

Effect of the Number of Neurointerventionalists on Off-Hour Endovascular Therapy for Acute Ischemic Stroke Within 12 Hours of Symptom Onset

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Background—Off-hour presentation can affect treatment delay and clinical outcomes in endovascular therapy (EVT) for acute ischemic stroke. We aimed to examine the treatment delays and clinical outcomes of EVT between on- and off-hour admission and to evaluate the effect of hospital procedure volume and the number of neurointerventionalists on off-hour EVT.

Methods and Results—From a multicenter registry, we identified patients who were treated with EVT within 12 hours of symptom. Annual hospital procedure volume was divided as low (<30), medium (30–60), and high (>60). The effect of the number of neurointerventionalists and annual hospital procedure volume on clinical outcome was estimated by the generalized estimation equation. Of the 31 133 stroke patients, 1564 patients met the eligibility criteria (mean age: 69 ± 12 years; median baseline National Institutes of Health stroke scale score, 15 [interquartile range, 10–19]). Of 1564 patients, 893 (57.1%) arrived during off-hour. The off-hour patients had greater median door-to-puncture time (110 versus 95 minutes; $P < 0.001$) compared with on-hour patients. Despite the treatment delay, the functional outcome at 3 months did not differ between off- and on-hour (odds ratio with 95% CI for 3-month modified Rankin Scale 0–2, 0.99 [0.78–1.25]; $P = 0.90$). The presence of three neurointerventionalists was significantly associated with favorable outcomes at 3 months during on- and off-hour (2.07 [1.53–2.81]; $P < 0.001$). The association was not observed for annual hospital procedural volume and the functional outcomes.

Conclusions—The number of neurointerventionalists was more crucial to effective around-the-clock EVT for acute stroke patients than hospital procedural volume. (*J Am Heart Assoc.* 2019;8:e011933. DOI: 10.1161/JAHA.119.011933.)

Key Words: hospital performance • interventional neuroradiology • stroke • stroke care • thrombectomy

Intravenous recombinant tissue plasminogen activator administered within 4.5 hours after symptom onset significantly improved clinical outcomes of patients with acute ischemic stroke, and earlier treatment with tissue plasminogen activator showed more-significant benefit.¹

Recently, endovascular therapy (EVT) showed significant clinical benefit among patients with acute ischemic stroke

attributable to large vessel occlusion when the procedure was performed within 6 hours after the onset of stroke symptoms. The benefit correlated well with a lesser time delay from symptom onset to reperfusion.² To be a successful EVT, it needs an experienced stroke endovascular team which is ready for 24/7. Because of a limited number of patients requiring such treatment among acute stroke patients, even

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Clinical Perspective

What Is New?

- The greater number of neurointerventionalists per hospital was associated with increased emergent endovascular therapy (EVT) service with reduced door-to-puncture time during off-hour for patients with acute ischemic stroke.
- The increasing number of neurointerventionalists per hospital was also significantly associated with favorable clinical outcomes at 3 months after the EVT.

What Are the Clinical Implications?

- At the hospital level, an appropriate number of neurointerventionalists are required to provide effective around-the-clock EVT for patients with acute ischemic stroke regardless of the time of day.
- A balance between a sufficient case volume to maintain competence and an excessive case volume that could lead to exhaustion of neurointerventionalists should be considered in estimating the number of neurointerventionalists.
- In addition to hospital procedural volume, a minimum number of neurointerventionalists providing EVT should be considered as a new requirement for designating comprehensive stroke center where the majority of EVT takes place.

large stroke centers could not have enough workforce responsible for around-the-clock EVT, which might lead to a treatment gap during off-hour. Previous research reported delayed door-to-recanalization time or picture-to-recanalization time in patients who received EVT during off-hour compared with those treated during on-hour.^{3–5} Unfortunately, all the previous studies were small-sized, single-center research, and they had not investigated the effect of hospital procedure volume or number of neurointerventionalists on treatment delay and outcomes during off-hour.

In the present study, we aimed to investigate the treatment delays and clinical outcomes of EVT between on- and off-hour admission using a large multicenter stroke registry and also to evaluate the effect of hospital procedure volume and number of neurointerventionalists on off-hour EVT.

Methods

The data and materials used in the present study are available from the corresponding author on request.

Study Design and Data Sources

In this study, we used data of consecutive patients enrolled in the CRCS-K (Clinical Research Collaboration for Stroke in Korea). It is

a web-based, ongoing, prospective, multicenter registry of patients with acute ischemic stroke. The registry started enrolling patients since 2008, and as of January 2018, 15 academic or regional stroke centers in South Korea have participated in the registry. Design, structure, and case characteristics of the CRCS-K registry have been published previously.^{6,7} This study was approved by the institutional review boards of all participating centers with a waiver of informed consent of individual patients because of study subject anonymity and minimal risk to participants. Between January 2010 and December 2015, we identified study participants using the following criteria from 12 hospitals; (1) acute ischemic stroke ≥ 18 years; (2) treated with EVT at the study hospitals within 12 hours of symptom onset. We excluded patients (1) who did not have exact time information on EVT, (2) whose functional status at 3 months after the stroke was not available.

Clinical Data and Outcomes

From the registry, we obtained demographic characteristics, vascular risk factors, prestroke medications, baseline National Institutes of Health Stroke Scale score, ischemic stroke subtypes, acute treatment, exact time information for hospital arrival, cranial imaging, groin puncture, final cerebral angiography at the end of the EVT, laboratory findings, symptomatic hemorrhagic transformation (SHT) during admission, and 3-month modified Rankin Scale (mRS) score. The onset time for unclear-onset stroke in this study was defined as the last-seen-normal time. Using the above time information, we calculated onset-to-door, door-to-puncture, door-to-image, image-to-puncture, and procedural time (from groin puncture to the final angiography). On-hour was defined as weekdays between 8:00 AM to 6:00 PM, and off-hour was defined as 6:00 PM to 8:00 AM for weekdays and all days for weekends and national holidays. Ischemic stroke was classified as large-artery atherosclerosis, small-vessel occlusion, cardioembolism, or undetermined etiology/other determined etiology using the TOAST (Trial of Org 10172 in Acute Stroke Treatment) classification with slight modification.^{8,9} The SHT was defined using the criteria suggested by the ECASS (European Cooperative Acute Stroke Study) III.¹⁰ Primary outcome was dichotomized 3-month mRS score (mRS 0–2 versus mRS 3–6). For secondary outcomes, we used the distribution of the mRS score and SHT during admission. For ordinal scale analysis, the mRS scores were converted to 6 categories by collapsing Seok 5 and mRS 6 into a single level of extreme disability or death.

Hospital Procedural Volume and Number of Neurointerventionalists

Annual hospital EVT volume was calculated for each year, and it was classified as low (<30), medium (30–60), and high

(>60) for the analyses. Low-volume threshold was defined as at 30 EVT procedures in accord with the annual number of acute ischemic stroke treatments required for accreditation of a neuroendovascular surgery program in the United States.¹¹ The number of neurointerventionalists, neurointerventional technologists, and dedicated nurses for EVT procedures was collected for each year from the hospitals. In South Korea, neurointerventionalists receive emergency calls only from the hospital where he or she is employed. If ≥ 2 patients who required the emergency procedure arrive at the hospital at the same time and the hospital has only 1 neurointerventionalist, 1 of the patients has to be transferred to another hospital where the treatment is possible.

Statistical Analysis

Data were summarized as mean \pm SD or median (interquartile range; IQR) for continuous variables and as number (%) for categorical variables. For missing values, simple imputation with median values was used for continuous variables with missing <10% of the total observations except for the time variables. Variables with missing >10% of total observations were excluded in the analysis. For the correlation between continuous variables, we used the Spearman test. Baseline characteristics between patients treated during on-hour and those treated during off-hour were compared using Pearson's chi-square test, Fisher's exact test, Student's *t* test, or Wilcoxon's rank-sum test according to the characteristics of the variables. For hospital-level data analysis, we created a hospital-year tier for each hospital for each year.

For unadjusted outcome analyses, the chi-square test or Fisher's exact test was used for binary outcomes. We used a generalized estimation equation for the binary outcomes and a multilevel ordered logistic regression analysis for the ordinal outcome to evaluate the independent effects of hospital-level variables on the outcomes, while also adjusting for patient-level variables including on- versus off-hour presentation. To investigate the possible mediation effect of shortened treatment time on the outcomes, a mediation analysis was done using *ldecomp* command, which was developed for estimating direct and indirect effects in a logit model.¹² All statistical analyses were performed using Stata data analysis software (Version 15.1; StataCorp LP, College Station, TX). In all analyses, $P < 0.05$ was considered statistically significant.

Results

Characteristics of the Patients

Of the 31 133 stroke patients who were admitted to 1 of the 12 participating centers between January 2010 and December 2015, 1564 patients met the eligibility criteria (Figure 1).

They had a mean age of 69 ± 12 years, and median baseline National Institutes of Health Stroke Scale score was 15 (IQR, 10–19). Of 1564 patients, 893 patients (57.1%) visited the hospitals during off-hour. Compared with the patients visited during on-hour, they were slightly younger and more frequently had unclear stroke onset time. However, they showed no significant differences in baseline National Institutes of Health Stroke Scale score, ischemic stroke subtype, and vascular risk factors except for atrial fibrillation (Table 1).

Off-Hour Effects on Treatment Delay

The patients that arrived during off-hour had significantly greater median door-to-puncture-time (DTPT; 110 versus 95 minutes; $P < 0.001$) and resultant greater median onset to puncture time (250 [176–360] versus 220 [160–317] minutes; $P < 0.001$). Exact image time was available for 1052 patients. Median door-to-image time did not differ significantly between off- and on-hour (19 [12–29] versus 19 [11–30] minutes; $P = 0.74$). However, the image-to-puncture time was delayed ≈ 17 minutes during off-hours (90 [67–117] versus 73 [49–105] minutes; $P < 0.001$). Procedure times were available for all patients except for 13, and the median procedure times were also significantly higher in patients that arrived during off-hour (75 [46–110] versus 67 [41–100] minutes; $P < 0.001$; Table 2).

Effects of Hospital Procedural Volume on Off-Hour EVT

Median annual hospital EVT volume was 15 (IQR, 6–33), and 34.1% of the patients treated at the hospitals with a volume of the EVT below 30 procedures per year, 23.3% at 30 to 60 procedures per year, and 42.6% at the hospitals offering >60 procedures per year. The annual number of the EVT procedures per hospital showed a significant negative correlation with average DTPT at the hospital level (Spearman's $\rho = -0.720$; $P < 0.001$). Both the DTPT during on- and off-hour showed a significant negative correlation with hospital EVT volume (on-hour, Spearman's $\rho = -0.518$; $P < 0.001$; off-hour, Spearman's $\rho = -0.712$; $P < 0.001$). In particular, low-volume hospitals showed significantly delayed DTPT compared with high-volume hospitals during both on- and off-hour. However, the DTPT showed a significant difference between low- and medium-volume center only during off-hour (Figure 2).

Effects of Number of Neurointerventionalists on Off-Hour EVT

The number of neurointerventionalists per hospital ranged from 1 to 3 per hospital, and the median number of

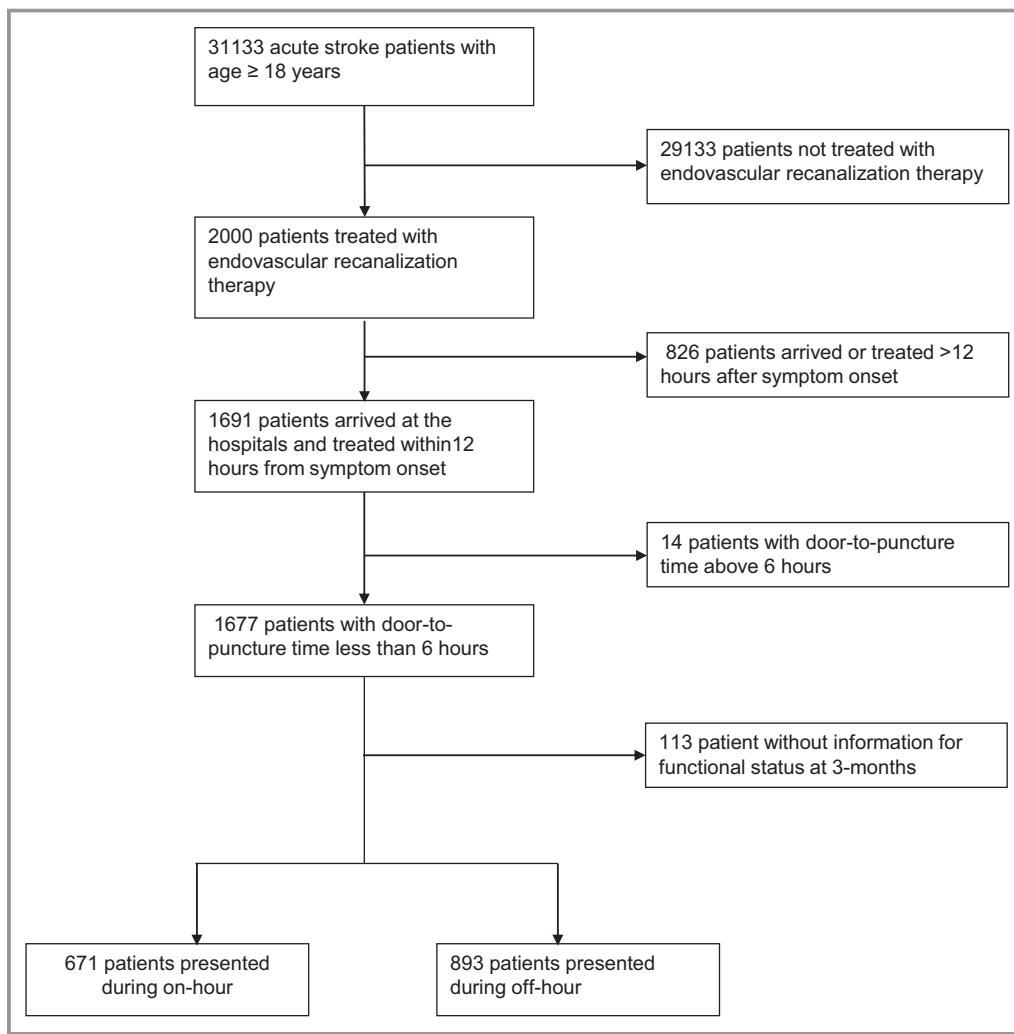


Figure 1. Flow diagram of enrollment.

neurointerventional technologists and dedicated nurses for 64 hospital-year was 2.0 (2.0–4.5) and 2.5 (2.0–4.0). The number of neurointerventional technologists and dedicated nurses did not differ between the hospitals with a single neurointerventionalist and 2 neurointerventionalists. However, the total number of technologists and dedicated nurses were significantly greater for the hospitals with 3 neurointerventionalists than those with 1 or 2 neurointerventionalists (median with IQR, 14 [14–14] versus 4 [3.5–8]; $P=0.002$). Of 1564 patients, 36.3% of the total EVT procedures were done at hospitals with a single neurointerventionalist, 41.6% at hospitals with 2 neurointerventionalists, and 22.2% at hospitals with 3 neurointerventionalists. The average annual volume of the EVT procedures per neurointerventionalist varied widely for a single neurointerventionalist (median annual procedure of 9 [IQR 4–42]), and 32% of the single neurointerventionalists were categorized as medium or high annual hospital procedural volume. The DTPT did not show a significant difference between hospitals with a single neurointerventionalist and 2

neurointerventionalists, but showed a significant difference between 1 or 2 neurointerventionalists and 3 neurointerventionalists per hospital both during on- and off-hour (Figure 2). Interestingly, the proportion of the EVT procedures during off-hour increased significantly with the number of neurointerventionalists per hospital ($P<0.001$), but it did not show a significant correlation with hospital EVT volume ($P=0.42$; Figure 3).

Outcome Analyses

Despite those significant treatment delays in patients arrived hospitals during off-hour, they exhibited no significant differences in functional outcomes at 3 months and SHT compared with those patients arrived hospital during on-hour (odds ratio for off- versus on-hour, 95% CI 3-month mRS 0 to 2, 0.99 [0.78–1.25], $P=0.90$; ordinal mRS, 1.00 [0.83–1.21], $P=0.98$; SHT, 1.06 [0.73–1.54], $P=0.76$; Figure 4). In the regression analyses adjusted for hospital-level variables, the presence of

Table 1. Characteristics of the Patients

	On-Hour (N=671)	Off-Hour (N=893)	Total (N=1564)	P Value
Demographics				
Age, y	69.6±11.8	68.4±11.9	68.9±11.8	0.045
Male	356 (53.1)	512 (57.3)	868 (55.5)	0.092
Risk factors				
Hypertension	420 (62.6)	592 (66.3)	1012 (64.7)	0.13
DM	170 (25.3)	237 (26.5)	407 (26.0)	0.59
Hyperlipidemia	173 (25.8)	214 (24.0)	387 (24.7)	0.41
Smoking	124 (18.5)	184 (20.6)	308 (19.7)	0.296
Atrial fibrillation	321 (47.8)	476 (53.3)	797 (51.0)	0.032
History of stroke	111 (16.5)	177 (19.8)	288 (18.4)	0.098
History of CAD	76 (11.3)	104 (11.6)	180 (11.5)	0.845
Laboratory finding				
Systolic blood pressure, mm Hg	139.9±26.2	142.6±26.5	141.5±26.4	0.048
Hemoglobin, g/dL	13.3±2.0	13.5±1.9	13.4±2.0	0.112
Fasting glucose, mg/dL	127.5±48.1	129.3±52.8	128.6±50.8	0.496
BUN, mg/dL	17.7±8.3	17.3±7.9	17.5±8.1	0.399
Creatinine, mg/dL	1.1±1.2	1.0±0.7	1.0±0.9	0.076
Platelet count, k/mm ³	214.0±70.3	206.7±69.8	209.8±70.1	0.041
LDL cholesterol, mg/dL	102.1±31.5	99.6±34.5	100.7±33.2	0.148
Stroke characteristics				
Clear onset	514 (76.6)	599 (67.1)	1113 (71.1)	<0.001
Onset to arrival time, min	149 (53–208)	172 (54–247)	162 (54–224)	0.002
Baseline NIHSS score	14 (10–19)	15 (10–19)	15 (10–19)	0.206
Ischemic stroke classification				0.234
LAA	146 (21.8)	196 (21.9)	342 (21.9)	
Cardioembolism	349 (52.0)	495 (55.4)	844 (54.0)	
Others	176 (26.2)	202 (22.6)	378 (24.2)	
IV-tPA use	436 (65.0)	570 (63.8)	1006 (64.3)	0.639
Door-to-needle time*, min	38 (28–52)	39 (29–57)	38 (29–55)	0.404

Data are N (%), mean±SD or median (IQR). Data were compared using Pearson's chi-square test, Student's *t* test, or Wilcoxon's rank-sum test according to the characteristics of the variables. BUN indicates blood urea nitrogen; CAD, coronary artery disease; DM, diabetes mellitus; IV-tPA, intravenous tissue plasminogen activator; LAA, large artery atherosclerosis; LDL, low-density lipoprotein; NIHSS, National Institutes of Health Stroke Scale.

*The exact time was not available for 12 patients among 1006 patients who received IV-tPA.

3 neurointerventionalists, but not 2 neurointerventionalists, was associated with significantly better functional outcomes at 3 months during on-hour compared with a single neurointerventionalist (2.74 [1.57–4.79]; $P<0.001$). However, both 2 and 3 neurointerventionalists were associated with significantly improved outcomes at 3 months during off-hour compared with a single neurointerventionalist (2 neurointerventionalists, 1.78 [1.07–2.96]; $P=0.026$; 3 neurointerventionalists, 1.69 [1.08–2.64]; $P=0.021$). Overall, the presence of 3 neurointerventionalists was associated with a >2-fold

increased chance of achieving a favorable clinical outcome at 3-month (2.07 [1.53–2.81]; $P<0.001$; Table 3). Annual hospital procedural volume was not associated with any clinical outcome in the entire patient population.

In the mediation analysis, the reduced time from door to finish of the procedure was responsible for around 17.5% (95% CI, 7.1–27.8; $P=0.003$) of the total effect of the number of neurointerventionalists on the favorable outcomes. The mediation effect was small and nonsignificant during off-hour (Table 4).

Table 2. Time Delays During On- and Off-Hour

	On-Hour (N=671)	Off-Hour (N=893)	P Value*
Onset-to-puncture			
Median (IQR)	220 (160–317)	250 (176–360)	<0.001
Mean±SD	251±128	290±152	<0.001
Door-to-puncture			
Median (IQR)	95 (72–123)	110 (89–137)	<0.001
Mean±SD	101±44	118±45	<0.001
Door-to-image time[†]			
Median (IQR)	19 (11–30)	19 (12–29)	0.74
Mean±SD	25±22	24±22	0.65
Image-to-puncture time[‡]			
Median (IQR)	73 (49–105)	90 (67–117)	<0.001
Mean±SD	81±47	96±44	<0.001
Procedural time[‡]			
Median (IQR)	67 (41–100)	75 (46–110)	<0.001
Mean±SD	76±48	85±54	<0.001

Data are minutes. IQR indicates interquartile range.

*Wilcoxon’s rank-sum test was used for comparing median values, and Student’s *t* test was used for mean values.

[†]Exact image time was available for 1052 patients (460 patients during on-hour and 592 patients during off-hour).

[‡]Procedure time was available for all patients except for 13 patients.

Discussion

In the current study of consecutive stroke patients who underwent EVT at 12 stroke centers in South Korea, we found that onset-to-puncture, DTPT, and procedural time were

significantly longer for patients undergoing treatment during off-hour, compared with those receiving treatment during on-hour. Despite this treatment delay during off-hour, we found no significant difference in clinical outcomes at 3 months after the stroke between on- and off-hour. At the hospital

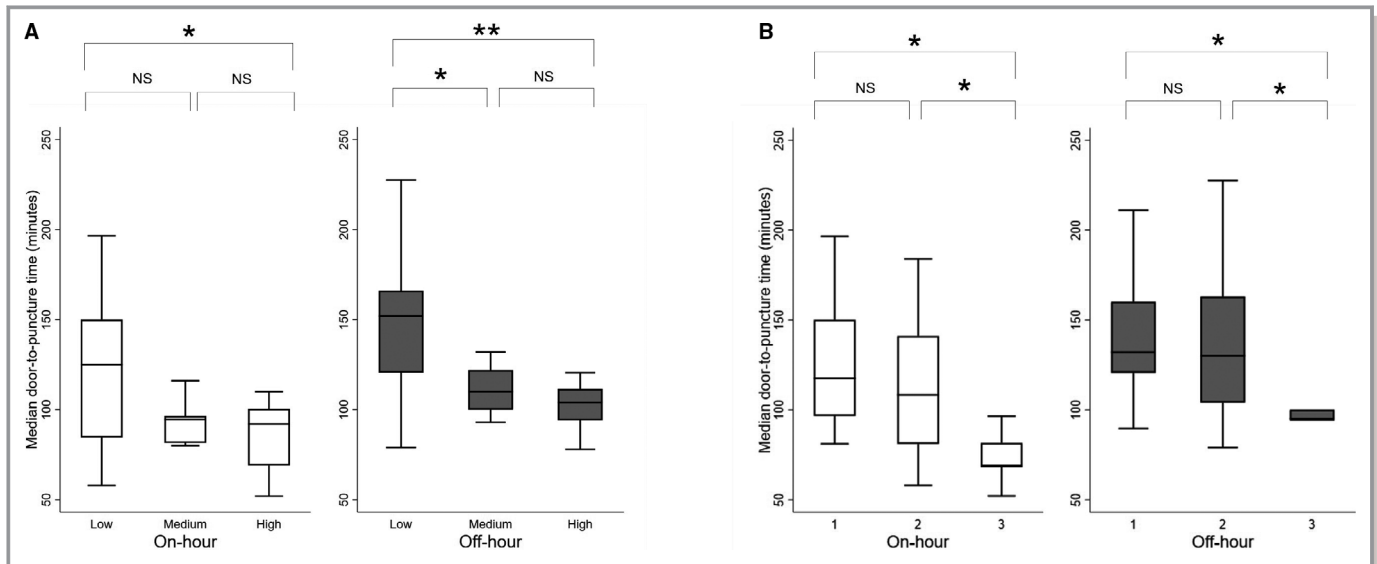


Figure 2. Boxplot showing door-to-puncture time (DTPT) during on- and off-hour by annual hospital procedural volume (A) and by the number of neurointerventionalists (B). The DTPT did not show a significant difference between medium- and high-volume centers during both on- and off-hour. The off-hour DTPT did not show a significant difference between hospitals with a single neurointerventionalist and 2 neurointerventionalists, but showed a significant difference between 1 or 2 neurointerventionalists and 3 neurointerventionalists per hospital. **P*<0.05; ***P*<0.01. NS indicates not significant.

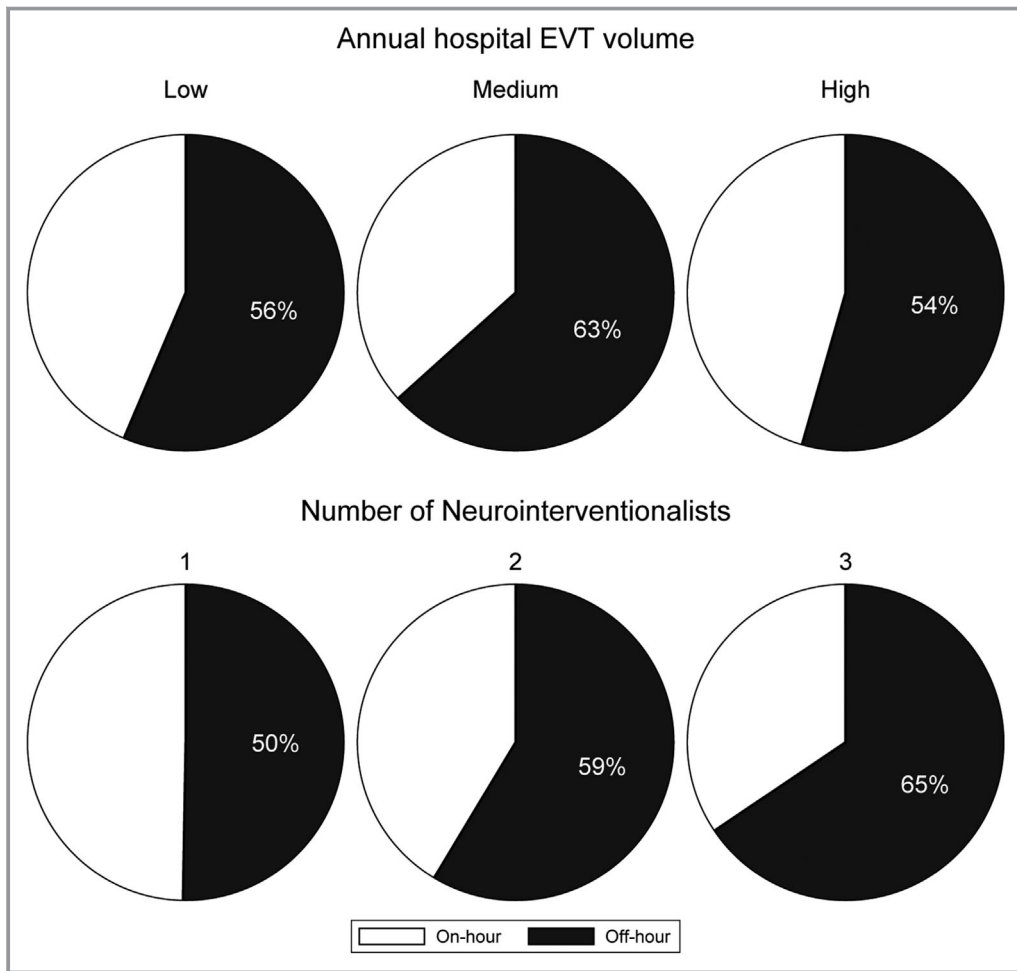


Figure 3. The proportion of the EVT procedures during off-hour. The proportion increased significantly with the number of neurointerventionalists per hospital ($P<0.001$), but not with the hospital EVT volume ($P=0.47$). EVT indicates endovascular therapy.

level, the DTPT was correlated well with hospital procedural volume and the number of neurointerventionalists per hospital. The proportion of the EVT procedures during off-hour increased significantly with the number of neurointerventionalists, but not with the hospital EVT volume. Finally, the

presence of ≥ 2 neurointerventionalists was associated with significantly improved outcomes at 3 months during off-hour compared with a single neurointerventionalist.

Because the benefit of thrombolytic therapy is significantly associated with time from symptom onset to reperfusion, the

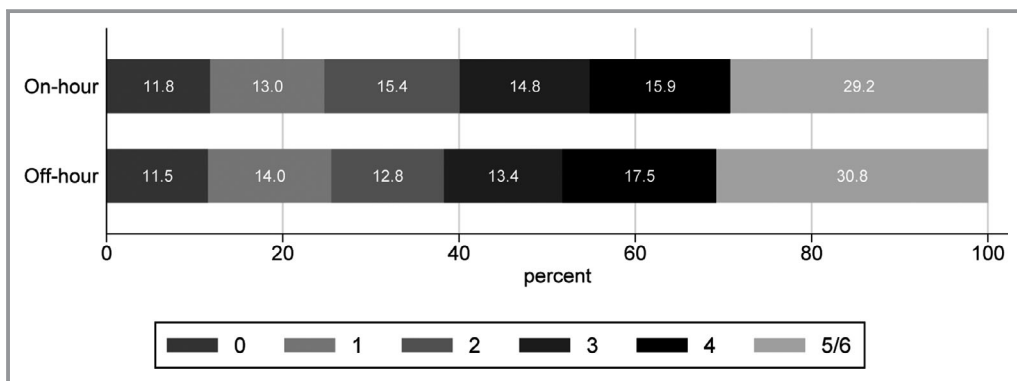


Figure 4. Distribution of modified Rankin Scale score at 3 months after the index stroke by the admission hour. Functional outcomes did not differ significantly between on- and off-hour ($P=0.25$).

Table 3. Effect of the Number of Neurointerventionalists on Clinical Outcomes in Regression Analyses

Clinical Outcome	No. of Neurointerventionalists	On-Hour			Off-Hour			Total		
		OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value
3-mo mRS 0 to 2	Single	Reference			Reference			Reference		
	2	1.01	0.61 to 1.65	0.98	1.78	1.07 to 2.96	0.026	1.43	0.97 to 2.11	0.073
	3	2.74	1.57 to 4.79	<0.001	1.69	1.08 to 2.64	0.021	2.07	1.53 to 2.81	<0.001
Ordinal 3-mo mRS	Single	Reference			Reference			Reference		
	2	1.01	0.69 to 1.49	0.95	1.61	1.14 to 2.26	0.007	1.34	1.04 to 1.72	0.025
	3	2.76	1.78 to 4.30	<0.001	1.79	1.24 to 2.59	0.002	2.08	1.57 to 2.75	<0.001
SHT	Single	Reference			Reference			Reference		
	2	1.30	0.44 to 3.83	0.63	0.97	0.46 to 2.04	0.93	1.09	0.57 to 2.08	0.80
	3	1.45	0.56 to 3.77	0.45	0.80	0.38 to 1.69	0.56	0.98	0.51 to 1.86	0.95

All analyses were adjusted for age, sex, prestroke modified Rankin Scale, initial NIHSS score, fasting blood glucose, hemoglobin, hypertension, diabetes mellitus, smoking, atrial fibrillation, use of intravenous tPA, use of a statin, onset to puncture time, procedure time, and annual hospital procedural volume. A generalized estimation equation was used for 3-month mRS and SHT analyses and a multilevel mixed-effects ordered logistic regression analysis was used for ordinal 3-month mRS analyses. mRS indicates modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; OR, odds ratio; SHT, symptomatic hemorrhagic transformation; tPA, tissue plasminogen activator.

treatment should be performed as soon as possible regardless of the time of the patient's visit to the hospital. This study showed an average of a 15-minute delay of the DTPT during off-hour. The treatment delay for EVT during off-hour is frequent in other reports,^{3,4} but not universal.⁵ In this study, the delay would represent the time spent for a commute of the neurointerventionalists and other interventional staffs from their residence to the hospital during off-hour because the door-to-image time and door-to-needle time was not different between on- and off-hour in this study. Despite the inevitable treatment delays during off-hour, the functional outcomes at 3 months did not differ significantly between the patients treated during on-hour and those treated during off-hour. Our findings are consistent with the previous research that also found no significant differences in clinical outcomes between on- and off-hour regardless of the presence of treatment delay.³⁻⁵ The patients with unclear-onset stroke were more frequent during off- than on-hour, and previous studies have already suggested that the substantial proportion of strokes that are evident after sleep occurred in the last few hours before awakening.^{13,14} Therefore, the most

probable reason could be that the actual onset-to-arrival time of patients with unclear-onset stroke in this study could be shorter than the last-seen-normal-to-arrival time used in this study.

Physician or hospital case volume is a well-established factor affecting clinical outcomes in percutaneous coronary intervention as well as carotid stenting or endarterectomy.¹⁵⁻¹⁸ However, only a few studies have examined the role of the number of physicians on the clinical outcome after acute cardiovascular diseases so far. In Japanese patients with acute heart failure and acute myocardial infarction, in-hospital mortality showed a significant negative correlation with the number of cardiologists per hospital, but not with physician case volume.^{19,20} Their results seem to be contrary to the established relationship between case volume and outcome reported in the earlier studies. They speculated that the total number of cardiologists per hospital could better explain the improved quality of care in the urgent illness that required specialized team care. In this study, we found that the number of neurointerventionalists was correlated with shortened DTPT, the proportion of the EVT procedures during off-hour,

Table 4. Summary of the Mediation Analysis

	On-Hour			Off-Hour			Total		
	OR	95% CI	P Value	OR	95% CI	P Value	OR	95% CI	P Value
Indirect effect	1.28	1.12 to 1.47	<0.001	1.09	1.02 to 1.17	0.015	1.13	1.07 to 1.21	<0.001
Direct effect	1.92	1.21 to 3.03	0.005	1.79	1.23 to 2.61	0.002	1.83	1.38 to 2.42	<0.001
Total effect	2.46	1.56 to 3.88	<0.001	1.95	1.34 to 2.84	<0.001	2.09	1.57 to 2.77	<0.001
Mediated proportion	0.27	0.03 to 0.52	0.026	0.13	-0.02 to 0.27	0.084	0.18	0.07 to 0.28	0.003

The effects are ORs for modified Rankin Scale score 0 to 2 at 3 months except for the mediated proportion. OR indicates odds ratio.

and favorable clinical outcome at 3 months after the index stroke. Although hospital EVT volume was correlated with DTPT, it was not independently associated with overall clinical outcome in this study. It should also be noted that the hospital EVT volume was not correlated well with the number of neurointerventionalists in this study because a single neurointerventionalist showed a wide range of case volume. In this study, the hospitals had, at most, 3 neurointerventionalists because EVT procedures are usually required for a very limited number of stroke patients even in a tertiary hospital. In this unique situation, the number of physicians could be a more-important factor for a patient's outcome than the hospital case volume because it must be a challenging mission for a small number of neurointerventionalists to deal with 24/7 interventional consultations and procedures for patients with acute ischemic stroke.

Currently, the exact number of neurointerventionalists required for 24/7 coverage of endovascular ischemic stroke therapy has not been defined in the recommendation for a comprehensive stroke center.²¹ A balance between a sufficient case volume to maintain competence and an excessive case volume that could lead to exhaustion of neurointerventionalists should be considered in estimating the number of neurointerventionalists and their minimum volume of cases at both the hospital and physician level.²² Although the DTPT was correlated well with both hospital procedural volume and the number of neurointerventionalists per hospital in this study, the proportion of EVT volume performed during off-hours did not reach 60% in hospitals with fewer than 3 neurointerventionalists, even though off-hours would account for >75% of the total hours. Interestingly, the presence of ≥ 2 neurointerventionalists was associated with significantly improved outcomes at 3 months during off-hour compared with a single neurointerventionalist, although the number of neurointerventional technologists and dedicated nurses was not different between institutions with a single neurointerventionalist and 2 neurointerventionalists. Therefore, this study showed that an appropriate number of neurointerventionalists was crucial to reducing treatment delay as well as providing effective treatment even during off-hour.

In this study, the reduced DTPT alone was not able to explain the entire relationship between the number of neurointerventionalists and clinical outcome because the mediation analysis found only a partial mediation effect of the reduced treatment time on the clinical outcomes. It is well known that a physician is vulnerable to burnout, and the physician's burnout can lead to increased medical errors.^{23,24} In general, work factors that contribute to physician burnout include excessive workloads, long working hours, specialty choice, frequent call duties (night call or weekend call), time spent at home on work-related factors, and risk of malpractice suits.²⁴ Among a broad spectrum of medical specialties, neurointerventionalists are

experiencing a high rate of burnout recently because of frequent nighttime consultations and procedures that are chased by time for a faster DTPT with the expansion of the EVT indication.^{25–28} In addition to reduced treatment time, other factors that led to improved outcome in hospitals with a higher number of neurointerventionalists, such as reduced workload, less chance of burnout, or improved collaboration with other medical staff, should be investigated further in future research.

This study has several limitations. First, though the CRCS-K registry includes geographically diverse hospitals with annual stroke volumes ranging from 300 to 1000, our results may not be generalizable to other countries with different regional stroke care systems. Nevertheless, the CRCS-K is the largest, most comprehensive current registry of acute stroke patients available in South Korea. Second, detailed EVT information, such as recanalization status, collateral status, and procedural complications, that may affect the functional outcome was not available in the current analysis. Third, our conclusions may be limited by the lack of assessment of ischemic stroke lesions on computed tomography or magnetic resonance imaging using the Alberta Stroke Program Early CT Score before deciding EVT.

Conclusions and Policy Implications

Onset to treatment time was significantly longer for patients undergoing treatment during off-hour, and it was correlated well with hospital procedural volume and the number of neurointerventionalists per hospital. The proportion of the EVT procedures during off-hour increased significantly with the number of neurointerventionalists, but not with hospital EVT volume. Our research is the first to highlight the association between the number of neurointerventionalists and clinical outcome among patients treated with EVT. Therefore, efforts to improve the quality of EVT should ensure that the proportion of patients receiving EVT and clinical outcomes is achieved regardless of the time of day. In addition to hospital procedural volume, a minimum number of neurointerventionalists providing EVT should be considered as a new requirement for designating a comprehensive stroke center where the majority of EVT takes place.

Appendix

Clinical Research Collaboration for Stroke in Korea (CRCS-K) Investigators

Participating stroke centers and site investigators

1. Seoul National University Bundang Hospital: Hee-Joon Bae (director), Moon-Ku Han, Beom Joon Kim, Jihoon Kang.
2. Nowon Eulji Medical Center, Eulji University: Jong-Moo Park, Kyusik Kang.

3. Eulji University Hospital: Soo Joo Lee, Jae Guk Kim.
4. Dong-A University Hospital: Jae-Kwan Cha, Dae-Hyun Kim.
5. Seoul Medical Center: Tai Hwan Park, Sang-Soon Park, Moo-Seok Park.
6. Soonchunhyang University Hospital Seoul: Kyung Bok Lee.
7. Yeungnam University Medical Center: Jun Lee.
8. Inje University Ilsan Paik Hospital: Yong-Jin Cho, Keun-Sik Hong, Hong-Kyun Park.
9. Hallym University Sacred Heart Hospital: Mi-Sun Oh, Kyung-Ho Yu, Byung-Chul Lee.
10. Dongguk University Ilsan Hospital: Dong-Eog Kim, Wi-Sun Ryu.
11. Chonnam National University Hospital: Joon-Tae Kim, Ki-Hyun Cho, Kangho Choi.
12. Jeju National University Hospital: Jay Chol Choi, Joong-Goo Kim.
13. Ulsan University Hospital: Wook-Joo Kim, Jee Hyun Kwon.
14. Chungbuk National University Hospital: Dong-Ick Shin, Kyu Sun Yum.
15. Keimyung University Dongsan Medical Center: Sung Il Sohn, Jeong-Ho Hong, Joonsang Yoo.
16. Hallym University Dongtan Sacred Heart Hospital: Min Uk Jang.
17. Hallym University Chuncheon Sacred Heart Hospital: Lee Sang-Hwa.
18. Chung-Ang University Hospital: Kwang Yeol Park.

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2. Ji Sung Lee (Clinical Trial Center, Asan Medical Center).

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Choi conceptualized and designed the study. Choi and J.-G. Kim reviewed the articles and collected the data. Choi, Bae, S.-J. Lee, Jong-Moo Park, T.H. Park, Cho, K.B. Lee, J. Lee, D.-E. Kim, Jae-Kwan Cha, J.-T. Kim, and B.-C. Lee recruited patients. Choi and D.J. Kim analyzed the data. All authors contributed to data interpretation, write-up, editing, and revisions of the final manuscript. All authors have contributed to the production of the final version of this manuscript.

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Disclosures

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