Association between flat-panel computed tomography hyperattenuation and clinical outcome after successful recanalization by endovascular treatment

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OBJECTIVE Hyperattenuation on CT scanning performed immediately after endovascular treatment (EVT) is known to be associated with the final infarct. As flat-panel CT (FPCT) scanning is readily accessible within their angiography suite, the authors evaluated the ability of the extent of hyperattenuation on FPCT to predict clinical outcomes after EVT.

METHODS Patients with successful recanalization (modified Thrombolysis in Cerebral Infarction grade 2b or 3) were reviewed retrospectively. The extent of hyperattenuation was assessed by the Alberta Stroke Program Early CT Score on FPCT (FPCT-ASPECTS). FPCT-ASPECTS findings were compared according to functional outcome and malignant infarction. The predictive power of the FPCT-ASPECTS with initial CT images before EVT (CT-ASPECTS) and follow-up diffusion-weighted images (MR-ASPECTS) was also compared.

RESULTS A total of 235 patients were included. All patients were treated with mechanical thrombectomy, and 45.5% of the patients received intravenous tissue plasminogen activator. The mean ($\pm$ SD) time from stroke onset to recanalization was 383 ± 290 minutes. The FPCT-ASPECTS was significantly different between patients with a favorable outcome and those without (mean 9.3 ± 0.9 vs 6.7 ± 2.6) and between patients with malignant infarction and those without (3.4 ± 2.9 vs 8.8 ± 1.4). The FPCT-ASPECTS was an independent factor for a favorable outcome (adjusted OR 3.28, 95% CI 2.12–5.01) and malignant infarction (adjusted OR 0.42, 95% CI 0.31–0.57). The area under the curve (AUC) of the FPCT-ASPECTS for a favorable outcome (0.862, cutoff ≥ 8) was significantly greater than that of the CT-ASPECTS (0.637) ($p < 0.001$) and comparable to that of the MR-ASPECTS (0.853) ($p = 0.983$). For malignant infarction, the FPCT-ASPECTS was also more predictive than the CT-ASPECTS (AUC 0.906 vs 0.552; $p = 0.001$) with a cutoff of ≤ 5 .

CONCLUSIONS The FPCT-ASPECTS was highly predictive of clinical outcomes in patients with successful recanalization. FPCT could be a practical method to immediately predict clinical outcomes and thereby aid in acute management after EVT.

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KEYWORDS endovascular treatment; stroke; prognosis; flat-panel computed tomography; vascular disorders

CONVENTIONAL multidetector CT is often performed after endovascular treatment (EVT) of acute stroke, as CT imaging can show periprocedural hemorrhagic conditions, including procedure-related intracranial hemorrhage and immediate hemorrhagic transformation due to reperfusion. However, most hyperattenuation on CT scanning is generally contributed by the contrast medium,

so-called contrast staining.^{1–5} This contrast material–related hyperattenuation is thought to result from leakage of contrast medium into the parenchymal extracellular space due to blood-brain barrier disruption caused by focal ischemic injury, chemotoxicity, or reperfusion injury.⁶ Therefore, hyperattenuation due to contrast staining on postprocedural CT can be presumed to reflect the infarct core.^{1,2}

ABBREVIATIONS ASPECTS = Alberta Stroke Program Early CT Score; AUC = area under the ROC curve; EVT = endovascular treatment; FPCT = flat-panel CT; ICA = internal carotid artery; mRS = modified Rankin Scale; NIHSS = National Institutes of Health Stroke Scale; ROC = receiver operating characteristic; tPA = tissue plasminogen activator.

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CT-like images can be obtained directly within the angiography suite with the use of modern angiographic systems equipped with a flat-panel detector (flat-panel CT [FPCT]). FPCT is often performed during or at the end of the EVT procedure, primarily to observe periprocedural hemorrhagic conditions, due to the ease with which it can be performed and its recently improved image quality. Given that hyperattenuation on postprocedural CT is associated with the infarct core, we reasoned that the extent of hyperattenuation on FPCT performed at the end of the EVT procedure might be closely associated with patients' clinical outcomes. In particular, we hypothesized that the greater the extent of hyperattenuation on FPCT, the poorer the patients' clinical outcomes. To test this hypothesis, we evaluated clinical outcomes according to the extent of hyperattenuation of FPCT and compared the ability of FPCT to predict clinical outcome with that of other imaging modalities.

Methods

Participants

We retrospectively reviewed consecutive acute stroke patients with intracranial large-vessel occlusion of the anterior circulation who underwent EVT between January 2010 and December 2018. Patients were selected from a prospectively maintained stroke registry at a tertiary stroke center. EVT was generally considered for patients who met the following criteria: 1) a CT angiography–determined endovascularly accessible intracranial large-vessel occlusion associated with neurological symptoms; 2) presentation to the hospital within 8 hours from stroke onset (in the later study period, patients within 8 to 12 hours were also considered if they had an Alberta Stroke Program Early CT Score [ASPECTS] ≥ 7); and 3) baseline National Institutes of Health Stroke Scale (NIHSS) score ≥ 4 . We also generally performed EVT in patients with premonitory modified Rankin Scale (mRS) scores ≤ 3 . The intracranial internal carotid artery (ICA) and M_1 or proximal M_2 segment of the middle cerebral artery were defined as intracranial large vessels. In the present study, patients 1) whose occlusion was successfully recanalized and 2) who underwent FPCT at the end of the EVT procedure were included.

All patients eligible for intravenous tissue plasminogen activator (tPA) or EVT were evaluated by noncontrast CT and CT angiography. Patients eligible for intravenous tPA treatment were treated with 0.9 mg/kg tPA. EVT procedures were performed according to common recommendations. The frontline EVT modality was stent retriever thrombectomy, contact aspiration thrombectomy, or a combination of these techniques. A balloon-guiding catheter was routinely used. Successful recanalization in EVT was defined as a modified Thrombolysis in Cerebral Infarction grade of 2b or 3. Follow-up MRI, including diffusion-weighted imaging and MR angiography, were performed routinely at around 24 hours after the EVT procedure.

The institutional review board approved this study and waived the requirement of informed consent for study inclusion based on its retrospective design.

Acquisition of FPCT

FPCT was routinely performed at the end of the EVT procedure to evaluate if procedure-related complications (e.g., subarachnoid hemorrhage) or hemorrhagic transformation had occurred. In patients who underwent intracranial stenting or received intraarterial glycoprotein IIb/IIIa inhibitor, FPCT was performed before the introduction of rescue modalities to evaluate the hemorrhagic condition. FPCT images were acquired on a biplane angiography system (Allura Xper FD20/20 or Allura Clarity FD20/20 Interventional Angiographic Systems, Philips Healthcare). This imaging system allows motorized rotational movement of the C-arm in the plane perpendicular to the longitudinal table axis around the head of the patient's position at the system isocenter. A total of 620 fluoroscopic frames in a circular motion were acquired with the following parameters: voltage 120 kV, tube current 250 mA, frame speed 30 frames per second, acquisition time 5 msec per frame, total angle 240°, rotation speed 22° per second, exposure time 20 seconds, field of view 48 cm, and 1024 $\times$ 1024-pixel matrix detector. Image reconstruction was performed using a dedicated workstation. Image postprocessing to correct for beam hardening and scatter was performed to achieve maximum spatial and contrast resolution. For evaluation, volume-rendering reconstruction was performed with 5-mm-thick slices and no gap, although the thickness can be customized from 1 to 100 mm.

Determination of FPCT-ASPECTS, CT-ASPECTS, and MR-ASPECTS

The extent of FPCT hyperattenuation was semiquantitatively assessed using the ASPECTS (FPCT-ASPECTS). To compare the predictive power of the FPCT-ASPECTS with other periprocedural imaging modalities, the ASPECTS on noncontrast CT images obtained before the EVT procedure (CT-ASPECTS) and diffusion-weighted images obtained after the EVT procedure (MR-ASPECTS) were also assessed. The CT-ASPECTS was calculated according to the original method.⁷ Similarly, the ASPECTS was calculated by subtracting the number of hyperattenuated regions from 10 to calculate the FPCT-ASPECTS and MR-ASPECTS. Locations of interest for determining the FPCT-ASPECTS and MR-ASPECTS were the same as those for the CT-ASPECTS. The CT-ASPECTS, FPCT-ASPECTS, and MR-ASPECTS were assessed by a total of six independent neuroradiologists and interventional neuroradiologists. The ASPECTS on each imaging modality was assessed independently by two raters. All raters were blinded to clinical and procedural outcomes. Interobserver agreements of the CT-ASPECTS, FPCT-ASPECTS, and MR-ASPECTS were 0.872, 0.936, and 0.957, respectively. Cases with discrepancies were resolved by consensus.

Statistical Analysis

To determine if there was an association between the FPCT-ASPECTS and clinical outcome after EVT, patients were grouped according to clinical outcome. In the present study, clinical outcome was evaluated based on functional outcome and malignant infarction.

Functional outcome was considered favorable if the

mRS score at 3 months after EVT was ≤ 2 . Based on this threshold, patients were assigned to the favorable outcome or the unfavorable outcome group. First, demographic factors, common risk factors for stroke, clinical and procedural information, and the FPCT-ASPECTS were compared between groups. The Student t-test, Mann-Whitney U-test, chi-square test, and Fisher's exact test were used for comparison. To identify independent variables associated with a favorable outcome, multivariable binary logistic regression analysis was performed. Variables with $p < 0.10$ in univariable analysis were entered into the multivariable model. Second, to determine the predictive power of the FPCT-ASPECTS for a favorable outcome, we performed receiver operating characteristic (ROC) curve analysis and calculated the area under the ROC curve (AUC) of the FPCT-ASPECTS for a favorable outcome. An optimal cutoff point of the FPCT-ASPECTS for a favorable outcome was determined by the Youden index. Then, using DeLong's test, the AUC of the FPCT-ASPECTS for a favorable outcome was compared with those of the CT-ASPECTS and MR-ASPECTS.

The association of the FPCT-ASPECTS with malignant infarction was assessed using the same statistical approach as described above. For malignant infarction, patients were assigned to the malignant infarction group or the no malignant infarction group. Malignant infarction was defined as brain swelling that was treated with decompression craniectomy or that caused death without intracerebral hemorrhage. Brain swelling was assessed on MR images routinely obtained around 24 hours after the EVT procedure. If a patient's neurological status worsened, follow-up CT or MRI was performed immediately. Additional brain imaging was often performed serially for high-risk patients to observe the evolution of brain swelling. All statistical analyses were performed using SPSS (version 23, IBM Corp.) and MedCalc (version 16.8.4) software; $p < 0.05$ was considered statistically significant.

Results

A total of 279 patients had both a successful recanalization and FPCT during the study period. FPCT images could be assessed in 235 patients (mean age 68.1 ± 13.6 years; 50.2% male) (Fig. 1).

FPCT-ASPECTS and a Favorable Outcome

After excluding 16 patients whose 3-month mRS scores were not available, 219 patients were analyzed (Fig. 1). Among them, 157 (71.7%) were classified as having a favorable outcome. The mean FPCT-ASPECTS was significantly higher in patients with a favorable outcome (9.3 ± 0.9) than in those with an unfavorable outcome (6.7 ± 2.6) ($p < 0.001$; Table 1 and Fig. 2). Along with a lower NIHSS score, the FPCT-ASPECTS was an independent factor for a favorable outcome (OR 3.28, 95% CI 2.15–5.01; $p < 0.001$). The AUC of the FPCT-ASPECTS for a favorable outcome was 0.862 (95% CI 0.809–0.905; $p < 0.001$), which was significantly greater than that of the CT-ASPECTS (0.637; $p < 0.001$) and similar to that of the MR-ASPECTS (0.853; $p = 0.983$; Fig. 3A). An optimal cutoff

FIG. 1. Patient selection flowchart.

point of the FPCT-ASPECTS for a favorable outcome was ≥ 8 (sensitivity 96.8%, specificity 54.8%).

FPCT-ASPECTS and Malignant Infarction

The mean FPCT-ASPECTS was significantly lower in patients with malignant infarction (3.4 ± 2.9) than in patients without malignant infarction (8.8 ± 1.4) ($p < 0.001$; Table 2). Furthermore, the FPCT-ASPECTS was an independent factor for malignant infarction (OR 0.42, 95% CI 0.31–0.57; $p < 0.001$). The AUC of the FPCT-ASPECTS for malignant infarction was 0.906 (95% CI 0.861–0.940;

TABLE 1. Comparison of variables and FPCT-ASPECTS between patients with and those without a favorable outcome

	Univariable Analysis				Multivariable Analysis	
	All Patients (n = 219)	Favorable Outcome (n = 157)	Unfavorable Outcome (n = 62)	p Value	OR (95% CI)*	p Value
Age, yrs	68.1 ± 13.7	66.0 ± 13.9	73.1 ± 11.7	<0.001	0.96 (0.92–1.00)	0.057
Male sex	112 (51.1)	84 (53.5)	28 (45.2)	0.295		
Hypertension	121 (55.3)	88 (56.1)	33 (53.2)	0.764		
Diabetes	39 (17.8)	25 (15.9)	14 (22.6)	0.246		
Smoking	26 (11.9)	21 (13.4)	5 (8.1)	0.356		
Atrial fibrillation	86 (39.3)	56 (35.7)	30 (48.4)	0.092	0.67 (0.28–1.59)	0.363
Coronary artery disease	26 (11.9)	19 (12.1)	7 (11.3)	0.999		
Initial NIHSS score	15.0 [7.0, 23.0]	14.0 [6.7, 21.3]	18.0 [12.0, 24.0]	<0.001	0.83 (0.75–0.93)	0.001
Intravenous tPA	102 (46.6)	74 (47.1)	28 (45.2)	0.881		
ICA occlusion	85 (38.8)	54 (34.4)	31 (50.0)	0.045	0.92 (0.36–2.32)	0.851
Time profile, mins						
Onset-to-image	238 ± 284	232 ± 465	251 ± 288	0.664		
Image-to-puncture	89 ± 67	90 ± 73	87 ± 43	0.807		
Puncture-to-recanalization	52 ± 38	46 ± 34	67 ± 42	<0.001	0.99 (0.98–1.01)	0.533
Onset-to-recanalization	380 ± 298	368 ± 299	406 ± 294	0.399		
CT-ASPECTS	9.3 ± 1.1	9.5 ± 0.9	8.9 ± 1.4	0.001	1.33 (0.90–1.97)	0.157
FPCT-ASPECTS	9.0 ± 2.0	9.3 ± 0.9	6.7 ± 2.6	<0.001	3.28 (2.15–5.01)	<0.001

Univariate results are expressed as mean ± SD, the number of patients (%), or median [IQR].

* Odds ratio for a favorable outcome.

$p < 0.001$) with an optimal cutoff point of ≤ 5 (sensitivity 82.4%, specificity 97.3%). The AUC of the FPCT-ASPECTS was significantly greater than that of the CT-ASPECTS (0.552; $p = 0.001$; Fig. 3B).

Discussion

In this study, we found that the FPCT-ASPECTS was significantly associated with favorable outcome and malignant infarction in patients with successful recanalization by EVT. More importantly, the FPCT-ASPECTS was significantly more predictive of a favorable outcome and malignant infarction than the CT-ASPECTS. The FPCT-ASPECTS was comparable to the MR-ASPECTS with regard to prediction of a favorable outcome. To the best of our knowledge, this is the first study of hyperattenuation on FPCT focusing on patients' clinical outcomes and the predictive ability of FPCT; most previous studies have focused on the association between hyperattenuation on imaging and hemorrhagic risk.

Hyperattenuation on Postprocedural CT and Clinical Prognosis

Early prediction of a patient's clinical prognosis is important in acute stroke management. Physicians can make short- or long-term management plans and monitor possible detrimental clinical events based on the prediction results. In routine clinical practice, malignant infarctions develop in the acute period, and later functional outcomes require prediction. Clinical outcomes after EVT have been predicted using common prognostic factors such as stroke extent based on initial brain images, time from stroke onset to

recanalization, and a patient's collateral status, to mention a few factors.^{6,8–11} Although many factors are well known to be associated with clinical outcomes after EVT, it is not easy to draw a conclusion by integrating these factors. Successful recanalization is also a strong determinant of a patient's clinical outcome. Nowadays, most patients have a successful recanalization with advances in endovascular technique. However, despite the successful recanalization, a favorable outcome cannot be achieved in a considerable number of patients. Thus, something more direct and practical is required to immediately predict clinical prognosis in patients with a successful recanalization.

Postprocedural CT findings may be useful for predicting a patient's clinical prognosis. Conventional CT is primarily performed after an EVT procedure to observe hemorrhagic conditions such as procedure-related intracranial hemorrhage or hemorrhagic transformation. Furthermore, hyperattenuation on postprocedural conventional CT images is a known risk factor for subsequent hemorrhagic transformation.^{3,12–14} According to previous studies, a substantial portion of hyperattenuation is due to contrast staining, not hemorrhage. Contrast staining on postprocedural conventional CT results from blood-brain barrier disruption, which is in turn caused mostly by ischemic injury of the affected region. In other words, regions of contrast staining on postprocedural CT indicate the extent of blood-brain barrier disruption and may be a surrogate of the final infarct core volume or infarction area. In support of this, the extent of hyperattenuation on postprocedural conventional CT images has been shown to match the final infarct volume well.^{1,2} FPCT is readily assessable and is widely performed during or at the

FIG. 2. Distribution of functional outcome according to the ASPECTS on FPCT (FPCT-ASPECTS).

end of endovascular procedures for the same purposes as postprocedural conventional CT. FPCT can detect postprocedural hemorrhagic conditions equally as well as conventional CT.^{15,16} The extent of hyperattenuation on FPCT is also associated with subsequent hemorrhagic transformation and final infarct volume.^{17,18} If hyperattenuation on conventional CT or FPCT is significantly associated with final infarct volume, the extent of hyperattenuation may be predictive of a patient's clinical prognosis.

Advantages of Using FPCT After EVT

In addition to its clinical relevance, FPCT has several advantages over conventional CT. FPCT is easier to perform; it can be performed on the same angiography table without transferring the patient to the CT room. Although the burden in transporting a patient to the CT room has been reduced by the recent availability of a portable CT scanner, FPCT is still more convenient. Furthermore, FPCT can be repeated at any time during the endovascular procedure. For this reason, FPCT performed at the end of the EVT procedure is starting to replace conventional CT performed after the EVT procedure. In addition, by performing FPCT at the end of the EVT procedure, FPCT might show hyperattenuation more optimally. Because hyperattenuation on CT might attenuate even over a short period of time, the timing of CT scanning is important. Even on conventional CT scanning performed approximately 1 hour after the EVT procedure, a considerable area of the infarction can become iso- or hypoattenuated.¹⁹ However, our findings in this study do not mean that FPCT is the only CT modality to show the predictability of clinical outcomes after EVT. If postprocedural CT findings need to be evaluated, any type of CT scanner can be considered.

We think that the postprocedural findings from FPCT could be also applied to findings from a conventional or portable CT scanner.

FPCT can be practically useful in a few ways. First, by performing FPCT at the end of the EVT procedure, procedure-related intracranial hemorrhage can be evaluated. Hemorrhagic transformation that develops during or as a result of EVT can also be observed. In cases in which cervical carotid stenting, intracranial stenting, or glycoprotein IIb/IIIa infusion is required, hemorrhagic conditions can easily be detected by performing FPCT during the EVT procedure. Although clinical or neurological examination findings could also hint at intracranial hemorrhage, neurological deterioration might possibly be due to other conditions, such as the progression of ischemic stroke, metabolic derangement, and unstable vital signs. In addition, unrecognized intracranial hemorrhage should be found in patients who need immediate antithrombotic medications after or during EVT. Second, by evaluating hyperattenuation on FPCT at the end of the EVT procedure, a patient's functional outcome, in addition to the possibility of malignant infarction, can be predicted at an earlier stage. This could help physicians monitor and prepare for further detrimental clinical events. With this clinical utilization, our center has performed FPCT in cases of EVT. After every procedure, we perform FPCT scanning rather than CT scanning.

Although the AUC of the FPCT-ASPECTS in predicting patient's functional outcome is similar to that of the MR-ASPECTS, we do not think it directly means that MR images obtained after EVT can be replaced with FPCT. Generally, MR images have their own role in acute stroke management: to define the exact extent of acute stroke and involved anatomical structures, to detect hemorrhagic transformation more sensitively, and to evaluate the follow-

FIG. 3. ROC curves for a favorable outcome and malignant infarction. **A:** ROC curves of the FPCT-ASPECTS, MR-ASPECTS, and initial noncontrast CT (CT-ASPECTS) for a favorable outcome. The AUC of the FPCT-ASPECTS was 0.862, which was significantly greater than that of the CT-ASPECTS (0.637) ($p < 0.001$). The AUC of the FPCT-ASPECTS was comparable to that of the MR-ASPECTS (0.853; $p = 0.983$). **B:** ROC curves of the FPCT-ASPECTS and CT-ASPECTS for malignant infarction. The AUC of the FPCT-ASPECTS (0.906) was significantly greater than that of the CT-ASPECTS (0.552) ($p = 0.001$).

up patency of the recanalized artery. In addition to the information about intra- or postprocedural hemorrhage, FPCT might be clinically referred to predict a patient's clinical outcome in advance to obtain MR images after EVT.

Although the ASPECTS on initial CT images (CT-ASPECTS) is an important prognostic factor for a patient's functional outcome, the CT-ASPECTS was less predictive than the FPCT-ASPECTS in our study. First, the CT-ASPECTS was originally devised to aid in determining treatment eligibility, not for assessing clinical outcome. Second, the CT-ASPECTS only reflects the extent of the infarct core before EVT. Because the infarct

core progresses until recanalization is achieved, the final infarct core might be significantly different from the initial infarct core, depending on the status of the collateral vessels and the elapsed time from initial CT to recanalization. For a patient with an initially large infarct core, the CT-ASPECTS might be predictive of a worse clinical outcome. However, the CT-ASPECTS might not predict a good clinical outcome even if a patient has an initially small infarct core. On the contrary, the FPCT-ASPECTS appears to reflect the volume of the final infarct core, as demonstrated by an AUC that is comparable to that of the follow-up MR-ASPECTS.

TABLE 2. Comparison of variables and FPCT-ASPECTS between patients with and those without malignant infarction

	Univariable Analysis				Multivariable Analysis	
	All Patients (n = 235)	Malignant Infarction (n = 17)	No Malignant Infarction (n = 218)	p Value	OR (95% CI)*	p Value
Age, yrs	68.1 ± 13.6	66.7 ± 12.3	68.2 ± 13.7	0.675		
Male sex	118 (50.2)	10 (58.8)	108 (49.5)	0.616		
Hypertension	131 (55.7)	8 (47.1)	123 (56.4)	0.461		
Diabetes	43 (18.3)	1 (5.9)	42 (19.3)	0.324		
Smoking	28 (11.9)	2 (11.8)	26 (11.9)	0.999		
Atrial fibrillation	95 (40.4)	6 (35.3)	89 (40.8)	0.799		
Coronary artery disease	28 (11.9)	2 (11.8)	26 (11.9)	0.999		
Initial NIHSS score	15.0 [7.0, 23.0]	14.0 [4.0, 24.0]	15.0 [7.0, 23.0]	0.019	1.03 (0.88–1.21)	0.695
Intravenous tPA	107 (45.5)	9 (52.9)	98 (45.0)	0.616		
ICA occlusion	91 (38.7)	11 (64.7)	80 (36.7)	0.036	2.07 (0.41–10.5)	0.379
CT-ASPECTS	8.9 ± 1.3	3.4 ± 2.9	9.3 ± 1.1	0.028	1.02 (0.65–1.59)	0.932
FPCT-ASPECTS	9.0 ± 2.0	3.4 ± 2.9	8.8 ± 1.4	<0.001	0.42 (0.31–0.57)	<0.001

Univariate results are expressed as mean ± SD, the number of patients (%), or median [IQR].

* Odds ratio for malignant infarction.

Limitations

Contrast material–related hyperattenuation (contrast staining) can be categorized as contrast extravasation or contrast enhancement.⁵ Compared with contrast extravasation, contrast enhancement on postprocedural CT is known to be less hyperattenuating, is confined to an anatomical border without mass effect, and disappears on follow-up images around 24 hours. Contrast enhancement was not associated with hemorrhagic lesions, whereas contrast extravasation was a negative prognostic sign and highly associated with intracerebral hemorrhage. However, we did not discriminate between contrast extravasation and contrast enhancement for this study. First, for earlier prediction of a patient's clinical outcomes, we wanted to establish the ability of FPCT to predict outcomes right after the EVT procedure, when contrast extravasation and contrast enhancement cannot be distinguished reliably. Second, as our hypothesis was based on the pathomechanism of blood-brain barrier disruption by ischemic injury, the principal observation in this study should include both contrast extravasation and contrast enhancement. The two types of contrast staining might simply reflect the severity of blood-brain barrier damage rather than a completely different pathomechanism.^{5,20} Considering that iatrogenic intracranial hemorrhage due to vessel rupture is very rare during the EVT procedure, hyperattenuation on FPCT, regardless of its severity, should develop in the area of ischemic injury to the blood-brain barrier. In fact, mingled (or undiscriminating) hyperattenuation on postprocedural CT was shown to be significantly associated with final infarct volume in previous studies.^{2,13,17,18} Therefore, as our and previous studies have shown, hyperattenuation on FPCT appears to reflect the final infarct volume.

This study was retrospectively conducted in a single stroke center. Although FPCT has been recommended for patients who undergo EVT at our institution, its performance was not forced under a specific protocol. Thus, FPCT was not performed in all patients who underwent EVT. However, the omission of FPCT was mostly accidental rather than intentional. Fortunately, basic demographics and clinical outcomes were not significantly different between patients with FPCT and those without FPCT (Supplemental Table). Furthermore, our goal was to evaluate the ability of FPCT to predict patients' clinical outcomes, not to determine clinical outcomes according to FPCT's performance. Thus, the fact that FPCT was not performed in all patients is unlikely to have significantly affected our findings.

In addition, the clinical significance of cutoff points of the FPCT-ASPECTS for clinical outcomes might be a little bit limited. Although these points were calculated under statistical significance, an internal or external validation process was not performed in this study. Further validation study is necessary in a prospective or multicenter-based cohort.

Conclusions

The FPCT-ASPECTS was highly predictive of a favorable outcome and malignant infarction in patients with a successful recanalization by EVT. In addition to the com-

mon use of FPCT to evaluate hemorrhagic conditions immediately after EVT, FPCT can help immediately predict clinical outcomes and thereby aid in acute management after EVT.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: BM Kim. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: BM Kim, Baek. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: BM Kim. Statistical analysis: BM Kim, Baek. Study supervision: BM Kim.

Supplemental Information

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