTS) and 90-day outcome data were analyzed. The effect of time on favorable outcome (modified Rankin scale, 0–2) was described via adjusted odds ratios (ORs) for every 30-minute delay.

Results—Median admission National Institutes of Health Stroke Scale was 17.0 (14.0–20.0), reperfusion rate was 66%, and rate of favorable outcome was 43.7%. Mean (SD) workflow times were as follows: OTR: 342 (107) minute, onset to CT: 204 (93) minute, and CT to reperfusion: 138 (56) minute. Longer OTR time was associated with a reduced likelihood of good outcome (OR for 30-minute delay, 0.74; 95% confidence interval [CI], 0.59–0.93). The onset to CT time did not show a significant association with clinical outcome (OR, 0.87; 95% CI, 0.67–1.12), whereas the CT to reperfusion interval showed a negative association with favorable outcome (OR, 0.72; 95% CI, 0.54–0.95). A similar subgroup analysis according to admission ASPECTS showed this relationship for OTR time in ASPECTS<8 patients (OR, 0.56; 95% CI, 0.35–0.9) but not in ASPECTS≥8 (OR, 0.99; 95% CI, 0.68–1.44).

Conclusions—Time to reperfusion is negatively associated with favorable outcome, being CT to reperfusion, as opposed to onset to CT, the main determinant of this association. In addition, OTR was strongly associated to outcome in patients with low ASPECTS scores but not in patients with high ASPECTS scores.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT01692379.

(Stroke. 2016;47:999-1004. DOI: 10.1161/STROKEAHA.115.011721.)

Key Words: odds ratio ■ probability ■ reperfusion ■ stroke ■ thrombectomy

Timely reperfusion of salvageable brain is the fundamental principle underlying reperfusion therapies for stroke. Several studies have demonstrated the progressive decrease in the odds of favorable long-term outcome as time to reperfusion increases. The most common studied time metric is time from symptom onset to reperfusion (OTR); however, other time intervals have been defined and their specific impact on outcome has been described. Although the overall time interval from OTR is known to be a critically important predictor of outcomes, a breakdown of various workflow intervals according to level of impact on clinical outcomes has not yet been described. Knowledge of such differential influence of various workflow intervals on clinical outcomes is important as strategies focused on reducing those intervals that have highest relationships to clinical outcomes to the minimum would likely yield highest gains in
terms of outcomes. Time from OTR represents a chronology-based indicator, whereas time from imaging (assuming indication to treat is based on imaging evidence of small core) to reperfusion reflects a physiology-based indicator. We sought to determine the specific relationship of different workflow metrics with clinical outcomes in a randomized trial of mechanical thrombectomy for acute stroke.

**Methods**

The Randomized Trial of Revascularization With Solitaire FR Device Versus Best Medical Therapy in the Treatment of Acute Stroke due to Anterior Circulation Large Vessel Occlusion Presenting Within Eight Hours of Symptom Onset (REVASCAT) trial investigated the effects of mechanical thrombectomy with Solitaire device compared with best medical therapy alone in patients with acute stroke because of major arterial occlusion in the anterior circulation within 8 hours from symptom onset. Main study design, patients characteristics, and results were published elsewhere.23 For the purpose of this analysis, we studied the mechanical thrombectomy group (n=103). The main inclusion criteria for this trial were anterior circulation stroke in which endovascular treatment could be started <8 hours from symptom onset, Alberta Stroke Program Early Computed Tomographic (CT) Scores (ASPECTS) score of ≥7 on prerandomization CT and identification of a major vessel occlusion (tandem internal carotid artery/middle cerebral artery, terminal internal carotid artery, M1-middle cerebral artery). We defined 3 workflow metrics: (1) time from symptom OTR, (2) time from symptom onset to the CT scan qualifying the patient for randomization, and (3) time from CT to reperfusion (CTR). Time of reperfusion was defined as the time when complete recanalization (TICI2b-3) was achieved. For those patients who did not achieve complete recanalization or those who recanlized between CTA and first angiogram (n=5), we used the time of end of procedure. Qualifying ASPECTS scores for enrollment in REVASCAT were obtained by local investigators (stroke neurologists and neuroradiologists) who before starting enrollment in REVASCAT had undergone additional training in ASPECTS score reading. However, the ASPECTS scores used for purposes of trial reporting were centrally adjudicated scores by an independent core laboratory blinded to clinical data.

The primary outcome was the severity of disability at 90 days, according to the centrally adjudicated modified Rankin scale scores. For this substudy, a favorable outcome was defined as mRS score of 0 to 2.

**Statistical Analysis**

Statistical analyses were obtained using SAS 9.3 software. Categorical variables are presented as absolute values and percentages, and the continuous variables are presented as mean±SD if symmetrically distributed, or median (interquartile range) otherwise. The effect of time on good clinical outcome is described via odds ratios (ORs) for every 30-minute delay. All patients allocated to the revascularization arm, including those who did not achieve revascularization, were included in the analysis. To account for possible confounding factors, such less severe patients recruited at longer arrival times, analyses have been repeated for patients with ASPECTS ≤8 or ASPECTS ≥8 on admission CT scan evaluated by the independent core lab. A P value of <0.05 was considered significant for all tests. Model goodness of fit was assessed via the Hosmer and Lemeshow test.

**Results**

A total of 103 patients were randomized to the thrombectomy arm, 55% were male and mean age was 65.7±11.3. Median admission NIHSS was 17.0 (14.0–20.0) and median ASPECTS value on initial CT scan was 7.0 (6.0–9.0).

**Figure 1.** The studied intervals and the observed times. CT indicates computed tomography.

Complete recanalization was achieved in 66% of patients and the rate of favorable outcome was 43.7%.

Median workflow times were as follows: (1) time from symptom OTR: 28.4 minutes shorter for thrombectomy than for best medical therapy (204±93 minutes, (2) time from symptom onset to CT scan: 138±56 minutes for thrombectomy and 269 (201–340) minutes for best medical therapy, and (3) time from CTR: 138±56 minutes for thrombectomy and 269 (201–340) minutes for best medical therapy (Figure 1). Additional baseline characteristics and workflow times are shown in Table 1. OTR was 28.4 minutes shorter for patients with NIHSS ≥17 (329.4±104 versus 357.8±111.1).

Longer time from symptom to reperfusion was associated with a reduced likelihood of good outcome (adjusted OR for 30-minute delay intervals, 0.74; 95% confidence interval [CI], 0.57 to 0.97). Complete recanalization was achieved in 80% of patients in the thrombectomy group and 0% (0/5) in the best medical therapy group.

**Table 1. Patients Characteristics at Baseline and Measured Workflows**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Thrombectomy Group (n=103)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age±SD, y</td>
<td>65.7±11.3</td>
</tr>
<tr>
<td>Male sex, no. (%)</td>
<td>55 (53.4)</td>
</tr>
<tr>
<td>NIHSS score: median (IQR)</td>
<td>17.0 (14.0–20.0)</td>
</tr>
<tr>
<td>Treatment with intravenous alteplase, no. (%)</td>
<td>70 (68.0)</td>
</tr>
<tr>
<td>Median ASPECTS value (IQR)</td>
<td>7.0 (6.0–9.0)</td>
</tr>
<tr>
<td>ASPECTS ≤–10, no. (%)</td>
<td>50 (48.5%)</td>
</tr>
<tr>
<td>Location of intracranial occlusion on CTA or MRA, no./total no. (%)</td>
<td></td>
</tr>
<tr>
<td>Single M1</td>
<td>66/102 (64.7)</td>
</tr>
<tr>
<td>Ipsilateral cervical carotid occlusion, no. (%)</td>
<td>19/102 (18.6%)</td>
</tr>
<tr>
<td>No occlusion on initial angiogram, no. (%)</td>
<td>5 (4.8%)</td>
</tr>
<tr>
<td>Modified thrombolysis in cerebral infarction 2b/3 after procedure-no. (%)</td>
<td>67 (65.7%)</td>
</tr>
<tr>
<td>Workflow times</td>
<td></td>
</tr>
<tr>
<td>Median time from stroke onset to groin puncture (IQR), min</td>
<td>269 (201–340)</td>
</tr>
<tr>
<td>Median time from hospital arrival to groin puncture (IQR), min</td>
<td>109 (85–163)</td>
</tr>
<tr>
<td>Median time from imaging to groin puncture (IQR), min</td>
<td>67 (47–84)</td>
</tr>
<tr>
<td>Median time from groin puncture to revascularization (IQR), min (n=92)</td>
<td>59 (36–95)</td>
</tr>
</tbody>
</table>

ASPECTS indicates Alberta Stroke Program Early Computed Tomographic Scores; CTA, computed tomographic angiography; IQR, interquartile range; MRA, magnetic resonance angiography; and NIHSS, National Institutes of Health Stroke Scale.

*The location of the occlusion was not available in 1 patient in the intervention group.
Overall, the odd of achieving a good outcome was reduced by 26% for every 30-minute delay in reperfusion.

When we analyzed the effect of time in each interval (Table 2; Figure 2), we observed a clear difference between both sub-intervals. Although in the initial interval, a longer time from symptom onset to imaging, did not show an impact on final outcome (OR, 0.87; 95% CI, 0.67–1.12), in the second interval, a longer time from imaging to reperfusion, showed a significant negative association (OR, 0.72; 95% CI, 0.54–0.95; Figure 3).

Analysis According to Admission ASPECTS
For those patients with an ASPECTS <8 on pretreatment CT scan (n=53, 51.5%), a longer time from symptom to reperfusion was also associated with a reduced likelihood of good outcome (OR, 0.56; 95% CI, 0.35–0.9). The probability of achieving a good outcome was reduced by 44% for every 30-minute delay in reperfusion. When we looked for the consistency of these results in each time frame, we found completely overlapping intervals with those observed in the whole population analysis (onset to imaging and imaging to reperfusion, showed a significant negative association (OR, 0.72; 95% CI, 0.54–0.95; Figure 3).

Discussion
In line with previous studies, our findings confirm a progressive decline of the probabilities of regaining a good functional outcome as time to reperfusion increases, overall a 26% decrease for every 30-minute delay. The stronger association with time when compared with previous similar studies may be because of the fact that unlike those studies we did not exclude from the analysis those patients who did not achieve recanalization after the procedure.

Our study however aimed to describe the specific relationship of 2 different intervals. Although the time elapsed from symptom initiation to the admission CT scan was not associated with a clear decrease in the odds of good outcome in the treated patients; in the second interval, CTR, showed a clear negative relationship with the odds of good recovery.

**Table 2. Adjusted and Unadjusted ORs for 30 Minutes Delay in Each Time Interval for All Patients, Patients With ASPECTS<8, and Patients With ASPECTS≥8**

<table>
<thead>
<tr>
<th>OR for 30-Min Delay (95% CI)</th>
<th>All Patients</th>
<th>ASPECTS&lt;8</th>
<th>ASPECTS≥8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time from symptom to revascularization</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.95 (0.85–1.06)</td>
<td>0.87 (0.73–1.03)</td>
<td>1.05 (0.9–1.24)</td>
</tr>
<tr>
<td>Adjusted</td>
<td>0.74 (0.59–0.93)</td>
<td>0.56 (0.35–0.90)</td>
<td>0.99 (0.68–1.44)</td>
</tr>
<tr>
<td>Time from symptom to imaging, min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.99 (0.87–1.13)</td>
<td>0.91 (0.75–1.11)</td>
<td>1.10 (0.92–1.32)</td>
</tr>
<tr>
<td>Adjusted</td>
<td>0.87 (0.67–1.12)</td>
<td>0.77 (0.47–1.27)</td>
<td>1.19 (0.75–1.88)</td>
</tr>
<tr>
<td>Time from imaging to revascularization, min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.83 (0.66–1.03)</td>
<td>0.72 (0.5–1.05)</td>
<td>0.92 (0.69–1.23)</td>
</tr>
<tr>
<td>Adjusted</td>
<td>0.72 (0.54–0.95)</td>
<td>0.5 (0.28–0.88)</td>
<td>0.81 (0.50–1.30)</td>
</tr>
</tbody>
</table>

ASPECTS indicates Alberta Stroke Program Early Computed Tomographic Scores; CI, confidence interval; and OR, odds ratio.

![Figure 2. Forest plot for the relationship between the 3 different interval times with dichotomized modified Rankin Scale at 90 days (0–2 vs 3–6) in all patients and according to baseline Alberta Stroke Program Early Computed Tomographic Scores (ASPECTS). Adjusted analyses were made for age, baseline National Institutes of Health Stroke Scale (NIHSS), and intravenous tissue-type plasminogen activator. CTR indicates computed tomography to reperfusion; OCT, onset to CT; and OTR, onset to reperfusion.](http://stroke.ahajournals.org/).
These findings could be explained by the fact that in our study, the favorable outcome end point for this analysis was dichotomized into good (mRS, 0–2) or poor (mRS, 3–6). Because infarct volume has been shown to be strongly associated with outcomes, at least theoretically, each individual will achieve a good outcome if reperfusion occurs before crossing the infarct volume threshold of no return to independent level of activity after which the outcome will be unfavorable regardless of recanalization. By convention, the term favorable and unfavorable outcome refers to mRS score of 0 to 2 versus 3 to 6 even though different degrees of disability exist within the unfavorable category that may favor those who experience recanalization. REVASCAT was designed to maximize the chance of a good outcome in patients who reperfuse and, therefore, an ASPECTS cutoff of ≥7 was chosen, acting de facto as a screening imaging method meant to detect any patient who surpassed the infarct volume threshold at the moment of imaging with consequent exclusion from enrollment in the trial. This fact explains the flat appearance of the curve in this initial time interval because most patients who may have caused the curve to decline were excluded by the CT scan (ASPECTS) screening. It is likely that the small association between time to CT and outcomes was driven by those patients enrolled in REVASCAT who had low ASPECTS scores. In other words, the fact that the curve is nearly flat confirms that the REVASCAT imaging selection criteria were sufficient to allow accurate patient selection in most patients.

Our findings do not mean that time does not have an impact on outcome before CT scan is performed. The positive impact of shortening this initial interval (prehospital and in-hospital pathways) cannot be measured in this group of treated patients, but a reduction in time to CT would likely result in an increase in the number of eligible patients who would benefit from thrombectomy because the earlier the time point from symptoms onset relative to imaging the higher the likelihood of a higher ASPECTS score.

The second studied interval, time from CTR did show a clear negative association with the probability of good outcome. Because we adjusted for main known prognosis factors, and we tried to minimize the risk of selection bias by including also patients who could not be recanalized, the interpretation of this relationship as causal is, at least, plausible. In this case, the positive impact of decreasing the CTR interval is easy to quantify: +28% likelihood of favorable outcome for each 30-minute reduction.

When analyzing according to initial ASPECTS, in patients with lower scores (ASPECTS <8) we observed the expected negative association of time and outcome in the initial interval. This may be because of the fact that the lower ASPECTS score group represents patients with poorer baseline collaterals who will experience rapid growth of ischemic core before reperfusion.
More sophisticated imaging techniques such as those used in EXTEND-IA (Extending the Time for Thrombolysis in Emergency Neurological Deficits–Intra-Arterial) (size of $T_{\text{max}} >6\text{s lesion}$) or ESCAPE (Endovascular Treatment for Small Core and Anterior Circulation Proximal Occlusion with Emphasis on Minimizing CT to Recanализation Times) (collateral imaging) may more precisely identify those patients with fast core growth who have a low likelihood of return to independent level of functioning in the absence of immediate reperfusion. Whether endovascular reperfusion therapies, unless feasible within the shortest period of time should be withheld in these patients awaits clarification from future randomized trials. However, this group represents a subgroup of patients particularly sensitive to time to reperfusion and every effort should be made to reperfuse the brain in the timeliest possible manner. Although tempting to more precisely characterize the status of collateral flow, this group of patients may represent the group where treatment decisions should be made with the minimum available information (ASPECTS score) to save precious time to reperfusion. However, the same analysis among patients presenting with an ASPECTS$\geq8$ did not show a clear association between time in any of the studied intervals and outcome. A probable explanation would be an increased proportion of patients with good collateral flow supplying the ischemic penumbra, despite major arterial occlusion, favoring high ASPECTS scores and a lower rate of core growth. Because time becomes less relevant in this scenario, our results might also indicate that in cases with an unknown time from onset a compatible favorable CT scan (ASPECTS$>8$) might be used to select patients who will benefit from thrombectomy or at least may allow some time for advanced imaging studies confirming favorable physiology (mismatch) based on which definitive treatment decision can be made. This contention however, needs to be confirmed by future trials.

The strength of our data consists in prospective prespecified data collection including time intervals (onset to CT and CTR) and core laboratory-adjudicated ASPECTS. This is the first prospectively collected data set analyzing granular time intervals because they relate to outcome with prespecified imaging criteria. The main limitation is the sample size that does not provide sufficient power for highly reliable subgroup analysis. Therefore, our findings await confirmation from larger, pooled data sets of prospectively collected acute endovascular stroke cases. The REVASCAT trial unfortunately did not include a screening log that prospectively recorded all patients excluded because of a large ischemic lesion on qualifying neuroimaging. This information could have been valuable to quantify the number of patients who could have benefited from thrombectomy if the symptoms to CT interval was decreased. Future studies related to workflow metrics should record patients excluded after neuroimaging.

Conclusions

Time to reperfusion has a negative impact in favorable outcome, although differently reflected in each interval. Although reducing the symptom to imaging time might increase the number of eligible patients for effective thrombectomy, reducing the time from CTR would increase the positive impact of thrombectomy performed in those patients selected for therapy. Our results enforce the convenience to design interventions to reduce recanalization times.

Appendix

The REVASCAT Investigators

List of Sites, Investigators, and Administrative Staff

Enrolling Clinical Centers (Number Recruited):


Angiography Corelab: R. von Kummer.

Critical Events Committee: J. Martí-Fàbregas and B. Jankowitz.


Data Management and Biostatistics: BioClever, Barcelona.

Central blinded evaluation of Modified Rankin Scale: J. Serena and M. Salvat-Plana. Trial Coordination Center: E. López-Cancio and M. Hernandez-Pérez, Hospital Germans Trias I Pujol, Badalona, Barcelona.

Disclosures

Dr Cobo received nonfinancial research grant from Generalitat de Catalunya (research group GRBIO); modest honoraria from Fundació ictus Malaltia Vascular. Institutional conflict of interest: Barcelona-Tech received a grant for statistical design of REVASCAT trial. Dr Dávalos received significant research grant from Covidien and modest honoraria from Covidien (lectures). Dr Jovin received grant, nonfinancial, from Fundació ictus Malaltia Vascular; modest honoraria from Silk Road (consultant); he is a consultant/advisory board member in Medtronic and Stryker Neurovascular (nonfinancial); and in J&J, Blockade Medical and Neuravi (modest). The other authors report no conflicts.

References


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Stroke. 2016;47:999-1004; originally published online March 8, 2016; doi: 10.1161/STROKEAHA.115.011721
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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