pISSN 2093-9043
eISSN 2233-6273

Neurointervention 2025;20:71-81
https://doi.org/10.5469/neuroint.2025.00178

Procedure Time of Endovascular Thrombectomy as Performance Measure of Acute Stroke Treatment

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Purpose: Procedure time (PT), defined as the time between groin access and vessel recanalization, is a recently recognized predictor of outcomes after endovascular thrombectomy (EVT) for acute ischemic stroke (AIS). However, the factors affecting PT and its potential value as a performance measure of AIS treatment remain unexplored.

Materials and Methods: Using the Korean Stroke Registry, we compared patients who underwent EVT for AIS from 2018 to 2022 based on 60 minutes PT. We conducted multivariate analysis to investigate whether PT <60 minutes was associated with successful recanalization and good functional stroke outcomes. We also investigated factors that independently predicted PT ≥60 minutes. Furthermore, we determined the cutoff point for PT.

Results: We analyzed 4,703 patients (mean age: 69.5±11.9, 60.3% male) who underwent EVT. The mean PT was 54.6±36.7 minutes. Multivariate analysis revealed that PT <60 minutes independently predicted a good functional outcome as represented by modified Rankin Scale scores of 0–2 (adjusted odds ratio [aOR]: 1.40, 95% confidence interval [CI]: 1.22–1.59). PT <60 minutes was significantly associated with successful recanalization after adjusting for confounding variables (aOR: 1.66, 95% CI: 1.33–2.07). Moreover, after adjusting for covariates, age≥65 years (aOR: 1.20, 95% CI: 1.05–1.38), onset-to-door time (aOR: 1.03, 95% CI: 1.01–1.04), door-to-puncture time (aOR: 1.05, 95% CI: 1.03–1.06), posterior circulation stroke (PCS) (aOR: 1.13, 95% CI: 1.02–1.28), and smoking (aOR: 1.24, 95%CI: 1.09–1.45) independently predicted PT ≥60 minutes. Finally, the highest aOR for good stroke outcome was observed in the 60-minute cutoff model (aOR: 1.45, 95%CI: 1.27–1.67).

Conclusion: PT <60 minutes was significantly associated with good functional outcomes. Conversely, PT ≥60 minutes was associated with older age, PCS, smoking, prolonged onset-to-door and door-to-puncture time. Further studies are necessary to develop refining strategies for optimizing PT to improve stroke outcomes.

Key Words: Ischemic stroke; Operative time; Registries; Thrombectomy

INTRODUCTION

Currently, endovascular thrombectomy (EVT) is the standard of care for treating acute ischemic stroke (AIS) due to large vessel occlusion.[1] The current American Stroke Association guidelines recommend EVT for patients with AIS who present within 24 hours of symptom onset with a National Institutes of Health Stroke Scale (NIHSS) score ≥6.[2] Despite the relatively significant effect of EVT, approximately 50% of patients who have successful recanalization fail to attain functional independence at 90 days.[3] Notably, several parameters, including onset-to-door time, door-to-computed tomography scan time, door-to-puncture time, and recanalization status, have been recognized as critical factors associated with clinical outcomes and serve as performance measures to improve the quality of care;[4] however, procedure time (PT) is relatively unexplored. PT, defined as the time between groin access and vessel recanalization, is a recently identified predictor of poor outcomes after EVT.[5-8] PT within 60 minutes, known as the "golden hour," has been associated with improved outcomes after EVT.[6,9] However, large population studies based on real-world data on the association between PT and AIS outcomes are still lacking, particularly regarding associated factors of prolonged PT. This makes it difficult to answer the question of what we can do to optimize PT and how long an intervention should last for the best clinical efficacy.

Therefore, we performed a retrospective analysis based on a nationwide representative acute stroke registry to determine the association between PT and post-thrombectomy vascular status and clinical outcomes. Furthermore, we examined factors significantly associated with prolonged PT.

Received: February 24, 2025 **Revised:** April 9, 2025
Accepted: April 9, 2025

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MATERIALS AND METHODS

Patient Population

Study participants were selected from a prospectively maintained Korean Stroke Registry (KSR) database, including patients who received EVT for AIS between January 2018 and December 2022 at 50 stroke centers.[10] Patients aged >18 years with anterior and posterior circulation stroke (PCS) were included. Individuals with disability (modified Rankin Scale [mRS] score >1) before index AIS were excluded (Supplementary Fig. 1). We included patients who underwent EVT using modern thrombectomy devices such as a stent retriever, direct aspiration technique, or a combination, which were used in previous randomized controlled trials.[11-13] Intravenous thrombolysis (IVT) was used in accordance with current guidelines and independent of the decision to have EVT.

Data Collection

Data collected included demographic variables, NIHSS scores on admission, use of IVT, pre-stroke mRS scores, and functional outcomes at discharge as represented by mRS scores. Stroke location (anterior or posterior circulation) and the grade of angiographic revascularization classified based on the modified Thrombolysis in Cerebral Infarction (TICI) score were determined by the neurointerventionist performing the procedure.[14] Additionally, the KSR collected information on the occurrence of symptomatic intracranial hemorrhage (sICH) after EVT in 2020 and beyond. We collected information on the occurrence of sICH after EVT in 29 centers that performed brain imaging within 3 days of EVT and registered information on the occurrence of sICH.

The onset-to-door time was computed from the onset time of stroke symptoms (first abnormal time: the time when the symptoms were first noticed by the patient or observed by a witness) to the time of arrival at the hospital, as documented in the KSR. Door-to-puncture time was calculated as the time from when the patient presented to the hospital until the thrombectomy was started. PT was defined as the time from groin access to either successful recanalization (TICI score ≥2b) or termination of the procedure if the procedure was stopped before ≥TICI 2b was achieved. We also checked whether the patient visited on a working day or on a weekend or public holiday, and whether they visited the hospital during working hours (9 AM–6 PM) or during night duty hours (6 PM–9 AM).

Statistical Methods

Demographics and clinical features were compared between participants with PT <60 minutes and those with PT ≥60 minutes. For continuous measures, means and standard deviations, or medians with interquartile ranges are presented, and P-values were calculated with independent samples t-test or Wilcoxon rank sum test. Frequencies and percentages are presented for categorical measures, and P-values were calculated with a chi-square test or Fisher's exact test. Univariate and multivariate analysis used a logistic regression model with functional stroke outcomes at discharge, successful recanalization, and PT ≥60 minutes as the dependent variables. We included those reported in previous studies or clinically relevant to each dependent variable as independent variables.[15-17] Good functional outcome was defined as mRS score of 0–2 at discharge. For good functional outcome and successful recanalization, a multivariate logistic regression model was developed with age, sex, initial stroke severity, PT <60 minutes, vascular risk factors (history of previous stroke or transient ischemic attack, coronary artery disease, hypertension, diabetes, dyslipidemia, smoking, and atrial fibrillation), previous medication use (anticoagulants, antiplatelets, and statins), use of IVT, onset type of stroke (clear onset or not), level of the hospital (tertiary referral hospital or others), location of the stroke, and admission time at the hospital (working days or weekends, working hours or not) as independent variables. We also examined the association between PT <60 minutes and functional outcome in the group of patients with complete reperfusion (TICI 3) after EVT and with PCS using multivariate logistic regression analysis.

For PT delays greater than 60 minutes, we included age, sex, stroke severity, time to visit after onset, time to puncture after visit, IVT use, vascular risk factors, previous medication use, stroke onset type, level of the hospital, location of stroke, and admission time at the hospital as confounding factors. Factors identified as P-value <0.10 in the univariate analysis were included as covariates in the multivariate analysis. Furthermore, we performed a 3-knot (knots=50th, 75th, 95th percentiles) restricted cubic spline analysis to evaluate the nonlinear association and logistic regression to explore the optimal cutoff point in the relationship between the PT and good functional outcomes.

All statistical analyses were performed using SAS statistical software (version 9.4; SAS Institute) and R statistical software (version 4.1.2; R Foundation for Statistical Computing). Statistical significance was set at a 2-sided P-value <0.05.

RESULTS

Baseline Characteristics

We analyzed 4,703 patients (mean age: 69.5±11.9, 60.3% male) who underwent EVT. The mean PT was 54.6±36.7 minutes. Patients with PT <60 minutes were younger (mean age: 69.2±12.0 *vs.* 70.1±11.5 years, P=0.017), had clear-onset stroke more often (57.1% *vs.* 50.3%, P<0.001), and had shorter onset-to-door time (138.9±139.9 *vs.* 170.9±168.4 minutes, P<0.001) and door-to puncture time (98.7±38.0 *vs.* 107.0±41.9 minutes, P<0.001) than those with PT ≥60 minutes. However, regarding risk factors, the PT <60 minutes group was significantly less likely to have a history of smoking (33.2% *vs.* 38.0%, P=0.001) and more likely to have atrial fibrillation (49.7% *vs.* 46.2%, P=0.025). Furthermore, the history of anticoagulation (13.5% *vs.* 11.2%, P=0.030) and use of IVT (47.3% *vs.* 42.8%, P=0.004) was significantly higher in the PT <60 minutes group. Finally, there were significantly more PT ≥60 minutes cases among patients with PCS than those with anterior circulation stroke (Table 1).

Clinical and Angiographic Outcomes

When assessed for functional status at discharge, the PT <60 minutes group had significantly better outcomes compared with the PT ≥60 minutes group in all ranges (mRS: 0–1 [28.0% *vs.* 19.8%, P<0.001], mRS: 0–2 [45.1% *vs.* 36.4%, P<0.001], and mRS: 0–3 [61.9% *vs.* 52.9%, P<0.001]). There was no significant difference in death during hospitalization between either group. However, bedridden status at discharge (mRS: 5–6) was significantly higher in the PT ≥60 minutes group than in the PT <60 minutes group (20.9% *vs.* 26.0%, P<0.001). When TICI grade ≥2b was defined as the criterion for successful recanalization, it was significantly achieved in the PT <60 minutes group (94.0% *vs.* 90.2%, P<0.001). Moreover, the incidence of sICH after EVT was significantly lower in the PT <60 minutes group than in the PT ≥60 minutes group (2.7% *vs.* 9.6%, P<0.001) (Table 2, Supplementary Fig. 2).

Association of Procedure Time and Functional Outcomes

To evaluate whether PT <60 minutes independently predicts good functional outcomes (mRS: 0–2) in AIS patients, we performed multivariate logistic regression, adjusting

Table 1. Baseline characteristics of all patients

	Overall (n=4,703)	<60 min (n=3,117)	≥60 min (n=1,586)	P-value
Age (y)	69.5±11.9	69.2±12.0	70.1±11.5	0.017
Sex, male	2,837 (60.3)	1,903 (61.1)	934 (58.9)	0.161
Clear-onset stroke	2,578 (54.8)	1,780 (57.1)	798 (50.3)	<0.001
Onset-to-door time (min)	149.7±150.8	138.9±139.9	170.9±168.4	<0.001
Door-to-puncture time (min)	101.5±39.6	98.7±38.0	107.0±41.9	<0.001
PT (min)	54.6±36.7	33.9±13.0	95.4±33.8	<0.001
Comorbidity				
Previous stroke or TIA	745 (15.8)	486 (15.6)	259 (16.3)	0.540
Coronary artery disease	592 (12.6)	592 (19.0)	379 (23.9)	0.232
Hypertension	2,910 (61.9)	1,913 (61.4)	997 (62.9)	0.336
Diabetes mellitus	1,262 (26.8)	837 (26.9)	425 (26.8)	0.999
Dyslipidemia	1,528 (32.5)	1,008 (32.3)	518 (32.7)	0.849
Smoking	1,637 (34.8)	1,035 (33.2)	602 (38.0)	0.001
Atrial fibrillation	2,283 (48.5)	1,550 (49.7)	733 (46.2)	0.025
Previous medication				
History of anticoagulation	599 (12.7)	421 (13.5)	178 (11.2)	0.030
History of statin use	1,134 (24.1)	749 (24.0)	385 (24.3)	0.881
Previous use of antiplatelets	1,173 (24.9)	388 (12.4)	785 (49.5)	0.614
Use of IVT	2,151 (45.7)	1,473 (47.3)	678 (42.8)	0.004
Initial NIHSS Score	13.1±6.3	13.1±6.3	13.2±6.3	0.607
Site of large vessel occlusion				0.034
Anterior circulation	4,170 (88.7)	2,786 (89.4)	1,384 (87.3)	
Posterior circulation	533 (11.3)	331 (10.6)	202 (12.7)	
Tertiary referral hospital	2,852 (60.6)	1,911 (61.3)	941 (59.3)	0.200
Admission day				0.469
Working day	3,452 (73.4)	2,277 (73.1)	1,175 (74.1)	
Weekends and public holiday	1,251 (26.6)	840 (26.9)	411 (25.9)	
Admission time				0.795
During off (6 PM–9 AM)	2,813 (59.8)	1,869 (60.0)	944 (59.5)	
During working (9 AM–6 PM)	1,890 (40.2)	1,248 (40.0)	642 (40.5)	

Values are presented as mean±standard deviation or number (%).
PT, procedure time; TIA, transient ischemic attack; IVT, intravenous thrombolysis; NIHSS, National Institutes of Health Stroke Scale.

for established prognostic factors. The results confirmed that PT <60 minutes was significantly associated with good functional outcomes (adjusted odds ratio [aOR]: 1.40, 95% confidence interval [CI]: 1.22–1.59). Multivariate analysis also identified age ≥65 years, initial NIHSS score, use of IVT, diabetes mellitus, clear-onset stroke, and tertiary referral hospital as factors significantly associated with stroke outcome in addition to PT (Table 3). In the other ranges, PT <60 minutes remained significantly associated with favorable outcomes after multivariate analysis (mRS: 0–1, aOR: 1.54, 95% CI: 1.32–1.79; mRS: 0–3, aOR: 1.34, 95%CI: 1.17–1.55). In contrast, PT ≥60 minutes independently predicted bedridden status after EVT (mRS: 5–6, aOR: 1.30, 95% CI: 1.12–1.50) (Supplementary Tables 1–3). The restricted spline curve shows the timewise ORs for achieving good functional outcomes in terms of PT. The result suggested that there was a nonlinear relationship between the PT and good functional outcome (P=0.046). Especially, aOR decreased sharply until PT 60 minutes and

Table 2. Clinical outcomes and death of patients treated with EVT

	Overall (n=4,703)	<60 min (n=3,117)	≥60 min (n=1,586)	P-value
mRS at discharge	3 [1, 4]	3 [1, 4]	3 [2, 5]	<0.001
0–1	1,186 (25.2)	872 (28.0)	314 (19.8)	<0.001
0–2	1,985 (42.2)	1,407 (45.1)	578 (36.4)	<0.001
0–3	2,767 (58.8)	1,928 (61.9)	839 (52.9)	<0.001
Clinical outcome				
Bedridden state or death (mRS ≥5)	1,063 (22.6)	650 (20.9)	413 (26.0)	<0.001
Death during admission (mRS 6)	247 (5.3)	158 (5.1)	89 (5.6)	0.472
Post-EVT status				<0.001
TICI grade 0–2a	342 (7.3)	187 (6.0)	155 (9.8)	
TICI grade 2b–3	4,361 (92.7)	2,930 (94.0)	1,431 (90.2)	
sICH after EVT	61 (5.1) (n=1,206)	21 (2.7) (n=791)	40 (9.6) (n=415)	<0.001

Values are presented as median [interquartile range] or number (%).
EVT, endovascular thrombectomy; mRS, modified Rankin Scale; TICI, Thrombolysis in Cerebral Infarction; sICH, symptomatic intracranial hemorrhage.

Table 3. Factors associated with mRS score 0–2 at discharge

	Unadjusted OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Age, ≥65 y	0.96 (0.95–0.96)	<0.001	0.97 (0.96–0.97)	<0.001
Sex, male	1.33 (1.18–1.50)	<0.001	1.15 (0.99–1.33)	0.071
Initial NIHSS score	0.88 (0.87–0.89)	<0.001	0.88 (0.87–0.89)	<0.001
PT, <60 min	1.43 (1.27–1.62)	<0.001	1.40 (1.22–1.59)	<0.001
Previous stroke or TIA	0.83 (0.71–0.97)	0.022	1.12 (0.92–1.35)	0.251
Coronary artery disease	0.92 (0.78–1.10)	0.380	-	-
Hypertension	0.64 (0.57–0.72)	<0.001	0.88 (0.76–1.01)	0.072
Diabetes mellitus	0.68 (0.59–0.78)	<0.001	0.68 (0.59–0.79)	<0.001
Dyslipidemia	1.10 (0.98–1.25)	0.114	-	-
Smoking	1.23 (1.09–1.39)	<0.001	0.89 (0.77–1.04)	0.158
Atrial fibrillation	0.71 (0.63–0.79)	<0.001	1.10 (0.96–1.27)	0.154
History of anticoagulation	0.92 (0.77–1.09)	0.338	-	-
History of statin use	1.07 (0.94–1.23)	0.321	-	-
Previous use of antiplatelets	1.02 (0.89–1.17)	0.738	-	-
Use of IVT	1.41 (1.26–1.59)	<0.001	1.43 (1.24–1.64)	<0.001
Clear-onset stroke	1.61 (1.43–1.81)	<0.001	1.23 (1.07–1.41)	0.003
Tertiary referral hospital	0.72 (0.64–0.81)	<0.001	0.70 (0.61–0.80)	<0.001
PCS	0.90 (0.75–1.08)	0.265	-	-
Admission on weekends and public holiday	0.99 (0.87–1.12)	0.841	-	-
Admission during working hour	1.00 (0.89–1.13)	0.986	-	-

mRS, modified Rankin Scale; OR, odds ratio; CI, confidence interval; NIHSS, National Institutes of Health Stroke Scale; PT, procedure time; TIA, transient ischemic attack; IVT, intravenous thrombolysis; PCS, posterior circulation stroke; –, not available.

later slightly declined (Fig. 1A). In addition, the probability of achieving good functional outcomes was increased with a shorter PT (Fig. 1B).

Association of Procedure Time and Functional Outcomes in Patients Who Achieved Complete Reperfusion (TICI 3) after Endovascular Thrombectomy

We performed a multivariate logistic regression analysis on the group of patients who had fully reperfused after EVT (TICI 3 group). Consequently, PT <60 minutes was found to be significantly associated with good functional outcomes (aOR: 1.49, 95%CI: 1.23–1.79). In addition, PT <60 minutes was found to be significantly associated with neurological function at discharge, with mRS 0–1 and mRS 0–3 (mRS: 0–1, aOR: 1.68, 95% CI: 1.36–2.06; mRS: 0–3, aOR: 1.50, 95% CI: 1.24–1.82) (Supplementary Tables 4–6).

Association of Procedure Time and Functional Outcomes in Patients with Posterior Circulation Stroke

Furthermore, a multivariate logistic regression analysis was conducted, with the study population consisting of patients with PCS. The analysis revealed that PT <60 minutes was significantly associated with good functional outcomes (aOR: 1.76, 95% CI: 1.17–2.67). Additionally, PT<60 minutes was found to be significantly associated with mRS 0–1 (aOR: 1.78, 95% CI: 1.11–2.83) and mRS 0–3 (aOR: 1.47, 95% CI: 1.03–2.18) functional status at discharge (Supplementary Tables 7–9).

Association of Procedure Time with Successful Recanalization

To determine the association between PT and successful recanalization of the affected vessel, we performed a multivariate analysis with factors associated with recanalization reported in previous studies as covariates and successful post-thrombectomy reperfusion status represented by TICI grade ≥2b as the dependent variable. The results showed that PT <60 minutes was significantly associated with successful recanalization, even after adjusting for confounding variables (aOR: 1.66, 95% CI: 1.33–2.07) (Supplementary Table 10).

Factors Associated with Delayed Procedure Time ≥60 Minutes

We conducted a multivariate analysis with PT ≥60 minutes as the dependent variable to identify factors associated with prolonged PT. After adjusting for confounding variables, age ≥65 years (aOR: 1.20, 95% CI: 1.05–1.38), onset-to-door time (aOR: 1.03, 95% CI: 1.01–1.04), door-to-puncture time (aOR: 1.05, 95% CI: 1.03–1.06), PCS (aOR: 1.13, 95% CI: 1.02–1.28), and smoking (aOR: 1.24, 95% CI: 1.09–1.45) independently predicted a delay in PT ≥60 minutes. However, clear-onset stroke (aOR: 0.75, 95% CI: 0.66–0.86) was significantly and negatively associated with PT ≥60 minutes (Table 4).

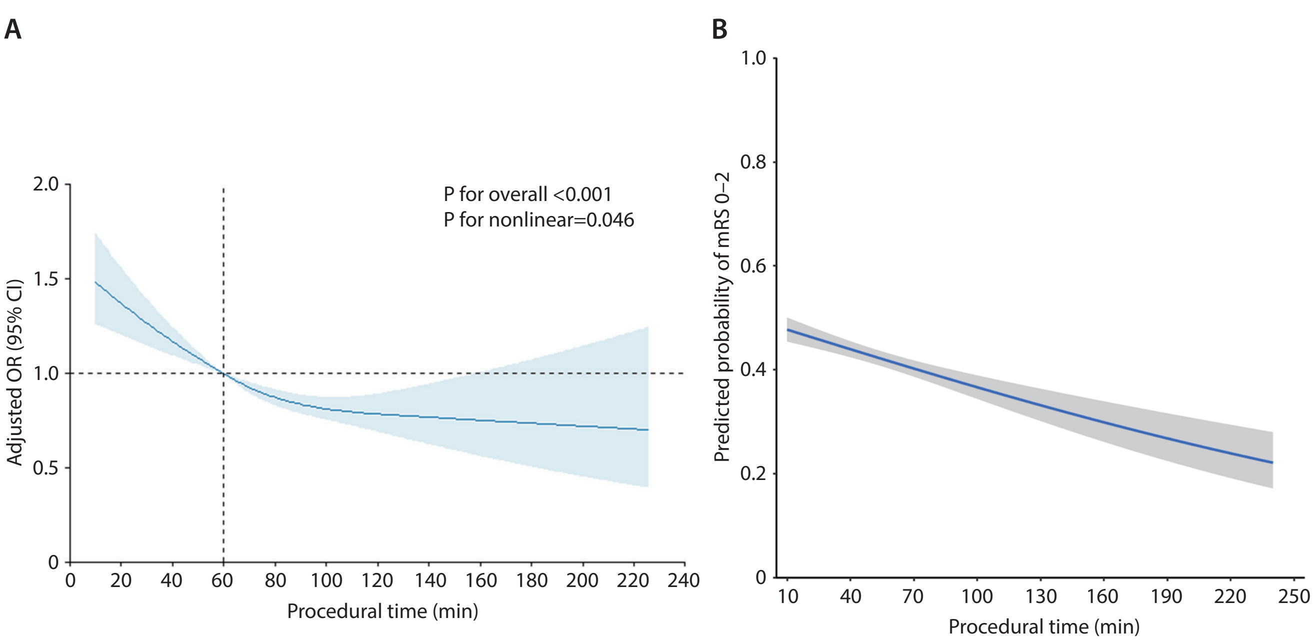

Fig. 1. Association between procedure time and good stroke outcomes. (**A**) Restricted cubic spline curve for procedure time and good stroke outcomes. The solid line depicts the ORs, and the shaded region shows the 95% CIs. (**B**) Probability for achieving good stroke outcomes (mRS 0–2) at discharge according to the procedure time. The shaded region shows the 95% CIs. OR, odds ratio; CI, confidence interval; mRS, modified Rankin Scale.

Table 4. Factors associated with PT over 60 minutes

	Unadjusted OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Age, ≥65 y	1.15 (1.01–1.31)	0.036	1.20 (1.05–1.38)	0.007
Sex, male	0.91 (0.81–1.03)	0.152	-	-
Initial NIHSS score	1.00 (0.99–1.01)	0.607	-	-
Onset-to-door time, 10 min	1.01 (1.00–1.02)	<0.001	1.03 (1.01–1.04)	<0.001
Door-to-puncture time, 10 min	1.05 (1.04–1.07)	<0.001	1.05 (1.03–1.06)	<0.001
Use of IVT	0.83 (0.74–0.94)	0.003	1.08 (0.93–1.24)	0.310
Previous mRS score	1.09 (0.88–1.35)	0.452	-	-
Previous stroke or TIA	1.06 (0.90–1.25)	0.512	-	-
Coronary artery disease	1.12 (0.94–1.34)	0.214	-	-
Hypertension	1.07 (0.94–1.21)	0.320	-	-
Diabetes mellitus	0.99 (0.87–1.14)	0.967	-	-
Dyslipidemia	1.02 (0.90–1.16)	0.756	-	-
Smoking	1.17 (1.03–1.32)	0.017	1.24 (1.09–1.45)	0.016
Atrial fibrillation	0.88 (0.78–0.99)	0.037	0.92 (0.81–1.06)	0.244
History of anticoagulation	0.81 (0.67–0.98)	0.027	0.88 (0.72–1.08)	0.233
History of statin use	1.01 (0.88–1.17)	0.853	-	-
Previous use of antiplatelets	0.96 (0.84–1.11)	0.589	-	-
Clear-onset stroke	0.76 (0.67–0.86)	<0.001	0.75 (0.66–0.86)	<0.001
Tertiary referral hospital	0.92 (0.81–1.04)	0.190	-	-
PCS	1.23 (1.02–1.48)	0.031	1.13 (1.02–1.28)	0.040
Admission on weekends and public holiday	0.95 (0.83–1.09)	0.448	-	-
Admission during working hour	1.02 (0.90–1.15)	0.771	-	-

PT, procedure time; OR, odds ratio; CI, confidence interval; NIHSS, National Institutes of Health Stroke Scale; IVT, intravenous thrombolysis; mRS, modified Rankin Scale; TIA, transient ischemic attack; PCS, posterior circulation stroke; –, not available.

Cutoff Point for the Procedure Time

Finally, to decide and confirm the cutoff point for the PT from puncture to reperfusion, 5 cutoffs at 15-minute intervals were selected (30, 45, 60, 75, and 90 minutes). A multivariate logistic regression model was developed for each cutoff time with a good stroke outcome of mRS 0–2 at discharge as the dependent variable. The highest aOR was observed in the 60-minute cutoff model (aOR: 1.45, 95% CI: 1.27–1.67, P<0.001) (Supplementary Table 11).

DISCUSSION

Using a nationwide representative stroke registry, this study showed that PT was associated with successful recanalization of the occluded vessel and clinical outcomes. Furthermore, older age, prolonged onset-to-door and door-to-puncture time, smoking, PCS, and mode of stroke onset (clear-onset stroke) were identified as factors associated with delays in PT ≥60 minutes, which has been reported as the "golden hour" in previous studies. Finally, our study identified 60 minutes as the cutoff time most strongly associated with functional stroke outcomes.

In previous studies, PT has been reported to be associated with functional outcomes in clinical trial populations and real-world data.[6,9,18] Similarly, in our study, PT was significantly associated with functional outcomes in patients with AIS, even after adjusting for patient baseline characteristics and comorbidities as covariates. Based on the KSR (2018–2022), our analysis reaffirms this relationship and provides new insights using a large East Asian cohort. This setting allows evaluation of the generalizability of prior findings in a different demographic context, where stroke characteristics and care systems may differ (Table 5).[5,6]

Our data support the role of PT as a predictor of functional recovery, as well as a reflection of procedural complexity for

https://doi.org/10.5469/neuroint.2025.00178

the refractory occlusion in response to mechanical thrombectomy. Even in patients with complete reperfusion (TICI 3), PT <60 minutes remained a significant predictor of good outcomes. This suggests that PT contributes to neurological recovery—likely by minimizing ischemic burden, avoiding vascular injury from repeated attempts, and enabling earlier post-procedural care.[9] Additionally, in patients with PCS, PT <60 minutes was significantly associated with better outcomes despite anatomical challenges, underscoring its value as a potentially modifiable factor. In contrast, sICH was more frequently observed in the PT ≥60 minutes group, suggesting that prolonged PT may increase the risk of post-EVT hemorrhagic complications. This finding aligns with previous studies indicating that longer PT may be associated with higher rates of vascular injury, endothelial damage, and microvascular reperfusion injury.[6,8]

Furthermore, as illustrated by the restricted spline curve (Fig. 1A), shorter PT is consistently linked to better outcomes, reinforcing the need to minimize PT when feasible. However, PT reduction should not come at the expense of procedural safety. Optimization efforts should include streamlining workflow, selecting appropriate devices, and making rapid clinical decisions. As a standardized and intuitive metric, PT enables comparisons across institutions and supports its role as a performance indicator in stroke care.

We identified factors associated with delayed PT ≥60 minutes. Notably, the multivariate analysis recognized onset-to-door time and door-to-puncture time after adjusting for confounding variables. These 2 time-related factors have been reported in previous studies as independent prognos-

Table 5. Comparison of key findings in major studies on EVT PT and its clinical implications

Aspect	Alawieh et al.[5]	Ash et al.[6]	Current study
Study design	Multicenter retrospective study	Multicenter retrospective study	Multicenter retrospective study
Study population	1,359 patients undergoing EVT	8,961 patients undergoing EVT	4,703 patients undergoing EVT
Patient recruitment period	2013–2018	2013–2022	2018–2022
Major country and ethnicity	US-based, predominantly North American population	Multi-national (predominantly North American and European populations)	Single-country (South Korea, predominantly East Asian population)
Data source	7 US Comprehensive Stroke Centers	STAR	KSR
Key findings on PT	PT >30 min associated with significantly worse outcomes; rapid recanalization (<30 min) led to best outcomes	PT >60 min associated with worse outcomes; every 10 min increase in PT raised odds of poor outcome by 10%	PT <60 min independently predicted good outcomes; impact of PT remained significant even in TICI 3 patients
Subgroup analyses	Divided PT into <30, 30–60, and >60 min groups; analyzed PT effects on sICH and mortality	Analyzed PT effects across anterior/PCSs, IV tPA use, ASPECT scores, age, and onset-to-groin time	PCS patients and TICI 3 subgroup
Significance of PCS	Found PCSs to be more sensitive to prolonged PT	PCSs showed highest sensitivity to PT, with tripled odds of poor outcome for PT >60 min	Confirmed PT <60 min cut-off as a strong predictor of good outcomes, reinforcing PT as a modifiable factor even in posterior strokes
Factors associated with delayed PT	Not explicitly analyzed	Not explicitly analyzed	Age above 65 y, PCS, smoking, prolonged onset-to-door time, and prolonged door-to-puncture time
Impact on clinical practice	Suggested that exceeding 60 min or 3 thrombectomy attempts should trigger futility assessment	Supports the 'golden hour' for EVT; suggests caution in prolonged procedures, especially in PCSs and elderly patients	Emphasizes PT as an optimization target rather than an absolute threshold, highlighting workflow improvements and individualized strategies

EVT, endovascular thrombectomy; PT, procedure time; STAR, Stroke Thrombectomy and Aneurysm Registry; KSR, Korean Stroke Registry; TICI, Thrombectomy in Cerebral Infarction; sICH, symptomatic intracranial hemorrhage; PCS, posterior circulation stroke; IV tPA, intravenous tissue plasminogen activator; ASPECT, Alberta Stroke Program Early Computed Tomography Score.

tic predictors after EVT in patients with AIS.[19-22] The earlier a patient presents to the hospital after the onset of AIS, the sooner the EVT is performed, the better the patient's prognosis. Similarly, it can be inferred that a quick thrombectomy after a blockage is associated with successful recanalization and shorter PT. While previous studies have suggested that prolonged onset-to-admission and door-to-puncture times could alter thrombus composition, increasing its fibrin content and adherence to the vessel wall,[23-25] this hypothesis remains uncertain due to limited direct evidence. Alternatively, differences in the etiology of strokes may be a contributing factor to variations in prehospital delay and PT duration. For instance, in cases of underlying intracranial atherosclerosis-related occlusion, patients may experience initial symptoms of a milder nature, which may result in delayed hospital arrival and delayed clinical decision-making, consequently leading to prolonged PT. Additionally, underlying atherosclerotic stenosis may necessitate multiple EVT attempts due to re-occlusion, which could contribute to an extended PT duration. Further studies incorporating detailed stroke etiology data and thrombus characteristics are needed.

Patient-specific, non-modifiable factors associated with a delay in PT ≥60 minutes may be considered when deciding when to stop EVT. Older age and smoking are associated with prolonged PT due to increased vascular tortuosity and atherosclerosis burden.[26-28] The longer the PT, the more the thrombus becomes entrapped in the vessel, the more vascular micro-injuries occur, and the higher the incidence of complications such as intracerebral hemorrhage.[29] Therefore, neurointerventionists need to decide whether to stop the procedure after a few attempts or after a certain amount of time if successful recanalization is challenging. These factors must be considered in conjunction with other complex clinical circumstances when deciding to continue or discontinue a procedure.

Notably, several possible explanations exist for the significant delay in PT in PCS. It has been reported that PCS is often subject to more futile recanalization than anterior circulation.[30,31] In PCS, the thrombectomy process can be prolonged due to anatomical features, including the small diameter of the vertebral artery.[32] Previous studies have also shown that PT is prolonged in patients with PCS, especially in cases of intracranial artery stenosis with atherosclerosis.[33] In addition, PCSs commonly present with vague symptoms, such as dizziness, which can delay detection and diagnosis.[34] This may cause late hospital arrival or in-hospital decision, which may delay PT for more than 60 minutes due to the late beginning of EVT. In fact, the onset-to-door time was significantly prolonged in PCS compared with anterior circulation stroke in this study's patient population (Supplementary Table 12). However, previous studies have shown that rapid PT can be achieved in the posterior circulation in patients with embolic strokes such as cardioembolism.[33] Hence, a tailored EVT strategy—one that considers stroke mechanism and vascular anatomy—is essential for optimizing PT and outcomes in PCS.

This study has some limitations. First, details regarding the thrombectomy process, such as first-pass recanalization and techniques, are lacking. Second, information on stroke mechanisms was unavailable, although patients with a history of atrial fibrillation had a shorter PT. Despite these limitations, the strength of our analysis lies in its scale and real-world relevance: a large, nationally representative multicenter cohort reflecting current thrombectomy practices in the post-2018 guideline era.[35]

CONCLUSION

This study confirms that PT <60 minutes was independently associated with successful recanalization and positive functional outcomes after EVT. Identifying and addressing factors that delay PT should be a priority in optimizing EVT care. Continuous monitoring of PT as a performance metric, combined with strategies for early hospital arrival and individualized procedural planning, especially in elderly and high-risk patients, will be crucial in enhancing stroke care outcomes.

SUPPLEMENTARY MATERIALS

Supplementary materials related to this article can be found online at https://doi.org/10.5469/neuroint.2025.00178.

Fund

The research was supported by the National Institute of Health (NIH) research project (project no. 2023-ER1006-02).

Ethics Statement

The Institutional Review Board (IRB) of Seoul National University Hospital, a representative of the involved hospitals, approved the procedure of this registry and the current study design (IRB no. H-1009-062-332 and H-2206-172-1336). We anonymized the patient information that could identify an individual.

Conflicts of Interest

The authors have no conflicts to disclose.

Author Contributions

Concept and design: EJL and KHJ. Analysis and interpretation: EJL, Jayoun Kim, NHP, and KHJ. Data collection: HYJ, MKK, DL, Jinkwon Kim, YHJ, SY, WJK, HJC, KL, THP, MSO, JSL, JTK, BWY, JMP, and HJB. Writing the article: EJL. Critical revision of the article: EJL, HYJ, and KHJ. Final approval of the article: KHJ. Statistical analysis: Jayoun Kim and NHP. Obtained funding: KHJ. Overall responsibility: KHJ.

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